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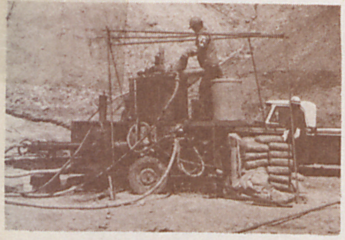

GEOTECHNICAL LABORATORY

TECHNICAL REPORT GL-84-13

FOUNDATION GROUTING PRACTICES AT CORPS OF ENGINEERS DAMS

by

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US ARMY ENGINEER WATERWAYS EXPERIMENT STATION

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Final Report

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This report includes results of review of 23 grouting case histories at 14 Corps of Engineers projects constructed over a 4-decade period. Corps grouting practices, including technical requirements, contractual procedures, and construction management of grouting work are analyzed. Results of the grouting projects are evaluated and costs are analyzed along with legal decisions and trends. The report identifies areas of needed improvements in the Corps grouting programs and makes specific recommendations for achieving those improvements.

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PREFACE

This study was sponsored by the Office, Chief of Engineers (OCE), US Army, under the Civil Works Investigation Study (CWIS) Work Unit 31222, "Review of Grouting Practice." The work was assigned to the US Army Engineer Waterways Experiment Station (WES) and was accomplished under Intra-Army Orders for Reimbursable Services (DA Form 2544) by Mr. John Albritton, Division Geologist for the US Army Engineer Division, Missouri River, and Mr. Lawson Jackson, Division Geologist for the US Army Engineer Division, Southwest, and under contract to Mr. Robert Bangert, COL, CE (Retired), now associated with George Washington University.

The individual authors, Messrs. Albritton, Jackson, and Bangert, conducted the study based principally upon their experience and knowledge as well as through contacts with other individuals in the US Army Corps of Engineers (as acknowledged). General overview of the conduct of the study and review of the work was provided by Mr. Paul Fisher, OCE Technical Monitor for the CWIS-Materials-Rock Program; Mr. Peter Hart, OCE; and Dr. Don Banks, Program Manager (WES) for the CWIS-Materials-Rock Program. The report was also reviewed by Office of the Chief Counsel (specifically the Assistant Chief Counsel for Procurement (DAEN-CCC)). Those portions of the report dealing with contracting issues have been reviewed by Mr. Solomon Ribakoff, an attorney with many years of experience with construction contracts, both as a Corps lawyer and then later as a lawyer for a major construction contractor. The report reflects his views as to the legal ramifications of the recommendations. Dr. W. F. Marcuson III was the Chief of the Geotechnical Laboratory (WES).

In addition to those who assisted in the preparation of this report, geotechnical personnel in the District and Division offices where the projects are located cooperated by providing project data and records and completing questionnaires on each project. The authors would like to particularly thank the following individuals for their cooperation and assistance:

Project	District	Names
A, John Martin Dam	Albuquerque	Victor Huesinger, Jim McAdoo
B, Norfork Dam	Little Rock	Charlie Deaver
C, Allatoona Dam	Mobile	Jack Bryan
D, Hartwell Dam	Savannah	Earl Titcomb

Project	District	Names
E, Oologah Dam	Tulsa	Arthur Burkart, Eugene Gilbert
F, Alvin Bush Dam	Baltimore	Richard Royer
G, Abiquiu Dam	Albuquerque	Victor Huesinger, Jim McAdoo
H, Eufaula Dam	Tulsa	Arthur Burkart, Eugene Gilbert
I, Dworshak Dam	Walla Walla	Tildon McDowell
J, Libby Dam	Seattle	Richard Galster, E. T. Bailey
K, Laurel Dam	Nashville	Marvin Simmons, Wayne Swartz, John Stanton
L, Clarence Cannon Dam	St. Louis	Michael Klosterman
M, Wolf Creek Dam	Nashville	Marvin Simmons, Wayne Swartz, John Stanton
N, Longview Dam	Kansas City	John Moylan, Victor Anderson, William Lowe

The Commander and Director of WES during the study and report preparation was COL Tilford C. Creel, CE; the Technical Director of WES was Mr. Fred R. Brown.

CONTENTS

LIST OF APPENDICES

LIST OF TABLES

LIST OF PLATES

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
degrees (angle)	0.01745329	radians
feet	0.3048	metres
gallons (U. S. liquid)	3.785412	cubic decimetres
inches	2.54	centimetres
miles (U. S. statute)	1.609347	kilometres
pints (U. S. liquid)	0.0004731765	cubic metres
pound (force)	4.448222	newtons
pounds (force) per square inch	6894.757	pascals
square feet	0.09290304	square metres

FOUNDATION GROUTING PRACTICES AT CORPS OF ENGINEERS' DAMS

PART I: INTRODUCTION

Purpose

1. This review was undertaken to document and evaluate past Corps of Engineers grouting practices and results on a selected project basis. The purpose of the assessment is to provide background information on the Corps' practices, identify shortcomings in specifications, estimates, grout placement techniques, and, in general, to determine the effectiveness of the Corps' grouting programs. The report reviews past grouting projects and describes the planning, execution, and performance evaluation of the programs. Ways in which Corps' policies and specifications concerning the grouting practices have developed and presently are applied are examined, as well as the effects on grouting caused by changes in construction management practices and legal decisions during the past four decades. Specifically, the investigation looks at the planned versus the estimated costs and quantities, performance of the program, need for remedial grouting, and changes in the way the Corps' grouting programs have taken place. Results of the study will enable the Corps to reduce costs and/or change construction methods in both original and remedial grouting projects and provide more efficient and effective future grouting of dams and other structures.

Scope

2. The number of projects and degree of detail were limited by available funds and time. The selected projects were chosen to cover a period of about 40 years. Thought was given to selecting projects as much as possible within a common geologic regime to minimize the variability caused by differing rock characteristics. This restraint was rejected as it was thought that a broader project selection with varying geologic conditions, different designers, contract managers, and structures would be more beneficial in the total evaluation. The final selection included 14 projects with 22 grouting contracts and one hired labor grouting project. The following projects were selected for the evaluation:

Order	Project Name	District/Division	Date	Geologic Description
A	John Martin	Albuquerque/SWD	1941-1942	Cretaceous-Dakota sandstone
B	Norfork	Little Rock/SWD	1941-1945	Ordovician limestone and dolomite
C	Allatoona	Mobile/SAD	1946-1949	PreCambrian-Cambrian
D	Hartwell (2 contracts)	Savannah/SAD	1955-1960	PreCambrian-Granite Gneiss
E	Oologah (2 contracts)	Tulsa/SWD	1956-1964	Pennsylvanian limestone
F	Alvin Bush (2 contracts + 1 in-house job)	Baltimore/NAD	1958-1974	Devonian sandstone, siltstone and shale
G	Abiquiu (4 contracts)	Albuquerque/SWD	1959-1980	Permian sandstone and shale
H	Eufaula	Tulsa/SWD	1960-1963	Pennsylvanian sandstone and shale
I	Dworshak	Walla Walla/NPD	1966-1973	PreCambrian metamorphics
J	Libby (3 contracts)	Seattle/NPD	1967-1973	PreCambrian metasediments
K	Laurel	Nashville/ORD	1969-1970	Pennsylvanian sandstone and shale
L	Clarence Cannon	St. Louis/LMVD	1973-1983	Mississippian limestone and shale
M	Wolf Creek	Nashville/ORD	1974-1975	Ordovician limestone
N	Longview	Kansas City/MRD	1979-1981	Pennsylvanian sandstone, limestone and shale

Approach

3. After the projects were identified, the appropriate Districts and Divisions were contacted. All available information pertinent to the grouting required on a particular contract was requested. This information ideally consisted of the plans and specifications, bid abstracts, final payment, and foundation and grouting reports. In most instances, some of the information was available. Additional information was obtained by responses to a questionnaire. A case history of each project was prepared with as much

detail as possible regarding the technical and contractual requirements and performance. Contacts were made with various persons at the District and Division whose projects were included. Various persons knowledgeable of grouting in general and of specific projects were also interviewed. These data are presented in various forms, tables, and charts. The case histories are presented in chronological order by the project which includes later remedial grouting as applicable. The tables for each grouting program are arranged in chronological order. The material was evaluated within the context of the then existing construction management practices. Based on the evaluations and summaries, certain conclusions are reached and recommendations are made.

PART II: BACKGROUND

General

4. Grouting, the injection of a material of flowing consistency into rock or soil, is an important means used in the construction of dams. The two primary purposes of grouting in dam construction are:

- a. To improve the strength and durability of the foundation.
- b. To prevent (or more accurately) limit seepage by reducing the rock mass permeability.

5. Other purposes of grouting include the prevention of loss of foundation or embankment materials through internal or subsurface erosion (piping) and repairing of structures and foundations.

6. Grouting is done both in connection with dam construction and for remedial work during the lifetime of a dam. Many of the comments in this report are appropriate to both construction and remedial grouting, but if discussion is pertinent to only one, that fact will be noted.

7. Grouting is a subject of great importance in connection with dams because properly designed and completed grouting operations play a key role in the stability and longevity of a dam and in the dam's ability to perform its primary function, the retention of water.

8. Grouting is important, too, because it plays a major role in the rehabilitation of dams, i.e., crack repair of concrete dams, filling voids in embankments and foundations to stop subsurface erosion, and reduce seepage amounts and velocities.

9. Grouting will be an increasingly important construction method because it is particularly applicable to repair and rehabilitate deteriorating structures as well as new construction. Potential applications of grouting are also increasing in numerous other types of projects besides dams.

10. This review was undertaken in order to identify areas where improvements in costs and technical and contractual considerations could be made. It was recognized by DAEN and the principal investigators for the study that it would be necessary to consider case histories over a period of time and relate technology and costs to historic changes. Changes in policy, technology, design, contracting procedures, construction management, legal trends, and their impacts must all be evaluated.

History of Cement Grouting

11. Evidence of grouting techniques prior to 1800 is meager and speculative. The first authentic documentation of grouting was in 1802 when a French engineer, Charles Berigny, used a slurry of hydraulic lime, clay, and water to fill voids and seal cracks in masonry walls in the city of Dieppe, France (Karol 1979). Berigny is generally credited as being the inventor of injection grouting.

12. The first use of portland cement grout was credited to Marc Isambard Brunel in 1838 during construction of the Thames tunnel in England (Karol 1979). With the construction of the steam railway system in North America, cement grouting became more widely used for repairing cracks in masonry bridge piers and other brick and stone masonry construction. Later, cement grouting was used in underwater construction of piers using preplaced aggregate and tremie placed grout.

13. The earliest use of cement grouting for filling fissures in rock was by Thomas Hawksley, an Englishman, in 1876 (Flagg 1975). By the end of the 19th century, cement grouting applications, in addition to the above, included grout curtains for dams and various mining uses.

14. "Pressure grouting the foundations of masonry and concrete dams became a construction practice in approximately 1900, and when properly used has been of value since that time. During the next two decades, the pneumatic process for grouting was used chiefly, because most cement grouts contained sand that made grouting difficult with the pumps that were then available. In approximately 1925, an extensive program of dam building began in the United States. With the construction of higher and more massive dams on foundations that frequently contained structural defects, grouting procedures underwent considerable improvement. The need for deeper grout holes brought about the development of highly maneuverable lightweight diamond drills, and the requirement for higher pressures for injecting grout created a demand for positive displacement pumps that were suitable for cement-grout service. Since that time, several types of pumps have been tried with varying degrees of success. These have included simplex, duplex, and triplex piston-type pumps, screw-type pumps, and centrifugal-type pumps" (ASCE Task Committee on Cement Grouting 1962).

15. ". . . the last twenty-five years have seen a rapid improvement in the understanding of the physical and rheological properties of the various systems, and application techniques have become more scientific and progressively more sophisticated. The development of plant and equipment has had to keep pace with these advances in technique and with the consequent demands from specialist contractors for higher outputs, longer pumping distances and higher pressure together with the attendant requirements for greater control in terms of batching materials, regulating flow and monitoring grout injection. In the early 1930's grouting practice, although advancing rapidly, still tended to rely on cement based systems and the early emphasis was therefore placed on designing plant and equipment for handling cement based grouts. This led to the production of high speed, high shear colloidal mixers and the first prototype units were developed in England in 1935 with production units being manufactured by the end of 1937" (Gourlay and Carson 1982).

16. Advantages of the colloidal mixing principle and use of bentonite in cement grouts in the last two decades are leading to their more general use. Modern, high speed, high shear colloidal mixers are now widely available from various sources.

17. The large scale use of grouting as a part of dam construction in the United States was developed primarily by Federal agencies of the U. S. Government. Consequently, the Corps and other Federal Agencies developed grouting practices and specifications which generally became standards for all grouting projects in the United States (Karol 1979). In recent years, however, grouting required by private owners and by contractors as a construction expedient has become more widely used. Private owners are placing more reliance on grouting specialists employed by grouting contractors.

18. Because of the wide range of potential grouting applications, much engineering and scientific interest is presently being given to the subject--both nationally and internationally. This interest was evident by the well-attended ASCE International Specialty Conference, "Grouting in Geotechnical Engineering," held in New Orleans, La., in February 1982 (Baker 1982). The ASCE Grouting Committee of the Geotechnical Engineering Division remains very active and has outlined an ambitious program for the 1980's which will tentatively culminate with another specialty conference in 1989. The committee will sponsor sessions at approximately 17 conventions or conferences prior to that time. Active grouting committees are also in existence in the

Association of Engineering Geologists, the American Concrete Institute, and the American Society of Testing Materials.

19. In addition to the scientific and engineering advances brought about by professional society committees, private grouting contractors and manufacturers of materials and equipment are achieving technological progress and innovative developments. Federal agencies are also maintaining a high level of interest as evidenced by their research programs, revisions to manuals and guide specifications, and cooperation with professional societies. The Waterways Experiment Station Report No. WES MP C-78-8 (USACE 1978) furnishes a comprehensive bibliography of grouting references up to its date of publication.

History of Cement Grouting in the Corps

20. Cement grouting practice in the Corps developed as a mean of treating dam foundations. Considerable experience was gained before and shortly after World War II. Grouting in the Corps advanced from a mysterious art practiced by a few individuals known as experts to a set of fundamental principles and procedures which could be established as the Corps practices. Beginning in 1945, these principles and procedures were published as formal guidance in Engineer Manuals (EM's). Less formal guidance in the form of Engineering Technical Letters supplements the EM's from time to time, and sometimes forms the basis for manual revisions. Engineer publications (Engineer Manuals, Technical Manuals, and Guide Specifications) relative to grouting and their dates of issue or reissue are as follows:

a. 1945 - EM for Civil Works, Chap. 18, Part CXXXV. Foundation Grouting (superseded).

b. 1948 - EM 1110-2-3502. Foundation Grouting - Equipment.

c. 1949 - EM 1110-2-3501. Foundation Grouting - Planning (superseded).

d. 1950 - EM 1110-2-3503. Foundation Grouting - Field Technique and Inspection (superseded).

e. 1951 - CE 1305.02. Guide Specifications - Tunnel Grouting (superseded).

f. 1951 - EM 1110-2-3801. Dental Excavation and Concrete Backfill (superseded).

g. 1952 - CE 1305.01. Guide Specifications - Foundation Drilling and Grouting (superseded).

h. 1959 - CE 1305.02. Guide Specifications - Tunnel Grouting.

i. 1959 - CE 1305.01. Guide Specifications - Foundation Drilling and Grouting.

j. 1963 - EM 1110-2-3503. Foundation Grouting - Field Technique and Inspection.

k. 1966 - EM 1110-2-3501. Foundation Grouting - Planning.

l. 1970 - TM 5-818-6. Grouting Methods and Equipment.

m. 1970 - EM 1110-2-3505. Dental Excavation and Concrete Backfill.

n. 1984 - EM 1110-2-3506. Grouting Technology.

21. As might be inferred from the above list, during the late 1940's and the 1950's, the Corps grouting practices adhered to an established pattern of planning, design, and field procedures (Burwell 1958). Since that time, however, through experience, research, and technological developments, many changes have taken place. While the same general methods of grouting are used, many variations have been developed in recent years. More specialized applications have been developed, and today's trend is to use the method best suited for a specific application. For instance, the Corps' Guide Specification only deals with stage grouting while probably most of our grouting today uses the stop (or packer) method. The new EM, Grouting Technology, furnishes up-to-date guidance on technical aspects of grouting. In light of recent claims experience, contractual guidance is also needed and should be furnished in the near future.

22. The importance of improving contractual considerations for underground construction has been well documented by the National Research Council (NRC) report, "Better Contracting for Underground Construction" (NRC 1974), and by the Missouri River Division (MRD), Corps of Engineers report, "Contracting Methods Study - MX Deep Basing" (USACE 1982). Many of the findings and recommendations of these reports are also applicable to grouting contracts.

23. Some of the important historical, technical, and contractual changes which might have affected Corps of Engineers' design and construction policies, costs, and procedures are as follows:

a. 1927 - "Changed Conditions" clause in general provisions was adopted by the Federal Government (Currie 1976).

b. 1959 - Malpasset Dam Failure. This was the first total failure in the history of arch dams and was blamed on a failure in the foundation (Bellier 1967). This caused a greater awareness of dam safety and adequacy of foundation exploration.

c. 1961 - Clause 7-602-10 was added to Armed Service Procurement Regulation for use in all construction contracts in excess of $10,000. It states that "The contractor shall (1) maintain an adequate inspection system and perform such inspections as will assure that the work performed under the contract conforms to contract requirements, and (2) maintain and make available to the Government adequate records of such inspections" (USACE 1983).

d. 1963 - Vaiont Reservoir Failure. A rock mass of approximately 250 million m^3 suddenly slid into the reservoir pushing out 40 million m^3 of water to a maximum elevation of 26 m above reservoir level and over the dam into the main valley, destroying completely four villages. The dam and abutments were not appreciably damaged (International Commission on Large Dams 1975). This incident caused more awareness of dam safety and prompted EC 1110-2-68, Survey of Potentially Dangerous Slides, to be issued.

e. 1965 - ER 1110-2-100, "Periodic Inspection and Continuing Evaluation of Completed Civil Works Structures" was issued. It prescribed procedures to be followed for periodically inspecting and evaluating the Corps civil works projects whose failure would endanger lives or cause substantial property damage and impair operational capability or serviceability of the structure. This ER began the Corps' formal dam safety program.

f. Approx. 1965 - Present. Developments in earthwork equipment make earth dams more and more cost effective. USACE trend shows increased use of multiline grout curtains, particularly in the upper zone.

g. 1966 - ER 1180-1-6 "Quality Management" was issued to implement ASPR clause 7-602-10. It was interpreted by most District and Division Engineers to require quality control organizations, separation from contractor's normal supervisory staff, and using unnecessarily large numbers of highly qualified personnel or registered engineers. In some cases contracts required Contractor Quality Control representatives to report to top management personnel of the contractor organization. Contractors considered this an unwarranted invasion of their rights to establish their own organizational line of authority (USACE 1983).

h. 1967 - ER 1180-1-6 revised and reissued. Established policy was to limit use of separate Contractor Quality Control organizations to critical and complex contracts; it provided that separate organization will report to the senior project manager; it provided for specialists for periods of limited duration when the quality control requirements could be met without full contract period employment (USACE 1983).

i. 1968 - Armed Services Procurement Regulation (ASPR) prescribed new general provisions paragraphs for DIFFERING SITE CONDITIONS (in lieu of "changed conditions") and CHANGES. Before 1968, only the cost/time for directly changed work was considered.

After the change, ALL remaining work must be considered - not only the directly changed work, but also the effect that the modification may have on unchanged work (USACE 1979, 1976).

j. Approx. 1970 - Present. Because of cost advantage over stage grouting, USACE practice shows increased use of stop grouting methods. There is also a trend for use of bentonite in small amounts to stabilize grout mixtures. Thinner grouts with bentonite have been effective.

k. Approx. 1975 - Present. Use of colloidal mixers is becoming more widespread in cement grouting. The high speed, high shear colloidal mixers have become available from a number of sources, thus allowing their benefits to be used without significant cost increase.

l. 1976 - Teton Dam failure. Dam safety again became a current political issue.

m. 1977 - Toccoa, Georgia Dam failure. This dam failure added momentum to dam safety issues. It prompted the President to direct the Corps of Engineers to inspect non-Federal dams that presented a high potential for loss of life and property damage if they fail. The 4-year program was developed to perform the following:

(1) Update national inventory of dams.

(2) Inspect about 9000 dams.

(3) Encourage and prepare the States to implement effective state dam safety programs.

(4) Provide data for the definition of a viable national dam safety program (USACE 1982).

n. 1978 - Perini Claim. Engineer Board of Contract Appeals No. 3745-BCA was found for Perini Construction Company. At Hidden and Buchanan Dams the underrun of placing grout quantities relative to drilling footage was determined to be a changed condition under General Provision (GP) - 4. The precedent has been used for several subsequent claims.

Dates of the above events are plotted along with study project dates and total cost/cu ft* of grout placed for each project in Plate 1a. The plate shows costs both in actual dollars and in 1982 constant dollars. There is no apparent correlation between the historical events shown and grouting costs. The reason for the abrupt decline in grouting costs from 1956 to 1960 is not apparent from the data available to this study. If additional projects are reviewed in the future, this anomaly should be investigated.

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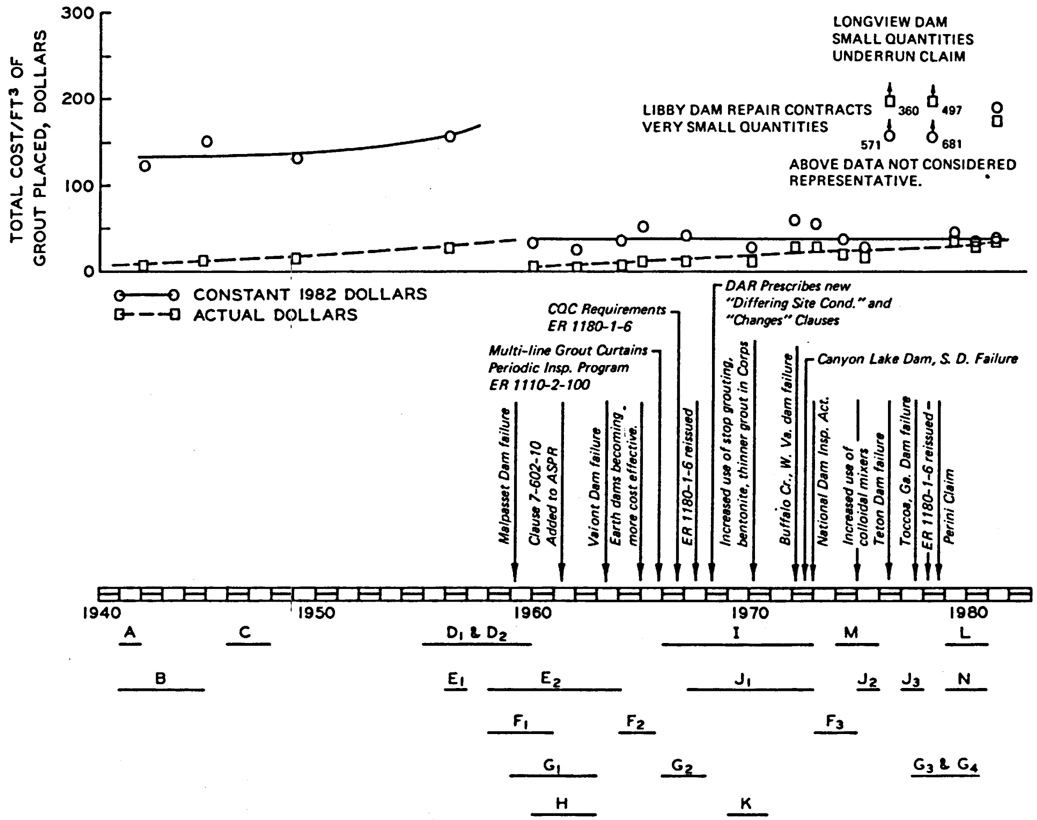
* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 6.



TOTAL COST/FT^3 OF GROUT PLACED

PROJECT	YEAR	Total Cost/FT^3 ACTUAL ($)	Total Cost/FT^3 1982 CONSTANT ($)
A John Martin	1942	8.67	120.17
B Norfolk	1945	12.14	150.78
C Allatoona	1949	15.64	125.43
D_1 Hartwell	1956	29.92	165.46
F_1 Alvin Bush	1960	7.60(E)	35.26
G_1 Abiquiu	1962	5.95	26.12
E_2 Oologah	1963	8.86	37.66
F_2 Alvin Bush	1965	13.15(E)	51.81
G_2 Abiquiu	1967	11.61	41.45
K Laurel	1970	10.07	27.79
I Dworshak	1972	26.53	57.84
J_1 Libby	1973	26.71	53.95
F_3 Alvin Bush	1974	18.40	34.78
M Wolf Creek	1975	14.07	24.34
J_2 Libby	1976	360.00	572.40
J_3 Libby	1978	497.00	685.86
G_3 Abiquiu	1979	34.83	44.23
G_4 Abiquiu	1980	29.48	34.79
L Clarence Cannon	1981	37.12	40.09
N Longview	1981	172.00	185.76

Note: (E) - Estimated cost x actual quantity

PROJECT CONSTRUCTION DATES, HISTORIC EVENTS AND TOTAL COST OF GROUT PLACED IN ACTUAL DOLLARS AND 1982 CONSTANT DOLLARS

Present Study

24. The effects and implications of changes in policy, guidance, contracting procedures and technological developments, and innovations are considered in this study in order to identify areas for improvement and cost savings in the Corps of Engineers grouting programs. Case history data form the major documentation of the report and the basis for the findings. As with underground construction, the last decade was characterized by claims arising from differing site conditions, changes, delays during construction and during settlement of disputes, and incomplete bid documents. Perhaps the most significant change affecting the Corps construction costs was in 1968 when new general provisions paragraphs were prescribed by Defense Acquisition Regulation (DAR) for differing site conditions and changes (USACE 1980). Since the new paragraphs went into effect, changes which may have insignificant direct costs have led to large settlements because of the requirement to pay impact (ripple) costs of the change, including overhead. Legal costs have escalated. In some cases both the government and the contractor have, in litigation, paid costs far in excess of what would otherwise have been required.

25. Results of this study identify areas of needed improvements in grouting procedures and guidance, contracting procedures, construction management, planning and design, geological and geotechnical studies, and in consideration of contractor innovations and alternatives. In some cases recommendations are made for the needed improvements, and in others, recommendations are made for additional studies or research.

PART III: PRESENT CORPS PRACTICE

Technical

Introduction

26. Cement grouting is the most widely used method within the Corps of reducing rock mass permeability of dam foundations and increasing the strength of foundation materials. When properly designed and constructed, effective results are achieved. Grouting in the Corps is performed as design requirements of permanent construction, postconstruction, remedial treatment, or an increment of expedient construction or repair. This discussion deals primarily with cement grouting as applied to earth and rockfill dams, concrete dams, tunnels, and shafts. The discussion is intended to be brief. However, a more complete treatment of the subject is found in EM 1110-2-3506 (USACE 1984) which is the Corps of Engineers standard for present and future foundation grouting.

27. In its broadest sense, grouting can be defined as injecting chemical grouts or suspended solids into voids or compactable material to reduce permeability; to consolidate, compact, strengthen or stabilize the host medium; to lift, move, and/or support structures; or to provide contact between structures or between structures and soil or rock.

28. Grouting has not totally achieved the status of a science but in some respects remains an art, primarily due to the large number of variables and unknowns involved. Past grouting practices have varied widely within the Corps and even on the same job. Good results have been attained by widely differing procedures and methods.

29. An important requirement for a good grouting job is field control by a geologist or geotechnical engineer who understands the geology and subsurface conditions, and also has grouting experience on similar jobs.

30. Because of physical and procedural limitations common in grouting, it is normally not recommended to rely on grouting as a single line of defense. It should be integrated with other design features (drains, filters, relief wells, impervious blanket, etc.) which act together to reliably achieve their purpose. One important design consideration is the possible requirement to regrout segments of a grout curtain at some future date. The curtain should be designed so that it is accessible with a full pool. Present practice by

many designers is to avoid designing grout curtains under the upstream toe of embankment dams, but rather to design the embankment for the grout curtain beneath a central impervious core. This allows access from the crest of the dam for possible remedial grouting. Internal access may be provided by tunnels and galleries in the original design. These features may add to the effectiveness of seepage and uplift control by providing for foundation drainage in addition to grouting.

Investigations

31. Project investigations for impoundments are designed to assess the need for grouting and to provide complete information for design of the grouting program. The need for grouting is not based on average permeabilities or average foundation conditions but is assessed by detailed project investigations. Major considerations include leakage potential, areal and structural geology, in-situ stress conditions, geohydrology, geochemistry, and compatibility of in-situ and grouting materials. The presence and characteristics of anomalous conditions are ascertained, and appropriate treatment is planned. Grout takes, mixtures, procedures, and pressures are best determined or estimated by conducting a grout test program at the site.

32. Numerous case histories have repeatedly demonstrated the necessity of thorough geological exploration prior to grouting and a day-by-day assessment during grouting. Until recent years, geological investigations for design of grouting treatment have more often than not been limited by either economic considerations or a failure to recognize their importance. Discovery of solution cavities during construction of major projects such as the Gathright Dam in Virginia and the Clarence Cannon Dam in Missouri have led to extensive investigations and design changes during construction which resulted in massive cost overruns. Such experiences have mandated more thorough investigation for design.

33. Investigations for grouting may encompass any geological or geotechnical method normally used for regional and site investigations. The investigations are in sufficient detail to eliminate major surprises. The full depth and lateral extent of the grout program is explored.

34. Engineer Manual 1110-2-3506 recommends test grouting be accomplished when feasible. In addition, regional ground-water and geological studies are made of the reservoir area. Piezometers are installed upstream and downstream of the proposed grout curtain in order to obtain baseline data prior to

construction. In addition, weirs are installed and periodic measurements made of downstream springs and seepages prior to and after construction. Water well measurements and records are obtained prior to construction.

Types of treatment

35. Cement grouting done by the Corps normally falls into one of seven categories: curtain grouting, area grouting (sometimes referred to as consolidation grouting or blanket grouting), tunnel grouting, cavity filling, backfilling boreholes, contact grouting, and specialized applications. Dental treatment and concrete backfill, mortaring of joints, broom or slush grouting, and positive cutoffs are frequently associated with and integrated with the grout curtain or area. A detailed discussion of the types of grouting treatment is found in EM 1110-2-3506.

Grouting methods

36. General. The Corps' grouting methods have become less standardized in recent years. The current Corps guide specification (CE 1305.01 Foundation Drilling and Grouting) only prescribes stage grouting, but current practice is to use the method which best meets specific job requirements (USACE 1952). A new guide specification is presently being prepared. It is not unusual to utilize several different methods at the same project. Drilling methods are normally determined by the contractor (subject to specified restrictions and Corps approval). Both rotary and percussion drilling methods are used in the Corps grouting programs. Washing and pressure testings are generally required. The actual grouting methods are usually a combination of methods outlined in the following paragraphs. Field adjustments are made as necessary to meet conditions encountered. A detailed discussion of drilling methods, washing and pressure testings, and grouting methods is found in EM 1110-2-3506.

37. The split-spaced method of drilling and grouting is a procedure whereby primary holes are drilled and grouted on a maximum predetermined spacing; then secondary holes are drilled and grouted at locations midway between primary holes. Each subsequent order of holes is at locations which split the spacing of the previous order of holes. Sometimes secondary or even tertiary holes are mandatory with subsequent split-spacing based on grout takes. At other times, only the primary holes are mandatory and the split-spacing is based entirely on grout takes.

38. Stage grouting. Stage grouting involves cycles of drilling, washing, pressure testing, grouting, and cleaning of holes, beginning with the primary

holes in the most shallow zone of a given section. The depths of the stages are governed by foundation conditions. After the first or most shallow stage of a hole is grouted, the grout within the hole is removed by washing or jetting before it has set sufficiently to require redrilling.

39. After all first stage grouting of the primary holes in the section is completed, a waiting period of 24 hr is required. Then the primary holes are deepened to their second stage of depth and grouted at higher pressures. The process of successively drilling primary holes to additional depths and grouting at higher pressures is continued until all primary holes in the section have been grouted to the depth of the first zone. Secondary holes are then drilled and grouted using the same procedures as for primary holes. The process of reducing the grout-hole interval by the split-spacing method and grouting by stages is continued until grouting of the section is completed to the full depth of the first zone. Using the same grout holes, successively lower zones are drilled and grouted in like manner until the full depth of grouting treatment is reached. Other sections are drilled and grouted in the same manner until the grout program is completed.

40. Usually, grout is injected at the top of the holes for each stage using higher pressures as deeper stages are grouted. Where bedrock conditions cause concern, surface leaks develop, or a danger of lifting the foundation exists. Packers may be used at the bottom of the first or deeper stage in order to safely use higher pressures.

41. Stop grouting (or packer grouting) is a method of drilling and grouting whereby each hole is drilled to full depth and grouted through an expansion plug or packer set at successively more shallow stops. An exception to the requirement of drilling the hole to final depth is made when lost circulation or artesian conditions are encountered. In either of these cases, the hole is grouted prior to drilling to final depth. The depths of the stops are at the top of the zone being grouted, or lower, depending on foundation conditions.

42. Circuit grouting is a method of grouting where the supply line and return line are connected to the hole by means of a special header that permits the injection pipe to be extended to the bottom of the grout hole.

43. This method can be used in combination with stage grouting procedures or with the single stage grouting method. The grout slurry is made to circulate from the sump or pump to the bottom of the hole, thence up the

annular space between the injection pipe and the wall of the hole to the header, thence through the return line from the header to the sump.

44. Single stage grouting method. The single stage grouting method is used for grouting shallow grout holes and sometimes for other applications as conditions warrant. It consists of drilling the hole full depth and grouting with one connection. Where conditions permit its use, it can be effective and economical. It is sometimes used in conjunction with the circuit grouting method for grouting fairly deep holes, but can also be combined with injecting through a normal circulating grout header, a tremie pipe, or a funnel at the top of the grout hole.

45. Series grouting method. The series grouting method is a variation of stage grouting whereby each successively deeper zone is grouted by means of a nearby drilled hole to eliminate the need for washing grout out of the hole before drilling deeper. This method is rarely used in current Corps practice. It is the most expensive of the methods described and has a much greater danger of lifting and damaging the foundation.

46. Tremie method. The tremie method of grouting consists of placing a grout-filled tube or pipe to the bottom of the hole and pumping until grout flows from the hole and then slowly withdrawing the injection pipe while pumping continues. It is used in foundation grouting programs mainly for backfilling drill holes but may also be combined with single stage grouting.

Grout mixtures

47. Most of the Corps' foundation grouting has been done with grout composed of portland cement and water. The addition of a small percentage (2 to 4 percent) of sodium bentonite has produced beneficial results. Settlement is almost eliminated without significant reduction in strength or increases in setting time. Fluidizing agents may be added to reduce the viscosity of very thick grouts or for sanded mixtures. Other additives are included in the mixture design when needed for a specific purpose. Other than bentonite, additives may be used to serve as fillers, accelerators, retarders, lubricants, nonshrinkage agents, stabilizing agents, admixtures to increase or decrease specific gravity, or to increase strength of the grout. Where specialized mixtures containing additives are contemplated, it is standard practice to design and test trial mixtures in the laboratory prior to preparing the specifications.

Grouting pressures

48. A common rule of thumb in determining maximum allowable pressures at the collar of the hole is that the pressure in pounds per square inch at any elevation should not exceed the depth in feet in rock plus one-half the depth in feet of overburden materials over the rock. This rule was derived while considering the weight of materials over the zone being grouted. Other factors affecting the maximum safe grouting pressure include rock strength and physical characteristics, consistency of the grout, tightness of the hole, geology, in-situ stresses, and hydrologic conditions. The rule of thumb is generally conservative. Higher pressures can safely be used in many cases.

49. Where grouting is done in the upper zone from the surface, gravity grouting is usually recommended. An overflow standpipe is frequently used to keep from overpressurizing the foundation. Pressure relief valves have also been used but are not as reliable as the standpipe. Another method of limiting pressure is to inject grout into a funnel at the top of the grout hole, nipple, or standpipe.

Grouting equipment

50. Many types of grouting equipment are available and have been used successfully by the Corps. Specifications frequently are general in regards to equipment, allowing the contractor to select the equipment subject to the Corps' approval.

51. The grout mixer and sump should have the same capacity. Where high takes are anticipated, two mixers may be arranged to discharge into the same sump. High speed colloidal grout mixers are superior to standard slow speed mechanical mixers and are now generally available. They produce grout of greater uniformity with better penetrability and pumpability. Cement clusters are separated and the individual particles are often broken and rounded to a significant degree in these mixers making it possible to grout tighter fractures than with standard mixers. Colloidal mixers are required for mixing and hydrating bentonite. Proper mixing of bentonite in grout requires mixing the bentonite in a separate mixer and fully hydrating it before being introduced into the grout mixer.

52. Various types of pumps are available for grouting. The pump should be specified with selection based on the individual job requirements. For the bulk of the Corps work, either piston pumps or progressing cavity pumps are

used. Either type can be powered by air, gasoline, or electricity. A standby pump is usually specified on all Corps jobs of significant scope.

53. Most Corps jobs have required a circulating grout header. Pressure gages should be required at the hole and also at the pump. The pressure range of the gages should be based on the pressures contemplated for the program.

54. Flexible hoses are generally used for grout lines. They should be capable of withstanding the maximum grouting pressure with an ample safety margin. Grout lines are normally a minimum of 1-1/2 in. (38 mm) inside diameter. Pipe for pressure lines, fittings, header, nipples, etc., should be of standard black steel or better, capable of withstanding maximum grouting pressures, with a minimum inside diameter of 1-1/2 in. (38 mm).

55. Valves for the grout line are used to control the flow of grout. They should be hand operated, quick acting valves capable of withstanding the maximum grouting pressure, and capable of accurately controlling pressure and rate of injection.

56. The packers specified should be capable of sealing the grout hole at any elevation and of withstanding the maximum grouting pressures. In packer grouting, it is not unusual to grout a packer in the hole. For this reason, the contractor should be required to have an adequate number of extra packers on the job in order to avoid unnecessary delays.

Grouting techniques

57. Grouting techniques depend on the job, policy, objective, geology, contractor, field personnel, and individual judgment and preference. Procedures subject to field technique include selection and adjustment of mixtures, changing grouting pressure, flushing the holes and washing the pump system during grouting, use of delays, intermittent grouting, and treatment of surface leaks.

58. Regardless of how well the grouting program is conceived and designed, its success depends upon the field techniques used and upon good judgment by field personnel. Grouting techniques for the Corps jobs are not subjected to contractor quality control but are directed by the Corps field personnel (USACE 1984). For this reason, it is mandatory that an experienced geologist or geotechnical engineer is in charge of the grouting program and that he is provided with an adequate and experienced staff.

59. For winter grouting, all grout is maintained at temperatures above 50°F (10°C) until injected. The temperatures of mixing water range from 50°F

to 100°F (10°C to 37.8°C) when added to the grout mixer. Storage of grouting materials is at temperatures above freezing. In addition, the grouted rock should be no colder than 40°F (4.4°C) when grout is injected and should retain that or higher temperature for a period of 5 days thereafter. It is normally the contractor's decision as to how to accomplish the above. Insulation, heated enclosures, and water heaters are frequently necessary. It is not unusual for the contractor to schedule grouting in nonwinter months in order to avoid winter operations. In extremely hot weather, grout and grouting materials are protected from direct sunlight. It is desirable to maintain the grout at temperatures at or below 90°F (32.2°C). The higher temperatures increase water demand and consequently shrinkage, as well as accelerate the setting time of the grout which decreases the working time.

60. Thin initial mixtures are usually recommended, especially if the hole is dry or pressure tests indicate slow or small takes. Some fractured formations such as meta volcanics and fractured limestone and dolomite are quite pervious but refuse 3:1 grout very quickly and accept considerable 6:1 or 5:1 grout. This justifies beginning with a thin grout even in pervious conditions. If the hole accepts a few batches of the starting mixture without pressure buildup, thicker mixtures are required; however, if the pressure builds up, grouting may continue with the same mixture until refusal.

61. Mixtures are usually thickened by batching a new mixture in the mixer and discharging it into the sump after most of the thinner grout has been injected. If immediate thickening is required, the hole is shutoff temporarily and cement is added to the sump. Mixing is accomplished by agitation of the sump and circulation through the pump and lines.

62. If the hole accepts a few more batches of the new thickened mixture without pressure buildup, the next thicker mixture is used. The process of thickening the grout continues until the pressure builds up. Then injection continues, and the rate of injection into the hole is slowly cut back when the pressure tends to rise until the hole refuses to take grout at the maximum pressure. When sudden refusal and pressure buildup is experienced, premature plugging may have occurred. If the hole is still taking a small amount of grout, water should be pumped into the hole to reopen it if possible. After the water injection, a thinner grout mixture may be required. If the hole is plugged, a new hole may be required. Other causes of sudden refusal include a blocked line, packer or hole, a collapsed hole, or the voids may be full.

63. During grouting when pressures begin to rise, they are controlled so that they are raised slowly in increments until the desired injection pressure is reached.

64. It is recommended that the pump system be flushed with water at intervals during grouting with thick mixtures (i.e., 2:1 or thicker). A few cubic feet of water is also injected into the hole when this is done.

65. A maximum pumping rate should be specified for injecting grout in order to restrain grout travel within reasonable limits and have better control of the job. Three ft^3/min is considered a reasonable maximum pumping rate for most foundation grouting.

66. When pressures cannot be built up using the thickest mixtures allowed, or when it is desirable to prevent grout from spreading too far, delays may be used. They may last from a few minutes to several hours. The amount of grout injected per delay is controlled to fulfill the intended purpose. If the delays are very long and thick grout is being used, the hole and pump system should be flushed before each delay. Also, the contractor's efforts are allowed to be directed elsewhere during the delay. If the delays are short and the contractor is required to standby, provisions are made in the contract for payment for stand-by time. In intermittent grouting, delays of several hours are required. Intermediate shorter delays during a single injection period may be required in order to restrict grout travel.

67. Surveillance of the area is made frequently during grouting to check for surface leaks and collect monitoring data from other holes, springs, piezometers, wells, and seeps. Records are kept of any discolorations, changes in flow, or changes in water levels. Leaks are controlled, if necessary, by dikes or caulking with materials such as oakum, wood wedges, burlap, or other materials. If the leaks are serious, an accelerator may be added to the ponded grout within a diked area and a delay used to allow the grout to set. If the leak cannot be stopped, grouting may be continued at reduced pressure and a thicker mixture used.

68. Up-to-date detailed records are kept of drilling, pressure testing, and grouting operations for technical evaluation as well as for determining payment quantities. In addition, geologic sections and profiles are kept up-to-date with drilling, testing, and grouting data, and records are made of monitoring data in order to evaluate the grouting program. This information is included in the foundation report for future reference.

69. Evaluation of grouting effectiveness must be constant and continuous during the program. It is a joint effort between engineering and construction personnel. If problems develop, reaction must be expeditious. Flexibility is maintained for making changes and improvements as the program progresses. Design changes of other project features are sometimes made based on knowledge of foundation conditions gained during grouting.

70. The evaluation of the performance of grout curtains should be accomplished throughout the lifetime of the project, and particularly when higher pool levels are experienced. Adequate instrumentation data for a complete evaluation is usually lacking, and grout curtain performance evaluation must be based on visual inspections along with the available instrumentation data. Statistically, of the 4898 dams, 15 m or more in height, built or under construction by January 1, 1974, only 60 had incidents caused by seepage in foundations or abutments (Flagg 1975). This represents only 1.2 percent of the total. This means that 98.8 percent did not have incidents caused by seepage in foundations or abutments. This would indicate very effective results have been achieved by most grout curtains. Even though project performance may be considered adequate, the question arises, would it have also been adequate without the grout curtain? This is a difficult question which can only be answered on a case by case basis. The need to grout is assessed during investigative and design phases of each project, and by studying project records, one can make an estimate of how the project would have performed without the grout curtain. Grout curtains were important design features and considered necessary for satisfactory performance of all of the projects studied in this investigation.

71. During construction, the reduction in grout takes as holes are split spaced, results of post grouting exploratory holes and water pressure tests, monitoring data, and geophysical measurements are often used to evaluate grouting results. Contracts are usually written to provide flexibility so that areas of the curtain with questionable results can be regrouted or additional holes or lines added to produce the desired results.

72. Although grout curtain performance cannot usually be evaluated totally from instrumentation data, there are many instances where instrumentation data is sufficient to verify grouting effectiveness. For exmaple, test grouting of Meramec Park Project, Missouri, demonstrated a grouting effectiveness of approximately 97 percent in reducing seepage, as measured by pumping

tests and monitored by piezometers before and after grouting (Klosterman, Wolff, and Jahren 1976). In addition, a number of dams with leakage problems have been effectively repaired by grouting (either temporarily or permanently) as indicated by both performance observations and instrumentation data. [Ex: Wolf Creek Dam, Ky. (Project M); East Branch Dam, Pa. (Fetzer 1977); and Alvin Bush Dam, Pa. (Project F)].

73. Presently, designers seem to place more emphasis on providing for piezometers to monitor grout curtain performance than in the past. Grout curtain performance should be constantly evaluated as part of the Dam Safety Program and documented in each periodic inspection of the Corps dams. Additional piezometers are needed at many projects to develop and monitor piezometric profiles across the grout curtain. Even with proper instrumentation, visual inspections remain very important in monitoring grout curtain effectiveness since the instrumentation data can only measure conditions at the points where the instruments are installed.

Contractual

Characteristics of grouting that affect contracting

74. Grouting is a unique form of construction operation bearing a resemblance to another type of construction--tunneling. The purpose of grouting is to fill voids in the rock below the surface, while the purpose of tunneling is to create a void (of a certain shape or size) in the rock. In both cases the challenge to be met and overcome is to accomplish the desired result in a medium of great and often unpredictable variability and which can only be sampled in a limited manner prior to the start of construction. This challenge almost invariably requires that significant engineering decisions must be made as the job progresses and as new or additional knowledge of the rock is gained. The challenge for grouting is, in a major way, even more difficult than for tunneling. Grouting is accomplished from the surface, i.e., without the opportunity to view directly the effectiveness of the work as it progresses, and therefore the effectiveness must largely be judged by indirect means. Coupled with this limitation, the effectiveness of the completed job--creation of a grout curtain to prevent seepage of water, may not be measurable for a long time (months or even years) after the work is done.

75. The design of grouting work is accomplished, as is design for other parts of the dam, in the office after necessary field explorations. The design is expressed in the form of drawings and specifications. The drawings include quantity estimates for drilling and grouting. The drawings and specifications are used by bidders as a basis for preparation of "unit price" bids and then as the direction for the successful bidder to construct the work described in the plans and specifications. Even so, it has long been recognized that the plans for the grouting are subject to change as the work progresses and as rock conditions become more fully known.

76. Traditionally, the Corps has retained detailed control over grouting operations as they are performed. The contracting officer, or more accurately, his authorized representative at the jobsite, directs the work. For instance, one specification states: "...grouting mixes, pressures, pumping rates, and sequence in which the holes are drilled, grouted and backfilled will be determined in the field and shall be as directed by and performed in the presence of the contracting officer"* (underscoring added).

77. Not only has the Corps traditionally maintained a high degree of control over how the grouting operations are to be performed, but it also almost invariably exercises approval authority over the plant and equipment that the contractor selects to do the grouting.

78. Documentation is another characteristic of grouting somewhat different from other construction. Although the need for "as-built" drawings is the same as for other construction, the detailed record of how the grouting is done is important for judging its quality and the degree to which its purpose is accomplished, since the results of grouting cannot be directly seen. A secondary use of the record is for the payment of the contractor.

79. The need for coordination of grouting with other work in the construction of a dam is vital because grouting is done in conjunction with other work, and if grouting is not on the project schedule's critical path, other work at the same location is performed. The need for coordination is also affected by the sensitivity of grouting to low temperatures, a fact which increases the necessity for careful coordination of operations.

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* Section 3B, Curtain Grouting and Exploratory Drilling, Specifications for Construction of Longview Dam Stage I, Kansas City District, Corps of Engineers, May 1979 (Appendix II hereto).

80. Variability is a characteristic of grouting operation. Variability in the location, pattern, depth, and direction of holes; variability in procedures for drilling, washing, and pressure testing; variability in grout injection - pressure, rate, and quantity--all characterize these operations. This variability emphasizes the need for careful supervision and the necessity for on-the-spot decisions. Because each damsite is unique in its geology and its response to grouting operations, design and construction must be site specific.

81. Although grouting is a vital part of the construction of a dam, it is usually a relatively low-cost operation when compared with the overall project cost.

82. Finally, a characteristic which has been mentioned earlier deserves reemphasis: The results of the grouting operation are measured indirectly and often after the passage of considerable time. Since rework is costly, this characteristic of grouting engenders a considerable degree of conservatism in both design and construction.

Contract/job management arrangements

83. In selecting the means by which grouting operations will be managed, the Corps may choose between two alternatives: to contract for the work or to perform the grouting with its own forces. Both means have been used, but the contracting alternative is the one more commonly selected. For this reason, this discussion will cover the contracting alternative in greater detail than it will the in-house alternative.

84. In dam construction the most used method of contracting is to include grouting in the general contract for the dam construction, which is almost always a firm fixed-price contract awarded after competitive bidding. Payment for the work is based on a combination of lump sum items and unit prices for measured quantities. Most general contractors subcontract to a firm specialized in drilling and grouting. Hence, the Corps deals with the prime contractor, but the work is performed by a subcontractor with whom the Corps does not have a contractual relationship.

85. For remedial work, bidders are usually specialized firms, and grouting contracts are awarded to the lowest qualified bidder. The work is performed by the firm selected as the contractor. In this case, the Corps deals directly with the firm doing the grouting.

86. In awarding contracts in this manner the Corps is following the policy enunciated in the DAR which states, "Procurement shall be made by formal advertising pursuant to 10 U.S.C. 2304(a) whenever such method is feasible and practicable under the existing conditions and circumstances..."*.

87. It has been the norm for the Corps to use the firm fixed-price contract type for both grouting done in connection with construction and for remedial grouting. However, there are other contractual arrangements permitted by the DAR when circumstances warrant. These include cost-plus-fee types and service contracts. No instance of the use of these types was found during this analysis, but the Albuquerque District (Appendix I-G1) reported as a possible improvement in grouting practice the use of a service type contract under which the contractor would supply the men and equipment, and the Corps would direct the work and pay the contractor on the basis of time used. An instance of such an arrangement for grouting work has not been tried insofar as this study could determine. However, service contracts for subsurface investigation drilling have been used by the Corps Districts. For instance, the Omaha District has awarded several (approx. 8) of these contracts in recent years. Their contracts are for drilling services at a single project, an entire state, or, in one case, a two state area (Wyoming and Montana) for a period of one fiscal year. Award is based on price, technical considerations, and bidder qualifications as evaluated from the contractor's response to an invitation for bids. A mobilization and demobilization price and unit prices for various sizes and types of drilling operations are established in the contract for work orders to be issued. Work orders are issued when and as needed throughout the fiscal year.

88. In contrast to contracting for drilling and grouting, the Corps has the option of performing the work with its own forces or using its own or rented equipment. Some Districts have, or have had, drill crews and equipment which have been used with satisfactory results, primarily for exploration. However, there appears to be no reason for the Corps to be unable to do its own grouting if it appeared to be advantageous.

89. The discussion of contract types up to this point has been concerned with either construction or remedial grouting undertaken after careful planning and design. There is another situation that requires consideration--an

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* DAR 2-101, Policy.

emergency which might arise, requiring grouting operations to be commenced at the earliest possible moment. Fortunately, the Corps has had considerable experience in coping with emergencies (of various kinds), and it has the necessary contractual authorities for emergency work. Most commonly, a letter contract would be issued to authorize the contractor to start work, and later the contract would be formalized in one of the other forms discussed previously.

90. Whatever contract/job management arrangements have been used, the Corps has traditionally retained close control over grouting operations. The reason is quite apparent. First, dam projects are built for a very long life, and the Corps is responsible for operating and maintaining the projects it builds during that long lifetime. Therefore, in its own self-interest the Corps must insure project safety, ability to perform its function, and its longevity; the adequacy of grouting plays an important role in each. Second, because grouting operations require engineering decisions in the field on a timely basis, the Corps has found it necessary to exercise close control. Third, since the long-term effectiveness of grouting is determined by proper balance of many variables and since that effectiveness can only be measured indirectly (and completely only at a later date), special attention by the Corps is imperative.

91. As an example of the way the Corps enunciates its intention to control grouting operations, the 12-page specification for curtain grouting and exploratory drilling for the Longview Dam Stage I* contains 20 statements concerning how the contracting officer will direct the grouting work.

92. The advantages and disadvantages of the various possible contract/job managements require examination in view of the requirement for detailed control by the Corps. One other factor that must be considered is the information that the Corps is able to ascertain and make available to bidders for use in preparing their bids and to the selected contractor for planning his work. The following statement appears near the beginning of Section 3B of the Longview Dam specifications:

> "...The program shown in the drawings and described herein is tentative and is presented for bidding purposes only. The amount of drilling and grouting which actually will be required is unknown and will be governed by conditions encountered..."

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* Appendix II.

Table 1a

Comparison of Contracting Methods and Contract Types

Procedure for Acquiring Contract Services	Type of Contract Resulting from Acquisition Procedure	Characteristics of Contract	Application of Contract to Construction	Approval Authority	Effects On: Quality of Construction	Effects On: Time of Construction	Effects On: Cost of Construction	Effects On: Risk Allocation (Financial)	Effects On: Incentives for Contractors	Effects On: Encouragement of Innovation
Formal Advertising-Competitive Bidding	Firm fixed-price (may include price adjustments)	Contract is based on plans and specifications prepared prior to bidding	Normally used when design is complete prior to bidding	Contracting Officer	Required quality definitely specified	Used when time of completion is not the critical factor	Theoretically lowest, may not work out that way due to changes	Contractor greatest-Government least	High incentive to control job costs	None in design, possibly highest in construction method
Two-Step Formal Advertising*	Firm fixed-price or fixed-price with adjustments	Contract is based on design proposal by the bidder	May be used when potential contractors' concepts are needed, basis exists for comparing concepts, time for procedure is available	Contracting Officer	Could be a factor in selecting contractor, therefore, potentially significant	Could be faster than by formal advertising-competitive bidding	Intermediate	Contractor-high-Government-medium	High incentive for engineering innovation, high incentive to control job costs	Probably highest in design, High in construction methods
Competitive Negotiation*,**	Cost-plus-incentive-fee (CPIF)	Based on agreed scope of work, has target cost and fee, fee adjustment formula	May be used when required work is not definitized, yet must be started as soon as possible	Chief of Engineers	Probably high, since cost of quality construction is reimbursable	Has potential of completing project earlier than by formal advertising-competitive bidding	Intermediate	Contractor-medium Government-medium	Highest financial incentive of cost reimbursement contracts	Difficult to judge
	Cost-plus-award-fee (CPAF)	Based on agreed scope of work, has minimum fee and bonus or award fee	Same	Chief of Engineers	Same	Same	Intermediate	Contractor-medium Government-medium	Medium	Same
Sole Source Negotiation*,**	Cost-plus-fixed-fee (CPFF)†	Based on agreed scope of work, provides fixed fee in addition to costs	Same	Chief of Engineers	Same	Same	Possibly highest but hard to determine in advance	Contractor-least Government-most	Lowest financial incentive of cost reimbursement contracts	Same

* Could result in a design-build contract.

** Could result in a letter contract to be definitized later.

† Specific written approval of CPFF contracts by the Assistant Secretary of Defense (Installations and Logistics) is required. (See paragraph 18-112 DAR).

This statement, or a similar one, is used in most Corps specifications for grouting.

93. Each of the types of contracting/job management arrangements listed has advantages and offsetting disadvantages. The firm fixed-price contract awarded after formal advertising and competitive bidding is the most highly favored method by which the Government procures construction. This is so because it is generally thought that the cost will be lower than if other methods are used. Also, the Government thereby avoids charges of favoritism in awarding contracts. Perhaps not so well known, a third reason is that this type of contract allocates a greater portion of the risk to the contractor. Table 1a lists several factors that should be considered in acquiring and selecting contract services and what type of contract to select (USACE, MRD 1982).

94. The major factors that should be considered when procuring grouting services are:

a. Whether the grouting is part of a larger construction project or whether it is a separate activity.

b. How well the work to be done can be defined in terms of locations and depths of holes, grout mixtures and quantities, procedures, time constraints and coordination requirements, and measurement of results.

c. The number and qualifications of potential bidders.

d. Whether qualified Corps personnel and adequate Government-owned equipment are available as an alternative to contracting for the grouting work, assuming that performance by Government forces is desirable and that such performance can be justified as an exception to the normal practice of contracting for such work.

Contract terms affecting grouting

95. Because most grouting operations undertaken by the Corps are performed by contractors, a review of contract specifications used by the Corps and an analysis of how the specifications affect the job is in order.

96. The specifications selected for review are those for the construction of Longview Dam Stage I, a recent (1979) Corps project. This was a contract for the construction of a dam, awarded to a general contractor who awarded the drilling and grouting to a subcontractor.

97. Although all of the 77 General and Special Provisions of the contract could have some effect on the grouting subcontractor and his work, 15 of

them appear particularly pertinent. These are contained in Appendix II. The potential applicability of these 15 are contained in Table 2a.

98. The technical specification covering grouting and exploratory drilling cannot easily be summarized. Therefore, they are included in full in Appendix II. In addition to the statement concerning the unknown quantities of drilling and grouting to be accomplished, the technical specification contains 20 statements concerning Government direction of the work. These statements are:

a. ...The locations, depths, orientation and number of grout holes shall be as directed... (underscoring added here and in following quotations).

b. ...Subsequent split spaced holes and horizontal holes shall be drilled and grouted at the locations, depths and orientations as directed...

c. ...The number of grout holes is increased, progressively, by this method as deemed necessary by the Contracting Officer...

d. ...An exception to the general rule of initially drilling of such holes to final depth may be made by the Contracting Officer...

e. ...Grouting pressures directed to be used in the work will vary...

f. ...The grout mix shall be changed, if so directed...

g. ...Should grout leaks develop, the leaks shall be calked when and as directed...

h. ...Grouting in the hole shall be discontinued when directed...

i. ...Additional drilling and grouting shall then be done... as directed...

j. ...At the end of pressure grouting each section, all holes shall be backfilled with grout having a water cement ratio of 0.7, or as directed...

k. ...The equipment shall be returned and additional holes for grouting shall be drilled and grouted as directed...orientations as directed...

l. ...Grouting mixes, pressures, pumping rates, and sequence in which the holes are drilled, grouted and backfilled will be determined in the field and shall be as directed by and performed in the presence of the Contracting Officer...

m. ...The grout mixes will be designed by the Contracting Officer...

n. ...This percentage (of bentonite) shall be increased or decreased if so directed by the Contracting Officer...

Table 2a

General and Special Contract Provisions Particularly Pertinent to Grouting

Number and Title - Contract Provision	Summary of Provision	How Grouting Work May be Affected
3. Changes	Provides authority for contracting officer to make changes within scope of contract. Provides for equitable adjustment in time and/or cost.	Contract changes may be made if contracting officer feels they are warranted.
4. Differing Site Conditions	Requires contractor to notify contracting officer of site conditions differing from those anticipated. Provides for equitable adjustment if conditions do materially differ.	If conditions are materially different from those anticipated, an adjustment may help the contractor.
6. Disputes	States procedure for resolving disputes between contractor and contracting officer. Requires contractor to proceed with performance pending resolution of disputes.	Allows job to proceed even though Government and contractor may disagree. Provides procedure for eventual settlement.
10. Contractor Inspection System	Requires contractor to maintain adequate inspection system and make available records of inspection to Government.	Apparently not greatly used in grouting although contractor's records of grouting are required by the Government.
47. Site Investigation	Requires contractor to investigate site, both surface and subsurface. Relieves Government of responsibility for conclusions or interpretations made by contractor on basis of Government-furnished information.	Places a great portion of the risk on the contractor's shoulders.
51. Subcontractors	Requires contractor to notify Government of subcontractors. Emphasizes there is no contractual relationship between subcontractor and Government.	Erects barrier between Government and grouting subcontractor.

(Continued)

Table 2a (Continued)

Number and Title - Contract Provision	Summary of Provision	How Grouting Work May be Affected
53. Additional Definitions	Emphasizes that Government direction or approval is required in certain instances.	Reemphasizes Government's authority to direct work.
55. Government Inspectors	Emphasizes that Government inspectors may not change contract provisions. Requires contractor compliance with contract provisions whether or not inspector is present.	May lead to contractor/subcontractor/Government problems as Government directs grouting work.
59. Value Engineering Incentive	Specifies procedures for submission, acceptance, and sharing of savings from contractor developed value engineering changes.	Provides means for contractor to recommend changes in grouting program.
70. Variations in Estimated Quantities	Provides for change in unit prices if actual quantities vary more than ±15% from quantities estimated in contract.	Provides for equity in payment when actual quantities are significantly different from those estimated by Government. Not commonly used for grouting. See SP-7 below.
SP-5. Physical Data	Emphasizes that data furnished on borings (among other types of data) are furnished for contractor's information and Government is not responsible for contractor's interpretations or conclusions.	Shifts risk to contractor.
SP-7. Variations in Estimated Quantities - Subdivided Items	Provides for contractor to distribute his indirect costs properly by subdivision of items; e.g., first 7000 cubic yards, cubic yards in excess of 7000. Provides for contract adjustments.	Commonly used for grouting.
SP-53. Laboratory and Testing Facilities	Requires contractor to maintain and calibrate measuring and testing devices.	Should help insure accuracy of measurements.

(Continued)

Table 2a (Concluded)

Number and Title - Contract Provision	Summary of Provision	How Grouting Work May be Affected
SP-57. Coordination Between Contractors	States requirement to coordinate with other contractor(s) to minimize delays and interference.	Because grouting may interfere with other work, it is normally a part of the general construction contract, and this provision may not always be important.
SP-64. Approved Equal	States that trade names used in technical specifications establish standard of quality but do not limit competition.	Allows use of contractor equipment other than that specified, if approved by Government.

o. ...Holes for grouting shall be drilled at the locations, in the direction, and to the depths shown on the drawings or as directed...

p. ...The Contracting Officer may require exploratory holes to be drilled at locations anywhere within the work area...

q. ...Exploratory holes in bedrock shall be pressure tested and stop grouted under pressure as directed...

r. ...A section is further defined as a portion of the grout curtain, as determined by the Contracting Officer...

s. ...Grout that cannot be placed, for any reason, within 2 hours after mixing shall be wasted as directed...

t. ...The information contained in the Government's drilling and grouting log shall be the basis of measurement...

99. This specification should leave no doubt in the minds of the contractor and his subcontractor concerning who is in charge of the grouting operation.

Trends in management of construction contracts and in relations between Government and contractors

100. The Corps and the U. S. Construction Contracting Industry have enjoyed a unique relationship for many years. Together they have built complex, difficult, one-of-a-kind, huge projects that have contributed greatly to the creation of the infrastructure of the United States. They share a mutual pride in these accomplishments. The construction task requires a certain amount of adversary relationship that tends to inhibit cooperation. Because of their different roles, they must perforce often be at odds.

101. Over the years there has been a considerable increase in the formality of the relationship. Today an exchange of letters between the Government and contractor managers is the norm in communication.

102. While the relationship has always been professional, today the people in both the Government and contractor organizations are more highly educated and often more specialized than in the past. It is not uncommon for both the Government and contractors to have engineers and geologists with advanced degrees and who are either permanent employees or consultants. A trend, not unnoticed by engineers, and often lamented, is the increasing number of lawyers employed by both agencies in the formation and administration of construction contracts, and in the settlement of disputes.

103. The trends toward greater formality and higher technical qualifications can and do help in completing projects of greater and greater technical

sophistication. They can also exacerbate the "arms-length" relationship between the Corps and contractors.

104. One way in which the Government has attempted to reduce friction is to improve contract specifications, both general and technical. Perhaps the best known change is the adoption of the "Differing Site Conditions" clause in 1968, superseding the "Changed Conditions" clause. The new clause provides for both an equitable adjustment, in money and time extension, for the work directly changed by the occurrence of an unforeseen site condition, and also for an adjustment for other work indirectly affected.

105. The Corps has experimented with improved technical specifications, as illustrated by the Albuquerque District's payment for grouting by time and quantity of cement rather than for cubic feet of grout injected.

106. More sophisticated scheduling has become an important trend during the four-decade period under examination. The increasing use of critical path method (CPM) scheduling in the 1950's and 1960's coupled with the introduction of the computer has led to much more detailed scheduling of construction projects. This trend is of importance here because grouting often takes place at a time and in a location such that it can significantly affect other work.

107. Another trend of some importance involves changes in methods and procedures for insuring the quality of construction. In the early part of the period under study the Corps relied on relatively large numbers of inspectors who were generally very experienced in construction, but who did not have a technical education (e.g., a bachelor's degree in an appropriate technology). The trend has been to reduce the numbers of Government inspectors but to require higher technical qualifications of those remaining on the job. Coupled with this trend, there has been an effort to increase the responsibility of contractors for inspection and control of the quality of their work. For instance, the clause used for the Longview job, Contractor Inspection System, was introduced in November 1964.* It requires the contractor to maintain an adequate inspection system, to perform inspections as will assure that the work performed conforms to contract requirements, and to maintain and make available to the Government records of the inspections. These requirements are somewhat difficult to reconcile with the technical requirements for grouting discussed earlier in this report. It may, in fact, be impossible to observe both.

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* See Appendix II for the exact wording of this clause.

108. The trends in management of construction contracts and in relations between Government and contractors that are of interest in examining grouting are:

- a. Greater documentation (by both parties).
- b. Greater formality in relations between the parties.
- c. Higher technical qualifications of contractor and Government personnel.
- d. More sophisticated scheduling of projects.
- e. Increased reliance on contractor quality control (CQC) and reduced numbers of Government inspectors.
- f. Changes in specifications aimed at resolution of problems previously encountered.

109. These trends, both singly and in combination, have changed both the construction process and the relations between Government and contractor. Depending on one's point of view, the changes may be considered as favorable or unfavorable. All will agree, however, that the changes must be dealt with in constructive ways.

110. These constructive ways might include further changes in specification, increased training, or changes in policy. This report sets forth certain recommended changes that are made necessary by these trends.

Trends in legal aspects
of construction contracting

111. Partially because of the trends discussed in paragraphs 100-110, and perhaps also as a consequence of the overall increase in litigation during the four decades under consideration, there have been some significant trends in the legal aspects of construction contracting. These trends have resulted in a large increase during these years in the number of contractor claims that have required decisions by Government contracting officers, appelate boards, and courts.

112. Although many events, actions, specification changes, and legal decisions since 1940 have undoubtedly left their marks on contracting for grouting work, two are most notable and have therefore been singled out for consideration.

113. The first concerns the contract provision used by the Corps (mandated for inclusion in Government construction contracts) to cope with site conditions encountered during construction. These conditions are materially different from those indicated in the contract or reasonably expected by the

contractors in the event no indications were given in the contract. The Corps has been a leader among contracting agencies in adopting policies (and enunciating them in specifications) that provide for equitable sharing of risk between the Government and the contractor.

114. The problem arises because the subsurface conditions at the project site can only be sampled and therefore can never fully be known in advance. Even so, design must proceed on the basis of the best available information. During construction, subsurface conditions are often encountered that require changes in design, construction methods, equipment, materials, and quantities, and often in the time required for construction. Although most (unfortunately not all) persons involved in design and construction now recognize that the risks involved in unforeseeable changes from expected site conditions are risks the owner, that is, the Government, should assume, it was not always so. Until about 57 years ago, all Corps contracts were silent concerning what action would be taken if an unforeseen condition were encountered. The specifications prepared in 1959 for the Kettle Creek Dam (now Alvin R. Bush) made no provisions for an equitable adjustment in the event that unforeseen conditions were encountered. To the contrary, the specification concerning site investigation* emphasizes the contractor's responsibility to acquaint himself with site conditions. The specification also states that the Government is not responsible for any interpretations of its data by the contractor or for any oral representations by its (the Government's) agents.

115. It was recognized that the Government owner who initiated a project (designed it, paid for construction, and benefited from its completion) should assume responsibility for unforeseen conditions encountered during construction. Accordingly, 57 years ago a "Changed Conditions" clause allowing an equitable adjustment in contract price and time for the work specifically affected by such a condition was adopted, but not used in every contract. In 1968 this specification was replaced by the currently-used "Differing Site Condtions" clause providing for an equitable adjustment in the event that such a condition was encountered by the contractor, with such adjustment to apply

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* Specifications for Kettle Creek Dam, Serial No. CIVENG 18-020-59-8, U. S. Army Engineer District, Baltimore, 17 March 1959 (GC-3, Site Investigation).

to any part of the work, whether or not changed as the result of the condition.*

116. This specification has stood the test of time, and as stated above, has been mandated for inclusion in construction contracts of all Government agencies.

117. As described in Part IV, it has been difficult for the Corps' designers to estimate accurately the amount of drilling and grouting that will be required in the construction of a dam or in later remedial work. As a matter of interest, a variation in quantities alone may be availed of as a differing site condition if the parties labored under a mutual mistake of fact concerning the quantities involved under the contract (Chernus Construction Company versus United States 1948). About 5 years ago a contractor successfully claimed that the difference between estimated and actual quantities of drilling and grouting were caused by, and in fact were evidence of, a differing site condition. The claim was made by the Perini Corporation under Contract DACW0572-L-0072 awarded in 1972 for construction of Hidden and Buchanan Dams. Table 3a shows a comparison of the estimated and actual drilling and grouting quantities.

Table 3a

Estimated and Actual Drilling and Grouting Quantities, Hidden Dam and Buchanan Dam

Hidden Dam			Buchanan Dam			Total		
Government Estimate	Actual	% Difference	Government Estimate	Actual	% Difference	Government Estimate	Actual	% Difference
Drilling, lin ft								
110,100	124,969	+13.5	56,000	69,516	+24.1	166,100	194,485	+17.1
Grouting, cu ft								
64,000	18,234	-71.5	18,500	12,286	-33.6	82,500	30,520	-63

118. The actual drilling quantities experienced were not nearly as far from estimated quantities as were the grouting quantities from the estimates.

* See Appendix II, Extracts, Specifications for Construction of Longview Dam Stage I (General Provision, para. 4).

The contractor, Perini Corporation, and his subcontractor, Continental Drilling Company, successfully argued before the Corps of Engineers Board of Contract Appeals (Eng BCA 3745 - 27 April 1978) that the very substantial underrun in grout was evidence of a differing site condition, and the Board awarded the Contractor an adjustment of $166,340.

119. The percentage difference in the data in Table 3a is not uncommon in practice, and the precedent suggests that other contractors would probably have been entitled to an adjustment because of wide variations between estimated and actual quantities, if they had submitted a claim.

120. It seems that in the future the Corps will be required to make equitable adjustments if estimates and actual quantities continue to vary so widely from each other and if the type and language of the contract remain the same. In fact, it might be said that the Corps was "lucky" that it did not have to make such adjustments long before the 1978 decision.

121. The question, then, is whether the Corps should continue to do business in the same way it has in the past, or whether it should look for ways to improve. By improvement, we mean development of different specifications and/or procedures that will facilitate equitable payment to contractors for work done without necessitating that they submit claims in order to receive equitable treatment. We also believe that the latter course of action should be selected, and specific suggestions to that affect are made later in this report (Paragraphs 186 and 187).

122. As stated earlier, there are undoubtedly other legal trends that have a bearing on grouting work, but the authors believe that the most important problem and the decision concerning that problem have been highlighted.

Foreseeable future developments:
technical, contractual, legal

123. What can be expected concerning grouting in future years? Speculation concerning future events, though dangerous, is necessary. This discussion will attempt to predict future trends and developments of a technical, contractual, and legal nature.

124. Perhaps forecasting technical trends is least difficult, since there are indications that point the way. First, it seems likely that there will be more grouting work done in the future to remedy conditions at existing dams, and that less grouting will be done in connection with new dams because fewer new dams are anticipated. For fiscal year 1984 the Corps' budget for

Operation and Maintenance of existing civil works structures is greater than its budget for Construction General, and there is reason to believe that this situation will be repeated in future years. As existing dams grow older, they will require maintenance to keep them in good condition, and grouting is certainly one of the maintenance measures that will be used. This may simplify the Corps' job management problems because remedial grouting contracts will be awarded directly to drilling and grouting contractors. Therefore, one echelon of management present on new construction projects (the general contractor), will not be present. This simplifies job management by making it possible for the Corps to work directly with the grouting contractor. Also, the problems of coordination that exist in an established project are fewer (and perhaps simpler) than those at a construction site.

125. The techniques and improved equipment for drilling and grouting have advanced in the 40 years covered by this case study, and this is probably one of the reasons that costs for drilling and grouting have declined (in constant dollars) during that period. Further improvements in technology and equipment can be expected. Better tools and techniques for exploration, better drilling equipment, and better grouting materials and grouting equipment can all be expected, but it seems most probable that these improvements will be of an evolutionary nature rather than revolutionary. The use of electronics, especially microcomputers, may make it possible to control both drilling and grouting more precisely than has been possible in the past. Similarly, improved equipment for exploration may be used to help the designer decide where and how to grout, and how much grout may be required.

126. However, even if these evolutionary improvements do materialize, the problems the designer and the grouting contractor face will probably not disappear, but will only become more manageable. Therefore, solutions must be found elsewhere.

127. One place to look is the contractual and job management area. There appear to be several likely ways of making improvements. These include:

- a. Better contract specifications.
- b. Different contract forms.
- c. Additional training for key Corps personnel as to remedial grouting.
- d. Increased use of Corps personnel for remedial grouting.

128. Better contract specifications are needed to reduce the number of disagreements between the Corps and its contractors, to provide for a more equitable means of payment for work accomplished, and particularly to provide incentives for the contractor to achieve the desired level of quality. For example, payment for the time spent in grouting rather than the quantity injected would tend to be fairer to the contractor and the Corps and, at the same time, bring their goals closer together.

129. However, improved specifications alone are not the whole solution. Contracting for grouting using the normal fixed-price construction contract, as is traditionally done, is a somewhat self-contradictory procedure. This type of contract is most successfully used where the job to be done is defined in detail, but where the contractor is quite free to select the tools and techniques for doing the job. Grouting, in contrast, is an ill-defined job at best, but it is one where the tools and procedures are so vital that the Government retains in great measures the right to direct how the job will be done. A better contract instrument is needed to help the Corps get what it needs while providing for competition among prospective contractors and fair pay for the successful bidder. The Corps may be fortunate that more grouting will be done in the future as an activity separate from construction, since it is difficult at best to separate grouting from the contract for dam construction. When grouting is done as a separate activity, and where the work will be contracted for rather than done by Corps personnel, serious consideration should be given to the use of a service contract to provide crews and equipment to drill and grout as directed by the Corps. Bidders could compete on the basis of cost for carefully specified equipment, crew sizes (and qualifications), and anticipated amounts of drilling and grouting. Separate items for standby-by time and working time could be included. This form of contract is much more in line with the situation as it actually exists than is the contract form now used. Anticipated results include fewer disputes between the Corps and its contractors and, hopefully, better quality resulting from eliminating opposing goals of the contractor and the Corps.

130. Increased education and training of the Corps personnel should be required for the future, and it should be stress Corps procedures and grouting policy.

131. The first training need is at the technical level for geotechnical engineers and geologists, and this training should be concerned with state of

the art grouting technology and lessons learned at each new grouting job. Even though grouting projects are site specific and no two are ever alike, each new project adds to the Corps' total knowledge, and lessons learned should be helpful in planning, designing, and carrying out succeeding projects. (Lessons learned can also be passed on by monographs, project reports, and/or seminars.)

132. Another training need is in the field management of grouting projects, and this training should include both the technical details and contract management procedures. The objective should be to enable field personnel to achieve the desired quality of grouting, properly documented, within the terms of the contract, i.e., without claims.

133. Another development that the Corps should undertake would be the development of contract specifications aimed at securing the required quality of grouting and equitable payment to the contractor. In this development, consideration should be given to more equitable sharing of risks. A consideration that should receive special attention is provision in the contract of a positive motivation for the contractor to achieve high quality.

134. The Corps should also consider whether to do more grouting by its own forces rather than by contracts. It does not seem likely that every District would require such a capability, but perhaps certain Districts, selected on the basis of grouting work load and existing expertise, could develop first class capabilities in both trained personnel and appropriate equipment. These crews could then be used by other Districts as well as their own. For example, the remedial grouting of Alvin Bush Dam by Mobile District was considered successful and in many ways more advantageous to the government than contract work. This suggestion may appear contrary to efforts to reduce Government work forces where the work can be done by contract, but there is justification for it if only to provide preparedness to respond to emergencies. Additionally, it may provide a yardstick against which to measure contractor performance. Establishment of specialized capabilities in selected Districts does appear consistent with the Corps practice in other types of work.

135. Another significant action that the Corps should take is to provide guidance to field operating agencies (FOA's) on available contracting procedures and construction management practices. From this study, it is apparent that technical goals and objectives, as well as the Corps' grouting philosophy, must be considered when selecting the most appropriate contracting methods and procedures.

PART IV: ANALYSIS OF CASE HISTORIES

Access to Data

136. Access to project documents varied in time and by Districts. The Districts' response to DAEN's request for data varied widely. Very comprehensive data, including portions of certain construction documents, foundation reports, and portions of plans and specifications were made available expeditiously by some Districts while other Districts were unable to respond until very late in the study. Completed questionnaires were returned when other data were sent. Some data could not be located. The lack of these data impacted on the review. Some additional data were obtained by informal request to the Districts after receiving the initial data; however, time became critical and the data collection effort had to be terminated in order to complete the report on schedule. Summaries of data developed in the case history studies are shown in Tables 1b, 2b, and 3b.

General

137. Fourteen projects located in 11 Districts and 7 Divisions were reviewed. A total of 23 grout reviews were made. Of those, Hartwell included two separate contracts for original grouting. Oologah had two original grouting contracts (right and left abutments), but cost data were available only for the left abutment grouting. Alvin Bush had an original and two remedial grout programs of which one was by hired labor. The Eufaula review contains data on the spillway, fault zone, and left abutment grouting, but no cost data were available. Abiquiu had an original contract with three subsequent deferred and remedial contracts. Libby had the original grouting plus two small remedial contracts. The Wolf Creek grouting review was the last phase of a three phase remedial grout program. The age of the formations grouted ranged from Precambrian through Cretaceous and included Precambrian, Cambrian, Ordovician, Devonian, Mississippian, Pennsylvanian, Permian, and Cretaceous. Rocks included granites, gneisses, metasediments, limestones, dolomites, sandstones, siltstones, and shales. Drilling through the embankment was necessary for remedial grouting at Abiquiu, Alvin Bush, and Wolf Creek. Of the 23 reviews, Continental Drilling Company was the drilling and grouting

Table 1b

Case History Cost Data

Project		$ Cost/ cu ft Grout Placed	Area sq ft, Curtain*	$ Cost sq ft, Curtain
A	John Martin	8.67	106,795	0.29 (concrete dam)
B	Norfork	12.14	368,340	0.45 curtain only 0.62 all grout
C	Allatoona	15.64	67,250	0.70
D_1	Hartwell		88,800	
D_2	Hartwell		142,500	
E_2	Oologah	8.86	40,000	0.65
F_1	Alvin Bush	7.72	42,150	3.78
G_1	Abiquiu	5.95	215,600	1.10
H	Eufaula	No cost data available	111,040	
F_2	Alvin Bush	13.15	58,250	4.01
G_2	Abiquiu	11.61	172,480	3.41
I	Dworshak	26.53	860,700	0.97
J_1	Libby	26.71	419,030	1.18
K	Laurel	10.07	110,158	1.15
L	Clarence Cannon	24.84	296,500	7.69
M	Wolf Creek	14.07	799,200	1.26
F_3	Alvin Bush	18.40	10,300	31.17
J_2	Libby	360.00	70,800	1.51
J_3	Libby	497.00	8,100	6.20
G_3	Abiquiu	34.83	214,000	10.29
G_4	Abiquiu	29.48	321,440	5.44
N	Longview	172.00	174,500	2.56

* Estimated.

Table 2b

Summary of Estimated and Actual Quantities and Costs for Curtain Grouting

Project	M&D $	Drilling Grout Hole Items, LF — Diameter 6"	Diameter 5"	Diameter 3-1/2"	Diameter 3"	Diameter 2"	Diameter 1-1/2" R	Diameter 1-1/2" P	Emb. & OB Drilling S	Emb. & OB Drilling NS	Rock Drilling S	Rock Drilling NS	Grout Holes	Previous Grout Holes
A John Martin Albuquerque Dist. 1941-1942	--				16,000 (14,542) $1.083 ($2.00)	8,000 (5,097) $0.678 ($1.50)								
B Norfork Little Rock Dist. 1941-1945	--		0-80' 13,000 (16,230) $1.50 ($2.85)	0-40' 23,000 (27,213) $1.80 ($2.50)	40-100' 20,000 (24,352) $1.80 ($2.60)	100-150' 1,000 (3,611) $1.81 ($2.85)	0-40' 20,000 (1,640) $1.40 ($2.00)							
C Allatoona Mobile Dist. 1946-1949	--						25,600 (13,225) $3.72 ($2.50)							
D_1 Hartwell Savannah Dist. Emb. 1955-1960	$1,700 (NA)												12,400 (6,458) NA ($2.30)	
D_2 Hartwell Savannah Dist. Concrete Spillway 1955-1966	NA NA						20,000 (22,969) NA (NA)							
E Oologah Tulsa Dist. 1958-1964	NA ($2,300)												5,500 (6,663) NA ($2.05)	
F_1 Alvin Bush Baltimore Dist. Original, 1958	$2,500 (NA)						4,040 (4,527) $4.50 (NA)							
G_1 Abiquiu Original Albuquerque Dist. 1959-1963	NA (NA)				a. 2,500 (1,565) NA ($7.00) b. 1,500 (0) NA ($7.00)		a. 10,000 (10,000) NA ($3.00) b. 8,000 (6,884) NA ($3.00)	6,300 (3,890) NA ($2.50)						
H Eufaula - No items, estimates, or actual costs are available. Tulsa District 1960-1963														
F_2 Alvin Bush Baltimore Dist. 1964	$1,000 (NA)									a. 8,000 (8,000) $6.00 (NA) b. 6,000 (6,000) $6.00 (NA)		a. 2,500 (2,500) $6.00 (NA) b. 2,000 (6,247) $6.00 (NA)		

Project	Grouting Items — PT HR	Cement ft	Sand	Clay	Mineral Filler lb/CF	Fluidifier	Other	Pipe lb or LF	Placing Grout CF	Placing Grout HR	Fittings	Connections	Standby	Dry Pak Holes	Clean Grout From Drains	Mod
A John Martin Albuquerque Dist. 1941-1942		CF							25,000 (6,830) $0.685 ($0.90)							
B Norfork Little Rock Dist. 1941-1945		GF							20,000 (20,000) $0.70 ($1.70)	20,000-40,000 (4,479) $0.60 ($0.60)						
C Allatoona Mobile Dist. 1946-1949								3,250 (3,250) $0.60 ($1.00)	18,000 (3,000) $1.75 ($3.50)		210 (210) $1.95 ($0.50)					
D_1 Hartwell Savannah Dist. Emb. 1955-1960		7,000 (791) NA ($1.55)						2,700 (NA) NA ($0.58)	7,000 (791) NA ($2.30)			500 (NA) $5.00 ($5.00)				
D_2 Hartwell Savannah Dist. Concrete Spillway 1955-1966		12,600 (4,221) NA (NA)							12,600 (4,221) NA (NA)			525 (NA) $5.00 ($5.00)				
E Oologah Tulsa Dist. 1958-1964	25 (56-1/3) NA ($20.00)								3,000 (2,936) NA ($2.90)			50 (81) $5.00 ($5.00)				
F_1 Alvin Bush Baltimore Dist. Original, 1958		4,000 (20,678) 3.00 (NA)	200 (200) 1.50 (NA)		100 CF (100) $3.50 (NA)				1000 lb (1000) $0.70 (NA)	4,300 (20,678) $3.50 (NA)		350 (350) $2.00 (NA)				
G_1 Abiquiu Original Albuquerque Dist. 1959-1963	a. 500 (425) NA ($12.00) b. 400 (0) NA ($12.00)	a. 30,000 (30,000) NA ($2.00) b. 25,000 (9,941) NA ($2.00)						LF 2,300 (3,296) NA (1.00)	a. 30,000 (30,000) NA (2.25) b. 25,000 (9,941) NA ($2.25)		900 (767) NA (5.00)					
H Eufaula Tulsa District 1960-1963																
F_2 Alvin Bush Baltimore Dist. 1964	a. 100 (NA) b. 100 (NA)	a. 6,000 (6,000) $1.65 (NA) b. 4,000 (11,774) $1.65 (NA)	300 (300) $0.25 (NA) b. 200 (200) $0.25 (NA)		a. 300 CF (300) $0.45 (NA) b. 200 (200) $0.45 (NA)				a. 6,000 (6,000) $3.75 (NA) b. 5,000 (11,774) $3.75 (NA)			a. 500 (500) $3.00 (NA) b. 300 (300) $3.00 (NA)				

LEGEND:

M&D = Mobilization and Demobilization
1-1/2" R = Rotary
1-1/2" P = Percussion
S = Sampled
NS = Not Sampled
PT = Pressure Test
GF = Grout Finished
MOD = Modification
LF = Linear Feet
CF = Cubic Feet
HR = Hour
Gov't Est. Q 100
Actual Q (100)
Gov't Est. Cost $2.00
Actual Cost ($2.00)
NA = Not Available

(Continued)

Table 2b (Concluded)

Project	M&D $	Drilling Grout Hole Items, LF: Diameter 6"	5"	3-1/2"	3"	2"	1-1/2" R	1-1/2" P	Emb. & OB Drilling S	Emb. & OB Drilling NS	Rock Drilling S	Rock Drilling NS	Grout Holes	Previous Grout Holes	Grouting Items: PT HR	Cement ft	Sand	Clay	Mineral Filler lb	Fluidi-fier	Other	Pipe lb or LF	Placing Grout CF	Placing Grout HR	Fittings	Con-nections	Standby	Dry Pak Holes	Clean Grout From Drains	Mod
G_2 Abiquiu Albuquerque Dist. Supplemental 1966–1967	NA ($80,892)				775 (14,655) NA ($7.00)		5,750 (9,148) NA ($2.30)								40 (235) NA ($15.00)							43,000 lb (55,687) NA ($0.50)	42,500 (41,060) NA ($3.05)			900 (864) NA ($6.00)				
I Dworshak Walla Walla Dist. 1966–1973	NA						a. 100,000 (100,000) NA ($4.00) b. 55,000 (61,307) NA ($4.00)			a. 500 (191) NA ($22.00) b. 500 (0) NA ($22.00)						a. 40,000 (11,522) NA ($1.80) b. 22,000 (0) NA ($1.80)				a. 10,000 lb (2,437) NA ($1.10) b. 5,500 (0) NA ($1.10)			a. 40,000 (9,262) NA ($3.40) b. 22,000 (0) NA ($3.30)			a. 1,500 (1,500) NA ($10.00) b. 700 (4) NA ($10.00)				$116,145 Price adj. for underruns
J_1 Libby Seattle Dist. Original 1967–1973	NA ($16,000)												65,000 (61,121) NA ($5.10)			32,500 (18,560) NA ($2.50)				8,125 lb (4,631) NA ($1.40)			32,500 (18,560) NA ($5.00)			1,500 (1,500) NA ($15.00)				
K Laurel Nashville Dist. 1969–1970	$12,400 (3,150)												20,000 (17,565) $6.78 ($2.63)			5,000 (10,934) $2.50 ($2.63)							6,000 (10,934) $3.96 ($2.63)			550 (550) $6.00 ($6.00)				
L Clarence Cannon St. Louis Dist. 1973–1983	$160,000 ($32,500)				14,150 (14,983) $30.00 ($15.00)			2,450 (2,818) $6.00 ($4.50)				83,100 (74,075) $12.00 ($11.15)			670 (324) $210.00 ($117.00)	55,000 (48,332) $5.00 ($4.40)	5,500 (1,159) $1.25 ($2.30)			27,000 lb (16,120) $0.60 ($0.70)	Bentonite 76,000 (7,327) $0.25 $0.07	1,700 LF (13,915) $15.00 ($12.00)	56,500 (50,495) $8.00 ($5.75)		Packers 65 (8) $200.00 ($100.00)	2,650 (2,109) $15.00 ($15.00)		2,500 CF 6,212 $5.00 ($8.50)		
M Wolf Creek Nashville Dist. 1974–1975	NA ($28,000)								1,000 (327) $13.60 ($14.00)	101,200 (86,871) $6.10 ($4.00)	23,300 (22,801) $7.90 ($6.50)	70,800 (46,615) $5.00 ($5.00)			40 (167) $100.00 ($40.00)	56,600 (18,686) $3.05 ($2.70)	124,000 (46,854) $0.53 ($0.60)	14,400 (6,544) $1.62 ($1.35)					195,000 (71,687) $2.50 ($2.00)			1,400 (1,165) $8.00 ($8.00)	200 hr (17.3) $50.00 ($25.00)			
F_3 Alvin Bush Baltimore Dist. Hired Labor 1973–1974	No item									NA (11,860)		NA (6,119)				NA (17,450)							NA (17,450)							
J_2 Libby Seattle Dist. 1975	$25,000 ($25,000)												5,200 (5,155) NA ($8.00)	1,100 (1,070) NA ($5.00)	150 (150) NA (50.00)	1,000 (255) NA (4.00)				Alum. 250 lb (64) NA ($2.00)	Cement 300 (41) NA ($6.00)		900 (296) NA ($12.00)			52 (56) NA ($50.00)	20 hr (20) NA ($100.00	52 (56) NA ($40.00)	3,000 (3,000) NA ($5.00)	
J_3 Libby Seattle Dist. 1977	$25,000 ($25,000)												660 (960) NA ($15.00)	50 (50) NA ($20.00)	25 (25) NA ($100.00)	75 (86) NA ($7.00)					15 (15) NA ($20.00)		95 (101) NA ($10.00)			15 (20) NA ($40.00)	16 hr (16) NA ($75.00)	15 (20) NA ($50.00)	200 (200) NA ($12.00)	
G_3 Abiquiu Albuqueque Dist. Inc. I 1978–1980	$232,063 ($120,000)		9,000 (11,117) $10.96 ($14.40)		27,000 (48,940) $8.03 ($10.80)		17,500 (21,217) $7.82 ($10.80)								250 (241) $179.22 ($120.00)	66,300 (59,722) $4.49 ($6.36)						4" 9,000 (10,956) $7.86 ($9.00) 2" 36,000 (54,263) $2.60 ($3.60)	70,600 (63,226) $3.26 ($7.20)			810 (1,221) $5.00 ($5.00)				Claim pending
G_4 Abiquiu Albuquerque Dist. Inc. II 1978–1980	$252,350 ($60,000)	14,000 (21,096) $13.35 ($12.00)		28,600 (55,492). $8.78 ($8.00)			21,300 (11,067) $8.65 ($9.00)								250 (72) $190.00 ($150.00)	83,100 (59,362) $5.30 ($6.00)						4" 14,000 (20,816) $8.05 ($8.00) 2" 42,000 (57,326) $3.06 ($3.00)		2,700 (1,822) $113.00 ($100.00)		900 (1,090) $5.00 ($5.00)				Claim pending
N Longview Kansas City Dist. 1979–1981	$35,100 (100,000)												74,000 (45,374) $11.40 $7.00			17,000 (3,225) $3.80 ($5.00)					Bentonite 50,000 (11,509) $0.07 ($0.10)		16,000 (2,608) $4.40 ($8.50)			3,000 (585) $10.00 ($10.00)				$80,000 Neg. settlement for differing site conditions

Table 3b

Summary of Drilling and Grouting Data for Projects Studied

				Drilling		Grouting		CF/LF Ratio	
Project	District	Geology	Contractor Prime or Sub	Estimated Quantity LF	Actual Quantity LF	Estimated Quantity CF	Actual Quantity CF	Estimated	Actual
A John Martin 1941-1942	Albuquerque	Cretaceous sandstone (Dakota)	Jones Core Drilling Co. (Sub)	3" 16,000 2" 8,000 24,000	14,542 5,097 19,639	25,000	6,830	1.04	0.35
B Norfork 1941-1945	Little Rock	Ordovician limestones and dolomites	Mott Core Drilling Co. (Sub)	0-80' 13,000 0-40' 23,000 40-100' 20,000 100-150' 1,000 0-40' 20,000 77,000	16,230 27,213 24,352 3,611 1,640 73,046	a. 20,000 b. 40,000 60,000	20,000 4,479 24,479	0.78	0.34
C Allatoona 1946-1949	Mobile	PreCambrian/ Cambrian quartzite	Continental Drilling and Grouting Co. (Sub)	25,600	13,225	18,000	3,000	0.70	0.23
D_1 Hartwell Emb. 1955-1960	Savannah	PreCambrian granite gneiss	Cunningham Core Drilling and Grouting Corp. (Sub)	12,400	6,458	7,000	791	0.56	0.12
D_2 Hartwell Concrete Spillway 1955-1960	Savannah	PreCambrian granite gneiss	Continental Drilling and Grouting (Sub)	20,000	22,969	12,600	4,221	0.63	0.18
E Oologah Left Emb. 1958-1964	Tulsa	Pennsylvanian limestone (Oologah)	Geo Prospectors (Sub)	5,500	6,663	3,000	2,936	0.55	0.44
F_1 Alvin Bush Original 1958	Baltimore	Devonian sandstones, siltstones, shales	Royal Contracting Co. (Sub)	4,040	4,527	4,300	20,678	1.06	4.57
G_1 Abiquiu Original 1959-1963 Grout complete 1961	Albuquerque	Permian sandstones, shales	Not Available	3" a 2,500 3" b 1,500 1½" a 10,000 1½" b 8,000 p 6,300 28,300	1,565 0 10,000 6,884 3,890 22,339	30,000 25,000 55,000	30,000 9,941 39,941	1.94	1.79
H Eufaula 1960-1963 Grouting 1961-1962	Tulsa	Pennsylvanian sandstone and shale	Continental Drilling and Grouting Co. (Sub)	Not Available	Not Available	Not Available	Not Available	Not Available	0.34
F_2 Alvin Bush 1964	Baltimore	Devonian sandstones, siltstones, shales	Layne New York Drilling Co. (Prime)	OB a 8,000 b 6,000 R a 2,500 b 2,000 18,500	8,000 6,000 2,500 6,247 22,747	6,000 5,000 11,000	6,000 11,774 17,774	0.59	2.03

(Continued)

Table 3b (Concluded)

Project	District	Geology	Contractor Prime or Sub	Drilling: Estimated Quantity LF	Drilling: Actual Quantity LF	Grouting: Estimated Quantity CF	Grouting: Actual Quantity CF	CF/LF Ratio: Estimated	CF/LF Ratio: Actual
G_2 Abiquiu Supplemental 1966-1967	Albuquerque	Permian sandstones, shales	Continental Drilling and Grouting Co. (Prime)	3" 775 1½" 5,750 6,525	14,655 9,148	42,550	41,060	6.52	1.72
I Dworshak 1966-1973	Walla Walla	Gneisses and amphibolites	Continental Drilling Co. (Sub)	a 100,000 b 55,000 OB a 500 OB b 500 156,000	100,000 61,307 191 0 161,498	a 40,000 b 22,000 62,000	9,262 0 9,262	0.40	0.06
J_1 Libby 1967-1973 Original	Seattle	PreCambrian metasediments	Continental Drilling Co. (Sub)	65,000	61,121	32,500	18,560	0.5	0.3
K Laurel 1969-1970	Nashville	Pennsylvanian sandstones and shales	ATEC (Sub)	20,000	17,565	6,000	10,934	0.3	0.62
L Clarence Cannon 1973-1983	St. Louis	Mississippian limestone and shale	Boyles Brothers (Prime)	99,700	91,876	56,500	50,495	0.57	0.55
M Wolf Creek Phase III 1974-1975	Nashville	Ordovician limestone	Murray Drilling Corp. (Prime)	OB s 1,000 OB us 101,000 Rx s 23,300 RX us 70,800 196,100	327 86,871 22,801 46,615 156,614	56,600 cem. 124,000 sand 14,400 clay 195,000	18,686 cem. 46,854 sand 6,544 clay 72,084	0.99	0.46
F_3 Alvin Bush 1973-1974	Baltimore	Devonian sandstones, siltstones, shales	Hired labor Mobile District	NA	11,860 6,119 17,979	NA	17,450	NA	0.97
J_2 Libby 1975	Seattle	PreCambrian metasediments	Jacques Co. (Prime)	y 5,200 x 1,100 6,300	5,155 1,070 6,225	900	296	0.06 0.14	0.02 0.05
J_3 Libby 1977	Seattle	PreCambrian metasediments	Continental Drilling Co. (Prime)	z 660 y 50 710	960 50 1,010	95	101	0.13	0.1
G_3 Abiquiu Inc. I 1978-1980	Albuquerque	Permian sandstones, shales	Continental Drilling, US (Sub)	5" 9,000 3" 27,000 1-3/8" 17,500 53,500	11,117 48,940 21,217 81,274	70,600	63,226	1.32	0.78
G_4 Abiquiu Inc. II 1978-1980	Albuquerque	Permian sandstones and shales	Continental Drilling, US (Prime)	6" 14,000 3½" 28,600 1-3/8" 21,300 63,900	21,096 55,492 11,067 87,655	2,700 hr 83,100 cem.	1,822 hr 59,362 cem.	1.3	0.68
N Longview 1979-1981	Kansas City	Pennsylvanian limestones, sandstones, siltstones, shale	Boyles Brothers (Sub)	74,000	45,374	16,000	2,608	0.22	0.06

contractor on nine occasions--three as the prime contractor and six as the subcontractor. Boyles Brothers was the grouting contractor on two occasions--once as the prime contractor and once as the grouting subcontractor. One remedial job was done by the Mobile District with hired labor, and the remaining contractors were represented on a single job. Of the 22 projects contracted, the drilling and grouting contractor was the prime on seven occasions. One contract had a price adjustment for underruns (Dworshak/ Continental Drilling Company). One had a negotiated settlement for a differing site conditions claim (Longview/Boyles Brothers), based on a higher ratio of drilling to placing grout than shown on the bid sheet, and two others had differing site conditions claims based on a higher ratio of drilling to placing grout than shown on the bidding schedule (Abiquiu Increment I and II/Continental Drilling Company). The first claim was at Dworshak (1966-1973). The Abiquiu claims were for the period of 1979-1980 and are still under litigation. The Longview claim was also for the period 1979 to 1980. It appears that contractors are more claim conscious where their costs increase. Price escalation on long contracts such as at Clarence Cannon, Phase II Main Dam, and grout quantity underruns are the basis of most contractor claims. "Changed conditions" are cited most often as the basis for claims.

Contractual

138. A review of the case histories reveals that the contracts were rather uniform in that a changed conditions clause, replaced later by a differing site condition clause, was common to most of them. Two Alvin Bush contracts did not contain a similar clause in the General Provisions, and General Provisions for several projects were not furnished. Also, statements that quantities were tentative and that actual quantities would be governed by conditions encountered in the field (or similar wording) were included in the technical provisions. With the exception of allowing contractor alternates in some cases and the standard Value Engineering clause after its initiation, there were no contractor incentives, and there were no escalation clauses. From the foundation reports and the questionnaires (often submitted however, because of necessity, by persons not directly knowledgeable about the project), it appears that in most instances relations between the Corps and the contractor were generally professional at both the field and management levels.

The exceptions to the good working relations were mostly in the later jobs where the Corps' personnel were attendant at the job and had firsthand knowledge of the relations. Written records were not generally available on the subject. The investigators did not have access to as many general provisions portions of the contracts as desired. Even when data were available at the field level, there was a tendency to furnish only the technical aspects of the contract, even though the complete specifications were requested. A review of the case histories suggests that all too often the authors of the foundation reports (drilling and grouting) are silent on the contractual aspects. The two earliest projects reviewed had the most comprehensive reports and included the entire construction activities. The following reports were specifically related to the technical aspects of drilling and grouting, foundation preparation, and treatment. This probably is because the staffs for the earlier projects were larger and stayed on site longer than those for insuing projects when dam building activities accelerated. Even though ER 1110-1-1801, Construction Foundation Reports, stresses the need for the resident foundation engineer or geologist to write the foundation report prior to leaving the site; all too often the report is finished by persons not at the site during construction. In the future emphasis should be placed on the inclusion of the contract management information in the report. The grout designers should also be more aware of the contractual requirements and be involved in all aspects of the plans and specifications, not just the technicalities of drilling and grouting. Change 2 to ER 1110-1-1801 dated April 1983 requires an outline of foundation reports be submitted to the engineering division of the appropriate Division Office for approval prior to start of construction. It also requires compilation of data and writing part of the report as construction proceeds. In addition the authors recommend that all remedial and deferred grouting be documented in foundation reports.

Technical

139. Bid items for drilling and grouting varied widely from project to project. Five projects had no mobilization or demobilization item, and three projects had no information on this item. The three projects without mobilization and demobilization were in the 1940's, one in the early 1960's, and one in the late 1960's. There was a wide range of drilling items varying from

6 in. to 1-1/2 in., predominantly rotary, but some percussion. In the last several years there has been more general acceptance of percussion drilling (USACE 1984). The earliest use of percussion drilling for grout curtain holes in the reviews was at Oologah and Hartwell in the early 1960's. Since that time, Tulsa District allowed the use of percussion drilling as an option, as long as water was used during drilling operations. Most Districts now allow this procedure in hard rocks. This type drilling may be used more in the future as it may be able to reduce drilling costs although sufficient cost data were not available to quantify its cost effectiveness. Core recovery generally was not required for drilling grout holes. A pay item for pressure testing by the hour was common to about half the projects and where not a pay item, pressure testing was generally required but the cost was included in another item. No attempt was made during this investigation to relate pressure testing results to grout takes due to time and data limitation; however, the relationship is not considered reliable for estimating grout takes even when considerable site specific data are available (Plates I-I22 through I-I25, Appendix I-I). The data for Dworshak Dam show a wide scatter. By using additional data from other projects, the scatter would probably tend to be wider. The only procedure considered reliable for accurate estimates of grout take must include site specific grouting data in each geotechnical classification of the site. Cement for grout was Government furnished for two projects during World War II years and paid for under separate pay items in 10 contracts. In the remaining contracts the cement was either paid for in another item, or no data were available. Neat cement grout was the mixture most commonly used. Water cement ratios specified for grout ranged from 10 to 0.6. Except for the 10:1 grout used at John Martin, the thinnest grout used in the field had a ratio of 6. Clay and sand additives were used for Phase III of Wolf Creek grouting. Mineral filler was used for two Alvin Bush grout programs, and Libby and Dworshak used fluidifiers. Aluminous cement was used for the two remedial grouting contracts at Libby in 1975 and 1977. Sodium bentonite was used at Clarence Cannon and Longview. The use of sodium bentonite in cement grout to prevent settlement and consequently shrinkage is now a recommended practice for most foundation grouting. Grouting was paid for by the cubic feet of solids (usually cement) placed on all but one job. Placing grout for Increment II at Abiquiu was paid by the hour (figured on time the pumps were actually pumping grout). This has been the standard method for

payment in Tulsa District for many years and is now being used by other Districts, as it is an effective alternative. Payment by the hour is more equitable to both parties--to the contractor because he is being paid for labor and equipment regardless of the rate or volume placed, and to the owner in that he can stay on a hole as long as desired even if pumping barely at or above the defined refusal rate, without pressure from the contractor to move. More use of this payment method could have an impact on reducing claims in that the contractor is getting compensated for labor and equipment regardless of the volume placed. Stand-by time was provided for in three contracts.

Costs and Estimates

General

140. The histories of the 23 grouting projects studied which covered a span of over 40 years reveal some interesting, and in some ways, surprising information. They show for instance, that the cost per cubic foot of grouting has declined when costs are converted to constant dollars. The index of construction costs, used to convert grouting costs to constant 1982 dollars, requires for instance, that the actual 1940 costs be multiplied by 15.81 to compare them with 1982 costs. The multiplier is successively reduced each year at a fairly uniform rate until a figure of 1.0 is reached for 1982. The unit cost (i.e., total cost/cu ft of grout placed) in 1982 dollars ranges from highs of about $150 in the mid-1940's to about $40 in 1982 (Plate 1a). Table 4 shows the conversion factors to 1982 constant dollars for the period 1940 to 1982.

141. Of greater significance to this analysis is the difficulty in making accurate estimates of the amount of drilling and grouting during the design phase. The Corps has long recognized the difficulty of making such estimates and has therefore generally included in its specifications the previously quoted statement that "...the amount of drilling and grouting which actually will be required is unknown and will be governed by conditions encountered..." Furthermore, drilling and grouting estimated quantities have traditionally been partially exempted from GP-70 (Variations in Estimated Quantities) requirements by SP-7 (Variations in Estimated Quantities - subdivided items) which allows quantity variations of any magnitude for all subdivided items except the first subdivision of that item without changing the bid unit price.

Table 4

Conversion Factors to 1982 Constant Dollars

Based on Construction Cost Index History (ENR/3-24-83)

Year	Conversion Factor	Year	Conversion Factor
1940	15.81	1962	4.39
1941	14.83	1963	4.25
1942	13.86	1964	4.09
1943	13.19	1965	3.94
1944	12.69	1966	3.75
1945	12.42	1967	3.57
1946	11.05	1968	3.31
1947	9.26	1969	3.01
1948	8.30	1970	2.76
1949	8.02	1971	2.42
1950	7.50	1972	2.18
1951	7.04	1973	2.02
1952	6.72	1974	1.89
1953	6.38	1975	1.73
1954	6.09	1976	1.59
1955	5.80	1977	1.48
1956	5.53	1978	1.38
1957	5.28	1979	1.27
1958	5.04	1980	1.18
1959	4.80	1981	1.08
1960	4.64	1982	1.00
1961	4.52		

142. Table 5 illustrates the record of estimated and actual feet of drilling and cubic feet of grouting compiled for 20 grouting projects. On the average, the actual feet of drilling accomplished was quite close to the estimate, but that average is made up of a great variation among projects. The lowest and highest ratios of actual to estimated were 42.9 percent and 173.1 percent. Of the 20, 11 came within ±15 percent (the figure used in the standard Variations in Quantities clause) while nine did not.

143. Grouting quantities were even more difficult to estimate. Nineteen projects had estimates expressed in cubic feet of grout required, and the average ratio of actual to estimated quantity was 57.4 percent, with a low of 11.3 percent and a high of 480.9 percent. Only five of the 19 projects were within ±15 percent of the estimate.

144. Table 5 also shows whether or not estimates have improved with time. Drilling estimates did not improve with time. The first two projects show ratios of actual to estimated quantities of 81.8 percent and 94.9 percent while the last two show ratios of 137.2 percent and 42.9 percent, respectively. The record is similar for the quantities of grouting required. The first two projects have ratios of 27.3 percent and 40.8 percent, while the last two have ratios of 71.4 percent (measured in sacks of cement, in this case) and 16.3 percent.

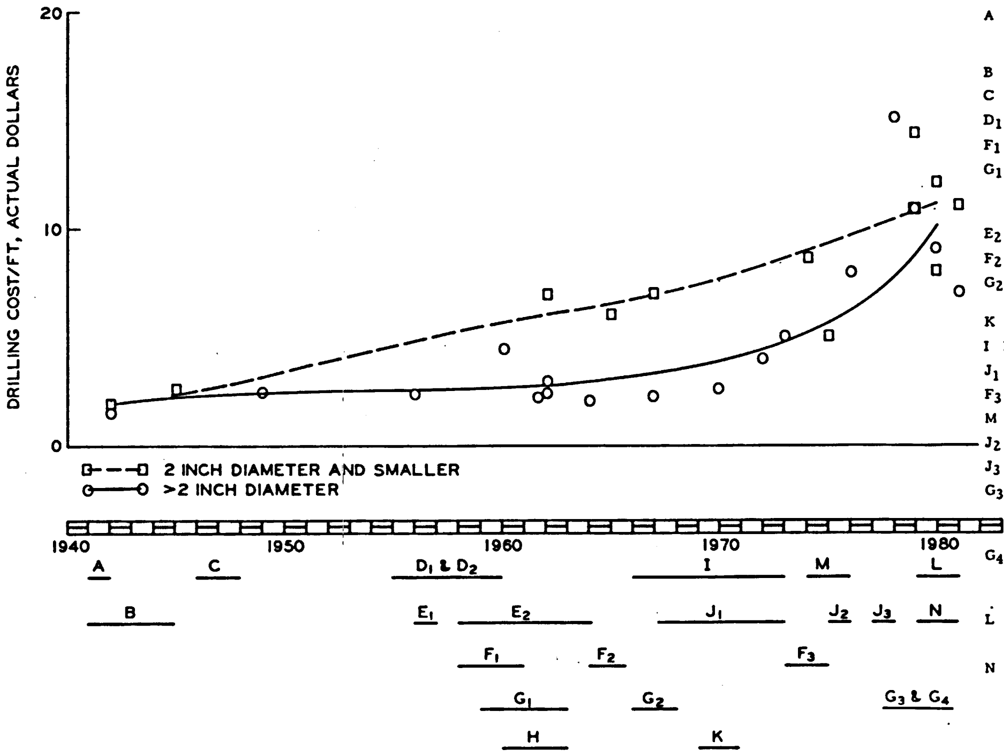
145. It can be fairly concluded that since grouting is a site specific activity and so far from routine, an overall learning curve does not exist. On the other hand, it may be that certain Districts improve their estimates over time, but this cannot be stated with certainty from the data available. For instance, the Albuquerque District more accurately estimated drilling requirements for the John Martin project in 1941 than for Increments I and II for Abiquiu in 1978, but the latter jobs had more accurate estimates for grout than did the earlier one.

146. One fact does become apparent in looking at these data. It is more difficult to estimate the quantity of grout required than the quantity of drilling. The preconstruction estimates of the amount of drilling required were equally divided between those that were too high and those that were too low. However, for grout quantities only four were too high, and 16 were too low, probably because of conservatism in estimating. And, as stated above, the variability was considerably greater for grout required than for drilling required. As a measure of the variability, the standard ±15 percent variation

Table 5

Estimated and Actual Drilling and Grouting Quantities, 20 Selected Case Histories

Identification	Project/Year	District	Drilling: Estimated Drilling lin ft	Drilling: Actual Drilling lin ft	Drilling: Ratio % Acutal/ Estimated	Grouting: Estimated Grouting cu ft	Grouting: Actual Grouting cu ft	Grouting: Ratio % Actual/ Estimated	Remarks
A	John Martin 1941-1942	Albuquerque	24,000	19,639	81.8	25,000	6,830	27.3	
B	Norfork 1941-1945	Little Rock	77,000	73,046	94.9	60,000	24,479	40.8	
C	Allatoona 1946-1949	Mobile	25,600	13,225	51.7	18,000	3,000	16.7	
D_1	Hartwell Embankment 1955-1960	Savannah	12,400	6,408	51.7	7,000	791	11.3	
D_2	Hartwell Spillway 1955-1960	Savannah	20,000	22,969	114.8	12,600	4,221	33.5	
E	Oologah Left Embankment 1958-1964	Tulsa	5,500	6,663	121.1	3,000	2,936	97.9	
F_1	Alvin Bush Original 1958	Baltimore	4,040	4,527	112.1	4,300	20,678	480.9	
G_1	Abiquiu Original 1959-1963	Albuquerque	28,300	22,339	78.9	55,000	39,941	72.6	
H	Eufaula Original 1959-1961	Tulsa							Data Not Readily Available
F_2	Alvin Bush 1964	Baltimore	18,500	18,747	101.3	11,000	17,774	161.6	
G_2	Abiquiu Supplemental 1966-1967	Albuquerque	13,750	23,803	173.1	42,550	41,060	96.5	
I	Dworshak 1966-1973	Walla Walla	156,000	161,496	103.5	62,000	9,262	14.9	
J_1	Libby Original 1967	Seattle	65,000	61,121	94.0	32,500	18,560	57.1	
K	Laurel 1969-1970	Nashville	20,000	17,565	87.8	6,000	10,934	182.2	
L	Clarence Cannon 1973-1983	St. Louis	99,700	91,876	92.2	56,500	50,495	89.4	
M	Wolf Creek Phase III 1974-1975	Nashville	196,100	156,614	79.9	195,000	72,084	37.0	
F_3	Alvin Bush 1973-1974	Baltimore							Performed by Corps Person. Govt Est: N/A
J_2	Libby 1975	Seattle	16,200	16,225	100.2	900	296	32.9	
J_3	Libby 1977	Seattle	710	1,010	142.3	95	101	106.3	
G_3	Abiquiu Increment I 1978-1980	Albuquerque	53,500	81,274	151.9	70,600	63,226	89.6	
G_4	Abiquiu Increment II 1978-1980	Albuquerque	63,900	87,655	137.2	2,700* 83,100**	1,822* 59,362**	67.5 71.4	* Hours ** Sacks Cement
N	Longview 1979-1981	Kansas City	74,000	31,761	42.9	16,000	2,608	16.3	
			974,200	917,963	94.2	678,045	389,275	57.4	



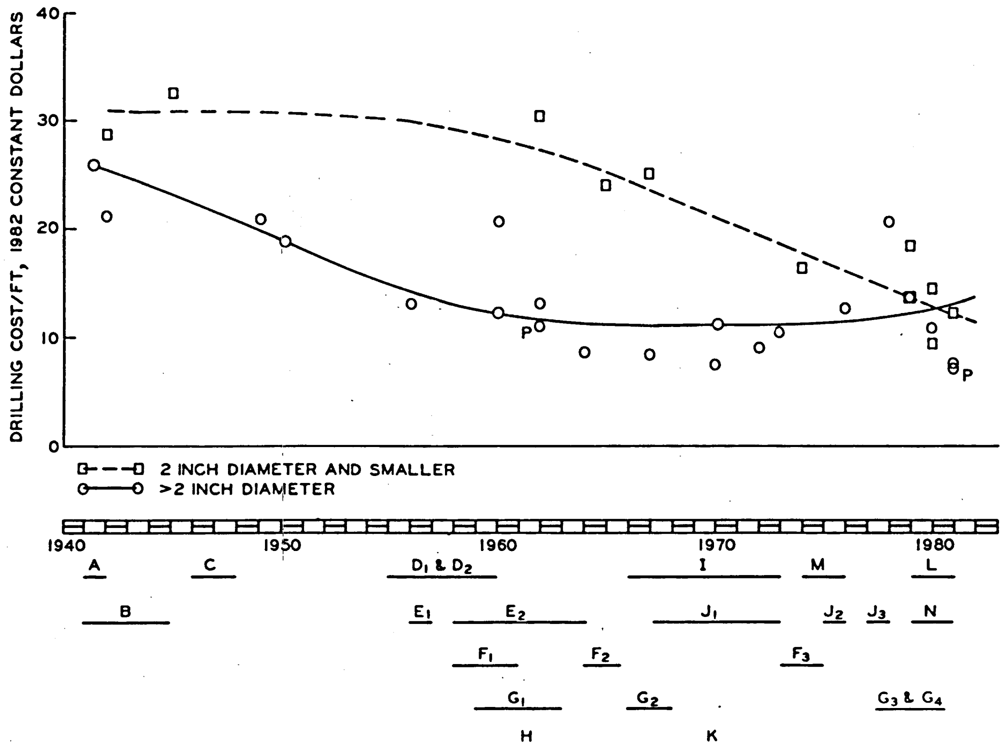
DRILLING COST/LINEAR FOOT

PROJECT	YEAR	DIAMETER	COST/FT ACTUAL ($)	COST/FT 1982 CONSTANT ($)
A John Martin	1942	2"	1.50	20.79
		3"	2.00	27.72
B Norfork	1945	3"	2.60	32.29
C Allatoona	1949	1½"	2.50	20.05
D_1 Hartwell	1956	1½"	2.30	12.72
F_1 Alvin Bush	1960	1½"	4.50(E)	20.88
G_1 Abiquiu	1962	3"	7.00	30.73
		1½"	3.00	13.17
		1½"(P)	2.50	10.98
E_2 Oologah	1963	2"	2.05	8.71
F_2 Alvin Bush	1965	3"	6.00(E)	8.08
G_2 Abiquiu	1967	3"	7.00	24.99
		1½"	2.30	8.21
K Laurel	1970	1½"	2.63	7.26
I Dworshak	1972	1½"	4.00	8.72
J_1 Libby	1973	1½"	5.10	10.30
F_3 Alvin Bush	1974	3"	8.64	16.33
M Wolf Creek	1975	5"	5.00	8.65
J_2 Libby	1976	1½"	8.00	12.72
J_3 Libby	1978	1½"	15.00	20.70
G_3 Abiquiu	1979	1½"	10.80	13.72
		3"	10.80	13.72
		5"	14.40	18.29
G_4 Abiquiu	1980	1½"	9.00	10.62
		5"	8.00	9.44
		6"	12.00	14.16
L Clarence Cannon	1981	3"	11.15	12.04
		1½"(P)	6.00	6.48
N Longview	1981	1½"	7.00	7.56

Notes: (P) - Percussion, all other rotary
(E) - Estimated cost x actual quantity

CASE HISTORY PROJECTS
ACTUAL DRILLING COST

CASE HISTORY PROJECTS
DRILLING COST IN 1982 CONSTANT DOLLARS



DRILLING COST/LINEAR FOOT

PROJECT	YEAR	DIAMETER	COST/FT ACTUAL ($)	COST/FT 1982 CONSTANT ($)
A John Martin	1942	2"	1.50	20.79
		3"	2.00	27.72
B Norfork	1945	3"	2.60	32.29
C Allatoona	1949	1½"	2.50	20.05
D_1 Hartwell	1956	1½"	2.30	12.72
F_1 Alvin Bush	1960	1½"	4.50(E)	20.88
G_1 Abiquiu	1962	3"	7.00	30.73
		1½"	3.00	13.17
		1½"(P)	2.50	10.98
E_2 Oologah	1963	2"	2.05	8.71
F_2 Alvin Bush	1965	3"	6.00(E)	8.08
G_2 Abiquiu	1967	3"	7.00	24.99
		1½"	2.30	8.21
K Laurel	1970	1½"	2.63	7.26
I Dworshak	1972	1½"	4.00	8.72
J_1 Libby	1973	1½"	5.10	10.30
F_3 Alvin Bush	1974	3"	8.64	16.33
M Wolf Creek	1975	5"	5.00	8.65
J_2 Libby	1976	1½"	8.00	12.72
J_3 Libby	1978	1½"	15.00	20.70
G_3 Abiquiu	1979	1½"	10.80	13.72
		3"	10.80	13.72
		5"	14.40	18.29
G_4 Abiquiu	1980	1½"	9.00	10.62
		5"	8.00	9.44
		6"	12.00	14.16
L Clarence Cannon	1981	3"	11.15	12.04
		1½"(P)	6.00	6.48
N Longview	1981	1½"	7.00	7.56

Notes: (P) - Percussion, all other rotary
(E) - Estimated cost x actual quantity

PLATE 2

may be used. While 55 percent of the drilling estimates were within ±15 percent, only 26 percent of the grouting estimates fell within ±15 percent.

147. The question might be asked: Is there a discernible trend in the overall amount of drilling and grouting? The answer to this question cannot be found in the data available, although an inference may be made that the answer is negative. The two earliest jobs reported required drilling quantities of about 20,000 ft and 73,000 ft and grout quantities of about 6,800 and 24,500 cu ft, respectively, and the latest 31,000 ft of drilling and only 2,600 cu ft of grouting. The biggest jobs, both in the amount of drilling and grouting, appear near the middle of the four-decade span studied.

148. Another interesting fact emerges from Table 5. Albuquerque District, which was responsible for five of the grouting projects (more than any other District), wrote one contract to pay for grouting by the hours of effort and the quantity of cement used rather than the quantity of grout injected. This appears to be a worthwhile alternate to change the method of payment for grouting which may be fairer to the contractor and at the same time assist in achieving the Corps' goal of injecting the right amount of grout.

Cost analysis

149. Plate 1b shows that actual drilling costs rose slowly during the study period until 1967 when the trend increased slightly. This was influenced in part by drilling costs at Abiquiu Increment I and II which required deep holes with special drilling and casing techniques. But using constant dollars, as shown on Plate 2, there has been a decrease in drilling costs with the larger diameter (over 2 in.) holes showing a more rapid decrease and approaching the cost of the smaller holes. This may reflect improvement in drilling equipment and capabilities as well as utilization of less labor. Some of the earlier jobs required core which could also have held the cost up.

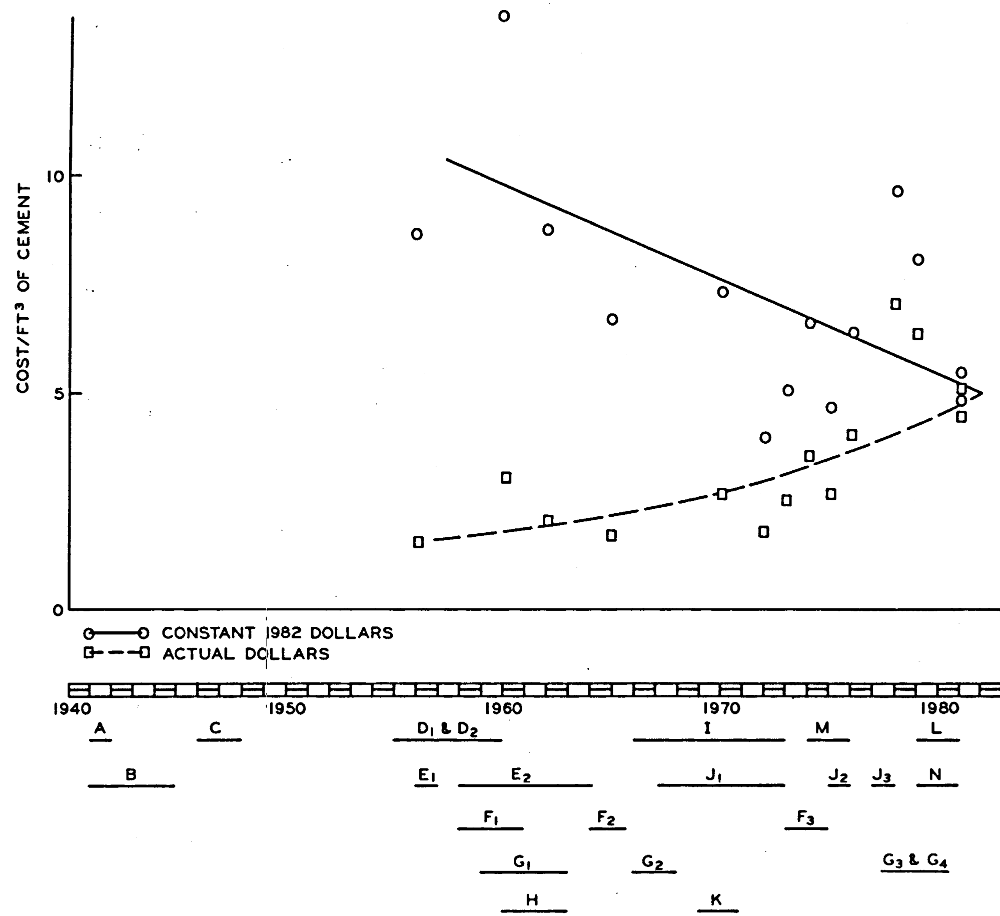
150. Specifically, bid prices for drilling grout holes varied from a low of $1.50 per lin ft for 2-in. holes at John Martin (1941-1942) to a high of $14.40 per lin ft for 5-in. holes at Abiquiu, Increment I (1978-1980). The latter was because of deep holes requiring much casing. In constant dollars, the $1.50 per lin ft at John Martin represents the highest price for 2 in. or smaller holes. Drilling through overburden or embankment was as high as $22.00 per lin ft for unsampled holes at Dworshak. An item for redrilling previously grouted holes was bid at $20.00 per lin ft at Libby in 1972. Bid prices varied considerably between these outer limits, but were generally

higher in the later review years. Bid prices for drilling were about evenly split over or under the Government estimate.

151. Pressure testing varied from a low of $12.00 per hour at Abiquiu in 1959-1963 to a high of $50.00 per hour at Abiquiu Increment I and II in 1978-1980. Plate 3 shows that actual dollar costs for cement rose slowly until 1970, then accelerated, whereas the constant dollar costs show a continued steady decline during the period of study. The cement in grout varied from a low of $1.80 per cu ft at Dworshak in 1966-1973 to a high of $7.00 per cu ft at Libby remedial grouting in 1977. Bid prices varied considerably between these extremes, but were generally higher in the later review years. Cement was furnished by the Government for John Martin and Norfork during World War II years.

152. Plate 4 shows that the average actual cost for placing grout rose slowly and steadily until 1967 when cost began to accelerate slightly, whereas the constant costs show a continued decline. The cost of placing grout varied from $0.90 per cu ft (solid/cement) placed at Norfork, 1941-1942, to a high of $12.00 per cu ft placed at Libby remedial grouting in 1975. If the Libby remedial grout jobs are not considered (very special and small volumes), then $8.50 per cu ft placed at Longview in 1979-1981 would be high. The prices again varied considerably between the extremes. Abiquiu Increment II grouting in 1978-1980 was bid at $100.00 per hour. Dworshak, 1966-1973 had a price adjustment of $116,145 for underruns. Abiquiu Increments I and II (1978-1980) are presently under litigation due to the unbalanced ratio of drilling to placing grout. A settlement of $80,000 for differing site conditions based on the unbalanced ratio of drilling to placing grout was negotiated at Longview Dam (1979-1981). Plate 5 shows that the average trend for actual dollar costs per square foot of curtain has increased only slightly with a corresponding slight decline for constant dollars.

153. Plate 6 shows that there has been a tendency to overestimate the amount of grout to be placed, which shows conservatism in estimating. Of the 22 contracts studied, 13 had significant grout quantity underruns, three had significant overruns, four had slight underruns, and estimated quantities were not available for two contracts. Estimates for drilling were closer than for placing grout as shown in Plate 7. Ten of the projects were overestimated, eight were underestimated, and two were extremely close to the estimated quantity. The total estimated drilling footage for the 20 contracts which had

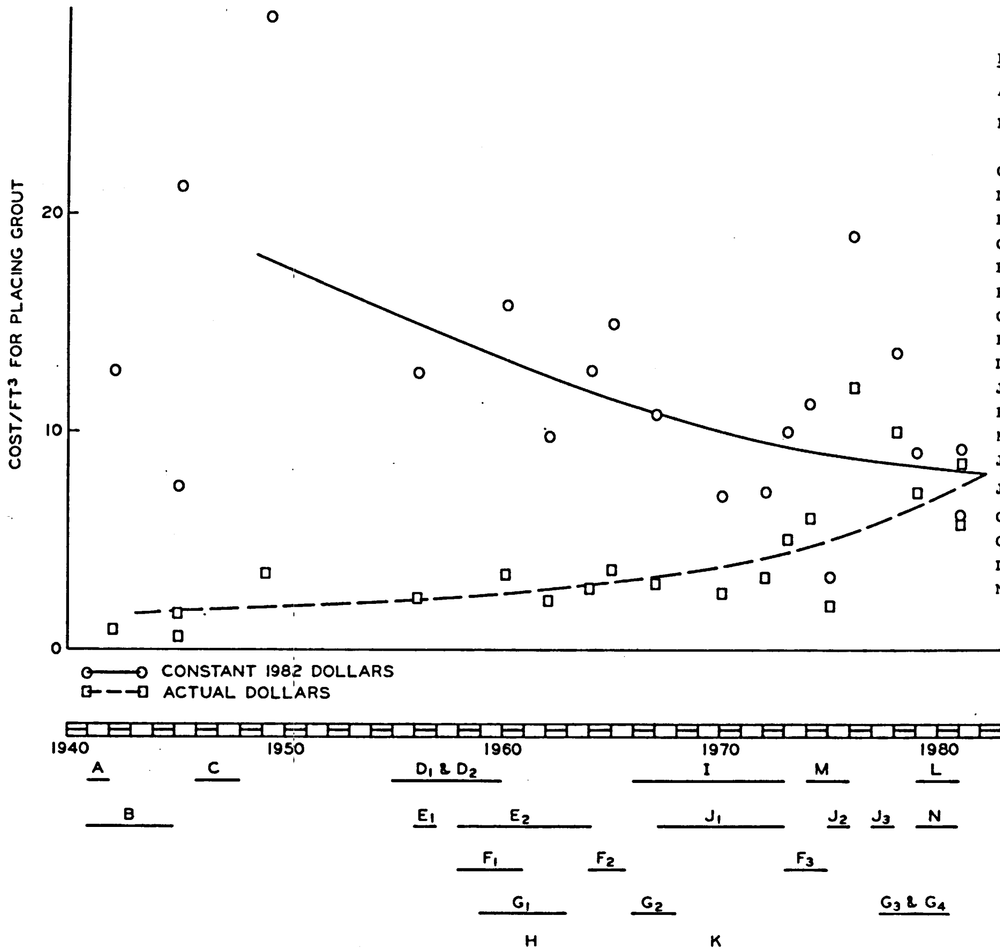


COSTS FOR CEMENT

PROJECT	YEAR	CEMENT ACTUAL ($)	CEMENT 1982 CONSTANT ($)
A John Martin	1942	Government Furnished	
B Norfork	1945	Government Furnished	
C Allatoona	1949	Data Not Available	
D_1 Hartwell	1956	1.55	8.57
F_1 Alvin Bush	1960	3.00(E)	13.92
G_1 Abiquiu	1962	2.00	8.78
E_2 Oologah	1963	-no data-	—
F_2 Alvin Bush	1965	1.65(E)	6.50
G_2 Abiquiu	1967	-no data-	—
K Laurel	1970	2.63	7.26
I Dworshak	1972	1.80	3.92
J_1 Libby	1973	2.50	5.05
F_3 Alvin Bush	1974	3.50(E)	6.62
M Wolf Creek	1975	2.70	4.67
J_2 Libby	1976	4.00	6.36
J_3 Libby	1978	7.00	9.66
G_3 Abiquiu	1979	6.36	8.08
G_4 Abiquiu	1980	6.00	7.08
L Clarence Cannon	1981	4.40	4.75
N Longview	1981	5.00	5.40

Note: (E) - Estimated cost x actual quantity

CASE HISTORY PROJECTS
COST OF CEMENT IN ACTUAL DOLLARS AND 1982 CONSTANT DOLLARS



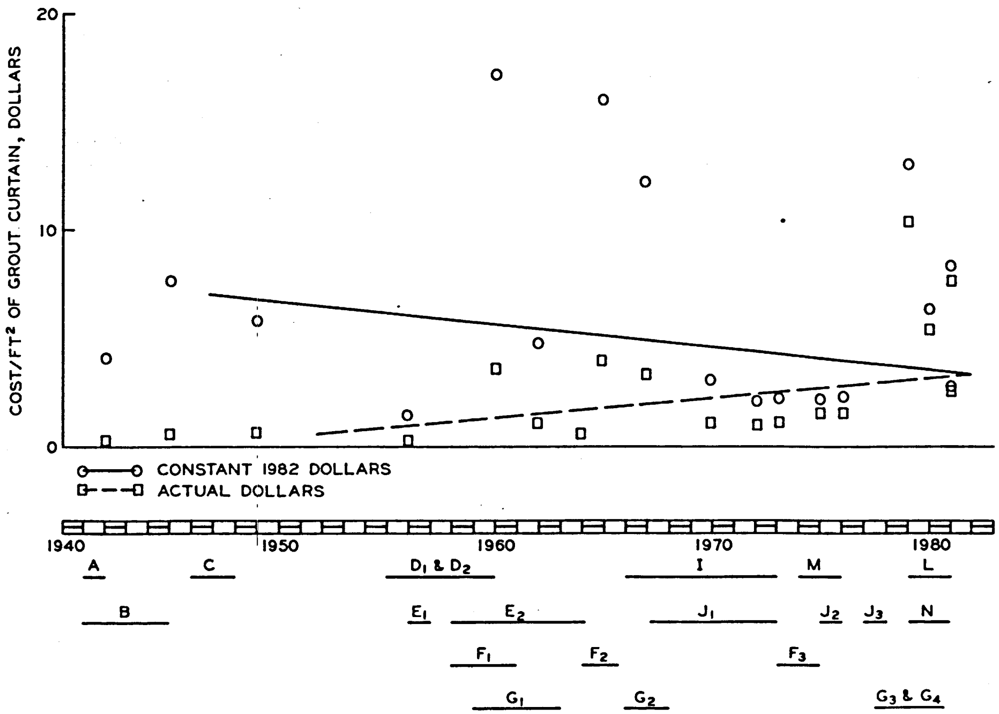
COST FOR PLACING GROUT

PROJECT	YEAR	PLACING GROUT ACTUAL ($)	PLACING GROUT 1982 CONSTANT ($)
A John Martin	1942	0.90	12.47
B Norfork	1945	1st 20,000 CF 1.70 over 20,000 CF 0.60	21.11 7.45
C Allatoona	1949	3.50	28.07
D_1 Hartwell	1956	2.30	12.72
F_1 Alvin Bush	1960	3.50(E)	16.24
G_1 Abiquiu	1962	2.25	9.88
E_2 Oologah	1963	2.90	13.33
F_2 Alvin Bush	1965	3.75(E)	14.78
G_2 Abiquiu	1967	3.05	10.89
K Laurel	1970	2.63	7.26
I Dworshak	1972	3.40	7.41
J_1 Libby	1973	5.00	10.10
F_3 Alvin Bush	1974	6.00(E)	11.34
M Wolf Creek	1975	2.00	3.46
J_2 Libby	1976	12.00	19.08
J_3 Libby	1978	10.00	13.80
G_3 Abiquiu	1979	7.20	9.14
G_4 Abiquiu	1980	($100/hour)	($118/hour)
L Clarence Cannon	1981	5.75	6.21
N Longview	1981	8.50	9.18

Note: (E) - Estimated cost x actual quantity

CASE HISTORY PROJECTS

COST FOR PLACING GROUT IN ACTUAL DOLLARS AND 1982 CONSTANT DOLLARS



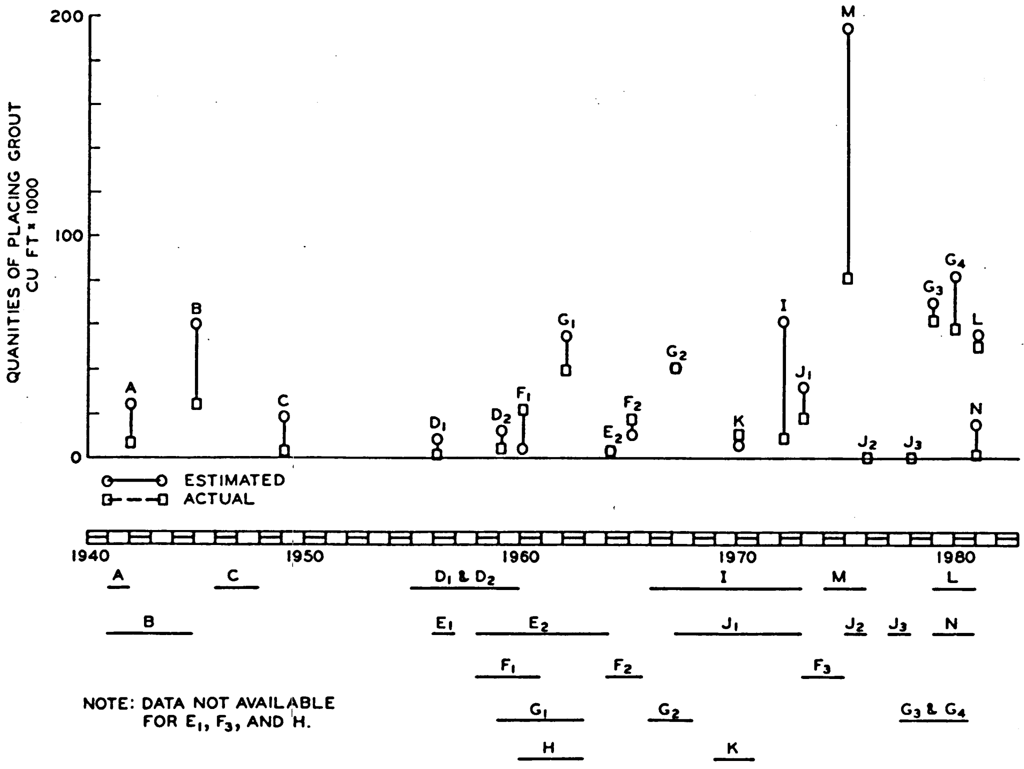
NOTE: REMEDIAL CONTRACTS F_3 AND J_3 ARE NOT INCLUDED AS THEY WERE NOT CONSIDERED CURTAIN GROUTING.

TOTAL COST/FT^2 OF GROUT CURTAIN

PROJECT	YEAR	COST/FT^2 ACTUAL ($)	COST/FT^2 1982 CONSTANT ($)
A John Martin	1942	0.29	4.02
B Norfork	1945	0.62	7.70
C Allatoona	1949	0.70	5.61
D_1 Hartwell	1956	0.27	8.30
F_1 Alvin Bush	1960	3.78	17.54
G_1 Abiquiu	1962	1.10	4.83
E_2 Oologah	1963	0.65	2.76
F_2 Albin Bush	1965	4.01	15.80
G_2 Abiquiu	1967	3.41	12.17
K Laurel	1970	1.15	3.17
I Dworshak	1972	0.97	2.11
J_1 Libby	1973	1.18	2.38
F_3 Alvin Bush	1974	—	—
M Wolf Creek	1975	1.26	2.18
J_2 Libby	1976	1.51	2.40
J_3 Libby	1978	—	—
G_3 Abiquiu	1979	10.29	13.07
G_4 Abiquiu	1980	5.44	6.42
L Clarence Cannon	1981	7.69	8.31
N Longview	1981	2.56	2.76

CASE HISTORY PROJECTS

TOTAL COST PER SQUARE FOOT OF GROUT CURTAIN IN ACTUAL DOLLARS AND 1982 CONSTANT DOLLARS

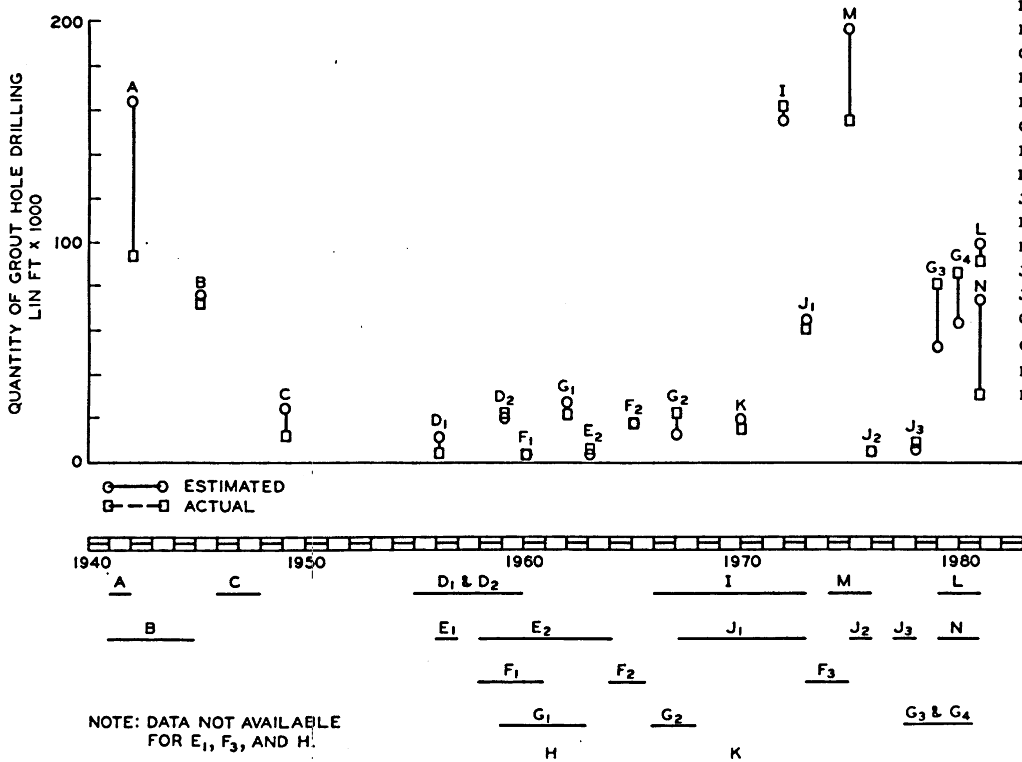


PLACING GROUT QUANTITIES

PROJECT	YEAR	PLACING GROUT (CF) ESTIMATED	ACTUAL
A John Martin	1942	25,000	6,830
B Norfork	1945	60,000	24,479
C Allatoona	1949	18,000	3,000
D_1 Hartwell	1956	7,000	791
D_2 Hartwell	1959	12,600	4,221
F_1 Alvin Bush	1960	4,300	20,678
G_1 Abiquiu	1962	55,000	39,941
E_2 Oologah	1963	3,000	2,936
F_2 Alvin Bush	1965	11,000	17,774
G_2 Abiquiu	1967	42,550	41,060
K Laurel	1970	6,000	10,934
I Dworshak	1972	62,000	9,262
J_1 Libby	1973	32,500	18,560
F_3 Alvin Bush	1974	—	—
M Wolf Creek	1975	195,000	72,084
J_2 Libby	1976	1,000	296
J_3 Libby	1978	95	101
G_3 Abiquiu	1979	70,600	63,226
G_4 Abiquiu	1980	83,100	59,362
L Clarence Cannon	1981	56,500	50,495
N Longview	1981	16,000	2,608

CASE HISTORY PROJECTS
ESTIMATED AND ACTUAL QUANTITIES OF PLACING GROUT

PLATE 6



DRILLING QUANTITIES

PROJECT	YEAR	DRILLING QUANTITIES (LF) ESTIMATED	ACTUAL
A John Martin	1942	165,000	94,553
B Norfork	1945	77,000	73,046
C Allatoona	1949	25,600	13,225
D_1 Hartwell	1956	12,400	6,458
F_1 Albin Bush	1960	4,040	4,527
G_1 Abiquiu	1962	28,300	22,339
E_2 Oologah	1963	5,500	6,663
F_2 Alvin Bush	1965	18,500	18,746
G_2 Abiquiu	1967	13,750	23,803
K Laurel	1970	20,000	17,565
I Dworshak	1972	155,000	161,306
J_1 Libby	1973	65,000	61,121
F_3 Alvin Bush	1974	—	—
M Wolf Creek	1975	196,100	156,614
J_2 Libby	1976	6,300	6,325
J_3 Libby	1978	710	1,010
G_3 Abiquiu	1979	53,500	81,274
G_4 Abiquiu	1980	63,900	87,655
L Clarence Cannon	1981	99,700	91,876
N Longview	1981	74,000	31,761

CASE HISTORY PROJECTS
ESTIMATED AND ACTUAL GROUT HOLE DRILLING QUANTITIES

information available was 1,104,300 lin ft for an average of 55,215 lin ft. The total actual footage was 982,836 for an average of 49,142. The underrun for drilling was approximately 10 percent. Estimates for placing grout were less accurate. The total quantity estimated for the 20 contracts was 761,245 cu ft (average 38,063) and the actual quantity placed was 448,638 (average 22,437). The underrun for placing grout (and consequently the grouting materials) was approximately 41 percent.

154. Some projects had very poor estimates for the initial construction but good estimates for postconstruction grouting. This would seem to justify more use of test grouting programs.

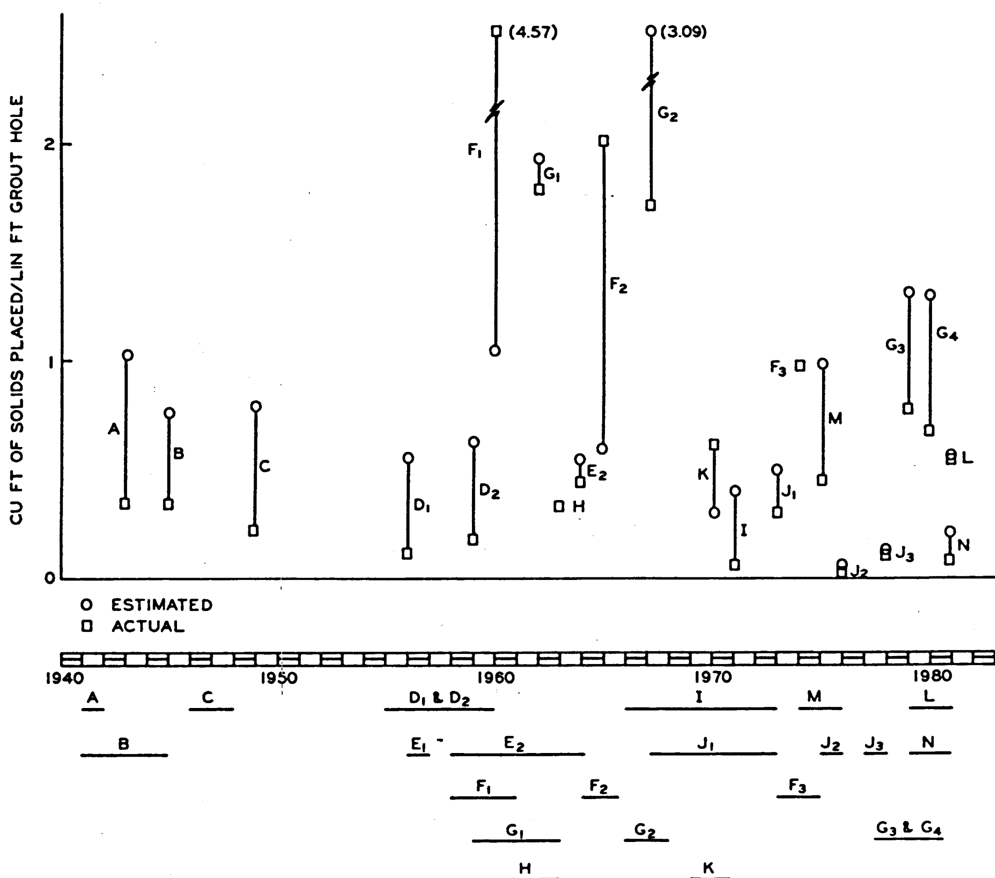
155. Postconstruction grouting, remedial grouting, and very small projects had costs much higher than initial construction grouting costs. Price escalation and increased drilling footages for drilling through the embankment dam, and in some cases small size contracts made unit costs or mobilization and demobilization costs higher.

156. In constant dollars, costs for drilling, grouting and materials in grout do not show a trend increasing with time during the span of this study. In fact, they all show a decline indicating that in terms of real dollars, grout costs have decreased during the period of this study. This can best be attributed to technological advances and competition.

157. Very small remedial grouting jobs and tests can most effectively and economically be performed in-house. Small contracts such as at Libby in 1975 and 1977 resulted in unusually high prices per cubic foot of grout placed. Both of these small contracts had mobilization and demobilization contract costs of $25,000. In-house mobilization and demobilization cost would have been minimal provided the District had the in-house capability.

Grout Take Analysis

158. The reviews included a wide range of rocks of differing ages, including metamorphics, granites, limestones, shales, sandstones, and siltstones. A review of Plate 8 shows that the actual volume of grout placed per linear foot of hole drilled for the most part is less than 1 cu ft/lin ft. The largest grout takes were Alvin Bush original, Abiquiu original, Alvin Bush first remedial, and Abiquiu remedial, and excluding the two Libby remedial programs, the least take was in the metasediments at Dworshak. Alvin Bush



C.F. SOLIDS/L.F. OF HOLE

PROJECT	YEAR	C. F. SOLIDS/L. F. OF HOLE ESTIMATED	ACTUAL
A John Martin	1942	1.04	0.35
B Norfork	1945	0.78	0.34
C Allatoona	1949	0.70	0.23
D_1 Hartwell	1956	0.56	0.12
D_2 Hartwell	1959	0.63	0.18
E_1 Oologah	1957	--	0.70
F_1 Alvin Bush	1960	1.06	4.57
G_1 Abiquiu	1962	1.94	1.79
E_2 Oologah	1963	0.55	0.44
H Eufaula	1963	--	0.34
F_2 Alvin Bush	1965	0.59	2.03
G_2 Abiquiu	1967	3.09	1.72
K Laurel	1970	0.30	0.62
I Dworshak	1972	0.40	0.06
J_1 Libby	1973	0.50	0.30
F_3 Alvin Bush	1974	--	0.97
M Wolf Creek	1975	0.99	0.46
J_2 Libby	1976	0.06	0.02
J_3 Libby	1978	0.13	0.10
G_3 Abiquiu	1979	1.32	0.78
G_4 Abiquiu	1980	1.30	0.68
L Clarence Cannon	1981	0.57	0.55
N Longview	1981	0.22	0.08

CASE HISTORY PROJECTS

ESTIMATED AND ACTUAL CUBIC FEET OF SOLIDS PLACED PER LINEAR FOOT OF GROUT HOLE

original contract had a high of 4.57 cu ft/lin ft and about 2 cu ft/lin ft for the first remedial grouting in Devonian sandstones, siltstones, and shales. Abiquiu original grouting and first remedial grouting had takes of 1.8 cu ft/lin ft and 1.7 cu ft/lin ft in Permian sandstones and shales. It is interesting to note that sandstones, siltstones, and shales were the large takers. It is also apparent that, with the exceptions of the four just-mentioned projects, the designers were conservative in estimating the potential grout takes. The mixtures were for the most part neat cement grout with a few additives in certain jobs. Bentonite as an additive has increasingly been used over the past several years and is recommended as the most inexpensive method of stabilization. It was recognized at John Martin that the neat cement grout would not flow through the Dakota sandstone, but the cement would filter out and stop the hole from taking grout. Project personnel recognized the need for chemical grouting, had a study made, and recommended that if remedial grouting became necessary later in the Dakota, chemical grout should be used. This is probably the only instance of a formation with primary (interstitial) permeability capable of being grouted that was reviewed. The remainder were secondary (fracture) permeabilities. Another need for chemical grouting was recognized at Laurel Dam where holes plugged off in sandfilled fractures on the abutment. In certain conditions there seems to be a need for chemical grouting in rock, despite a general reluctance to consider its use. There is a need for an awareness of chemical grouting capabilities, and chemical grouting should be considered by designers in certain cases.

159. Of the original grout programs reviewed, only Alvin Bush and Abiquiu have required major remedial or deferred grouting. The two small remedial jobs at Libby are not included as they were rather special. The grouting review at Wolf Creek was remedial only. With those exceptions the original grout curtains appear to have been adequate and have performed satisfactorily (see Appendix I). It should be noted, however, that Clarence Cannon and Longview have not been tested at significant reservoir levels. Alvin Bush has had two remedial grout programs. The actual grout takes were reduced from 4.57 cu ft/lin ft originally to 2.0 cu ft/lin ft for the first remedial work to 1.0 cu ft/lin ft for the last remedial work. This reduction indicates that the remedial programs were effective in improving the grout curtain. At Abiquiu, the first remedial grouting increased takes from 1.8 cu ft/lin ft originally to 3.09 cu ft/lin ft and then reduced to 0.8 cu ft/lin ft for

Increment I and to 0.7 cu ft/lin ft for Increment II. This may or may not be a true indication of progressively tightening the curtain as the first remedial and subsequent Increments I and II included extension of the original curtains into previously ungrouted rock. The two special jobs at Libby were small in volume but high in cost, and it suggests that perhaps in-house grouting capability should be utilized for this type of work. All remedial grouting projects studied (Projects F, G, J, and M) resulted in significant reductions in leakage (Appendix I). Although exploration for grouting in some cases was not sufficient in depth, lateral extent, or amount of pressure testing, it is concluded that design of the curtain based on the geological conditions was proper and should continue. Future projects should require more detailed exploration and grout test programs in order to improve design parameters and quantity estimates. As a result of these reviews, it is noticed that the need and subsequent execution of a grout program vary and are often dependent on funds available at a particular time rather than the technical need. We also noted that Laurel, Cannon, and Longview were designed with multiple line grout curtains. There has been a general trend toward installing multiple line curtains under embankments for the last few years. As a result of the review of grout takes in this section, it is also recommended that technical personnel responsible for design and construction of grout curtains be educated in contract considerations as well as in drilling and grouting methods. Since inexperienced Government supervision of grouting will result in an inadequate product, it is important to stress the need for well-trained, experienced people on both initial and remedial grouting. This training should be consistent with the current Corps' manuals and the training should reflect lessons learned and experience gained on past Corps' projects. As a final observation, it is worthy to note that timely remedial grouting was credited with saving Wolf Creek Dam from a catastrophic failure. So when do we grout leaking dams foundations? How long do we observe and monitor? The determination as to when to grout a leaky dam foundation needs to be addressed, and solution and erosion rates of different rocks and grout under actual field conditions need to be determined. Also, the need for remedial drilling and grouting often requires drilling through embankments. Drilling through embankments is another area of concern as this type of drilling is likely to increase with time. Standards must be developed and carefully applied so as not to damage the embankment during drilling.

PART V: CONCLUSIONS AND RECOMMENDATIONS

Summary of Findings

160. The following statements summarize the major findings of this study.

161. Grouting is of major importance both in dam construction and maintenance.

162. The decrease in the number of new dams under construction and to be constructed and the increase in the number of existing dams that will need maintenance combine to indicate that future grouting will be more heavily weighted to remedial grouting and less heavily to new construction.

163. The cost of grouting has not increased (when measured in constant dollars) during the past 40 years.

164. The effectiveness of grouting work can usually be measured only indirectly, and often only after the passage of considerable time following completion.

165. The design of grouting in advance of its accomplishment in the field must necessarily be modified during the course of the work as a result of conditions encountered during that work.

166. It is quite difficult to estimate accurately, in advance of construction, the amount of drilling that will be required, and extremely difficult to estimate the amount of grout needed to be injected. In the case histories examined, the amount of grout required was generally overestimated.

167. For justifiable reasons the Corps directs drilling and grouting work in great detail, and writes specifications accordingly.

168. All of the above make it difficult to write contracts that are fair to both the Government and the contractor. Particular difficulties are experienced in establishing pay items and in providing motivation to the contractor to achieve high quality grouting.

169. Because of the difficulties in writing equitable contracts, the Corps has experienced claims for differing site conditions based solely upon wide disparities between Government-estimated quantities of grout to be injected and the actual quantities injected. In fact, a recent decision of the Corps of Engineers Board of Contract Appeals has resulted in an award to a contractor on this basis.

170. A necessity to review and improve contract specifications and contract types exists to insure that grouting accomplished under contract is done properly and with fairness to both the Government and the contractor.

171. Drilling and grouting capabilities should be established and/or maintained in certain Districts of each Corps Division to insure an in-house capability to perform grouting on an emergency basis or where other conditions require in-house accomplishment of grouting, especially as in small or specialty type grouting programs. In-house grouting should be considered for any job if it is the most cost effective method available, especially if other advantages can be realized. Generally, in-house grouting can be relied on to produce a superior grout curtain to that achieved by contract work.

172. A need exists for additional education and training of geotechnical engineers, geologists, and field personnel in grouting.

173. A requirement exists to provide field guidance on contracting procedures and construction management for grouting.

174. Of the projects reviewed, sandstones, siltstones, and shales were the large takers, and mixtures for the most part were neat cement grout.

175. Recent Corps contractual experience has dictated the need for better exploration programs and test grouting programs in order to produce better designs and more accurate estimates. These programs should be designed to subdivide the grout curtain into geotechnical units of similar characteristics relative to grouting. Test grouting should be performed in each geotechnical subdivision except those found to be impervious from water pressure testing. Pumping tests should be considered in conjunction with the grouting tests. Water pressure (pump in) tests are also recommended, but results are considered empirical for use in estimating grout takes. The case histories revealed no reliable relationship between the two. For example, see Plates I-I22 through I-I25.

176. Sodium bentonite in small amounts (2 to 4 percent of amount of cement) is generally considered effective in stabilizing cement grout and is recommended for most foundation grouting applications (USACE 1984). This study, however, revealed that when bentonite was used, improper mixing of bentonite, cement, and water was the rule rather than the exception. To prevent phase change of sodium bentonite to calcium bentonite, it is necessary to fully hydrate the bentonite before allowing it to come in contact with cement or even a cement contaminated mixer. Therefore, a separate, colloidal mixer

should be required for mixing bentonite and water prior to adding it to the grout mixer. A more detailed discussion of mixing bentonite slurries and grouts is contained in Effects of Mixing Bentonite Slurries and Grouts (Jeffries, 1982). Further research is needed on the subject.

177. Colloidal grout mixers, although generally available, are still rarely required by specifications although they are allowed as options. Because of their technical advantages, they are generally advocated for future grouting jobs.

178. Stress release processes caused geologic defects which needed to be grouted at several of the projects studied. Exploration programs should investigate the potential presence of high angle joints in abutments normal to the dam, in-situ stress conditions, and valley arching tendencies. Design of grouting programs should take these features into consideration as they affect allowable safe grouting pressures and hole orientations. Horizontal grout holes should be required when needed.

179. Karst features encountered during grouting or other construction activities but not identified during design or treated during construction have caused massive cost overruns (Clarence Cannon Dam) or expensive remedial measures (Wolf Creek Dam). Adequate exploration must be performed to define and design treatment for these features prior to construction.

180. Lifting or fracturing of rock foundations with grouting pressures was noted at some of the projects studied. Factors contributing to causing these effects included: poor control of pressures in the field, establishing allowable pressures that were too high, improper valves, defective gages, and grout injection at too fast a rate.

181. Relaxing specification requirements by the Corps' Contract Administration for the convenience of the contractor or to expedite construction had adverse technical effects on grout curtain effectiveness at some projects. Changes in specification requirements of technical provisions should only be made with the concurrence of the designer. Some projects studied, experienced leakage problems because of failure to remove faulty foundation materials and replace with impervious, engineered backfill during construction. Excavation and backfill are generally the preferred seepage cutoff method where groutability of surficial materials is doubtful. Regardless of the method used for seepage reduction, properly designed drains and filters should be used to prevent piping of embankment and foundation materials where the possibility exists.

182. None of the projects studied utilized chemical grout, however, it was recommended for one project and may prove applicable to grouting certain rock foundations in the future. Chemical grout should receive more consideration for future grouting, especially in combination with cement grouting.

183. In caving or squeezing ground, grouting through drill rods is an economical and effective alternative to circuit grouting. If this method is used, the hole diameter should be 1 in. or more larger than the outside diameter of the drill rods.

184. Payment for connections to grout holes was generally made at a government established fixed price for each packer setting, however, some contracts used a bid price. Also, in stop grouting, at one project, payment of a government established fixed bid price was made for moving on the hole to the first packer setting, but subsequent packer settings for grouting (stops) did not qualify for payment as connection to grout holes. Usually only one connection was paid for per hole.

185. At one project exploration results (water pressure testing) were not consistent with project performance after construction. The pressure testing was done by contract in sub-zero weather with no government inspector present. Small takes may have resulted from frozen water in lines and pipes rather than a relatively tight foundation. Remedial grouting was later required.

186. Government inspection and supervision of grouting were not adequate at some projects due to lack of qualified people being assigned to the construction staff. This generally led to costly field mistakes and reduced grout curtain effectiveness. Sometimes, remedial work was required at a later date. Even where specifications are very detailed and based on extensive subsurface data and previous grouting experience, the need for qualified, experienced government supervision is not diminished. EM 1110-2-3506 emphasizes this requirement.

187. Of the projects studied, grout curtain performance was usually evaluated on the basis of project performance and observed leakage. There is a general need for more piezometers to establish piezometric profiles across grout curtains for monitoring purposes.

Recommendations

188. New contract specifications should be developed that will insure equitable payment to contractors for grouting work, provide motivation to contractors to achieve high-quality grouting, and reduce the need for contractors to submit claims based on differing site conditions. In this development, consideration should be given to payment for effort expended (time) rather than results achieved (cubic feet of grout injected). This method of payment, however, would not eliminate the need for more accurate estimates.

189. The use of service-type contracts rather than construction contracts should be considered for grouting.

190. The Corps should establish and/or maintain an in-house capability in selected Districts to perform grouting work.

191. A program of education and training in grouting should be established and implemented.

192. More detailed guidance should be provided on contractual procedures and construction management for grouting.

193. Technical advances in grouting should be fostered by the Corps both to insure high quality and to contain costs.

194. Geologic characteristics should continue to be used as a basis for grout curtain design.

195. Acceptable standards should be established for drilling through embankments for grouting foundations of existing dams to avoid damage to the structures.

196. Criteria should be established to determine when to initiate remedial grouting in order to preclude the necessity of remedial action under emergency conditions.

197. Guidance should be issued on the use of bentonite in grout and proper mixing of grout, especially grout containing bentonite.

198. Test grouting programs are recommended when practical. In addition, boring exploration programs should thoroughly cover the full extent of the proposed grout curtain. They should be accompanied by water pressure testing and pump testing as needed.

199. Instrumentation requirements for dams should include piezometers for obtaining baseline data, evaluating grouting effectiveness and monitoring grout curtain performance. Piezometric profiles should be developed across the grout curtain in the dam foundation and abutments.

REFERENCES

ASCE Task Committee on Cement Grouting. 1962. "Cement Grouting," Proceedings, ASCE, Vol 88, No. SM2, pp 51-52.

Baker, W. H. ed. 1982. "Grouting in Geotechnical Engineering," ASCE Proceedings, 1018 pp.

Bellier, J. 1967 (July). "The Malpasset Dam," Presented at Engineering Foundation Conference. Proceedings, The Evaluation of Dam Safety, Published by ASCE, N. Y.

Burwell, E. B. 1958. "Cement and Clay Grouting of Foundations," Practice of the Corps of Engineers, ASCE Proceedings, Paper 1551, Vol 84, No. SM1, pp 1551-1 - 1551-22.

Chernus Construction Company versus United States. 1948. 110 ct. cls. 264, 267, 75 F. Supp. pp. 1018, 1019.

Currie, O. A. 1976. "Preparation and Trial of Construction Litigation," Construction Contracts Transcripts, Practicing Law Institute.

Department of Defense. DAR 2-101, Policy: Defense Acquisition Regulation.

____________. DAR 18-112: Defense Acquisition Regulation.

Departments of the Army and Air Force. 1970 (Feb). "Grouting Methods and Equipment," TM 5-818-6/AFM 88-32, Washington, DC, 86 pp.

Engineering Board of Contract Appeals No. 3745-BCA, 1978.

Engineering News Record. 1983 (Mar). "Construction Costs Tracked for U.S," ENR Quarterly Cost Roundup Index History.

Fetzer, C. A. 1977 (Aug). "Seepage Problems of Earth and Rockfill Dams on Rock Foundations," Water Power and Dam Construction, pp. 38-44.

Flagg, C. 1975 (Oct). "Problems in Cutoff Trenches and Grouting," presented at U. S. Army Corps of Engineers Geotechnical Conference, Dallas, Tex.

Gourlay, A. W., and Carson, C. S. 1982. "Grouting Plant and Equipment," Proceedings of the Conference on Grouting in Geotechnical Engineering, ASCE Proceedings, pp. 121-135.

International Commission on Large Dams. 1975. Lessons from Dam Incidents.

Jeffries, S. A. 1982 (Feb). "Effects of Mixing on Bentonite Slurries and Grouts," Proceedings, ASCE Conference on Grouting in Geotechnical Engineering, New Orleans, La., pp. 62-76.

Karol, R. H. 1979 (Oct). "Chemical Grouting Practice in the United States," 1970-1980, Unpublished Paper Presented at U. S. Bureau of Reclamation Foundation Treatment Seminar.

Klosterman, M. J., Wolff, T. F., and Jahren, N. G. 1976. "Quantitative Relationships of Grouting to the Reduction of Groundwater Flow Through Rock Foundations," U. S. Army Engineer District, St. Louis, Mo.

National Research Council. 1974. "Better Contracting for Underground Construction," Prepared by the Subcommittee on Contracting Practices, U. S. National Committee on Tunneling Technology, National Academy of Sciences, Washington, DC, 143 pp.

U. S. Army Corps of Engineers. 1945. "Foundation Grouting," Engineering Manual for Civil Works, Chap. 18, Part CXXXV, Washington, DC, (superseded).

__________. 1948 (Apr). "Foundation Grouting - Equipment," EM 1110-2-3502, p. 32, Washington, DC.

__________. 1949 (Apr). "Foundation Grouting - Planning," EM 1110-2-3501, Washington, DC, (superseded).

__________. 1950 (Aug). Foundation Grouting - Field Technique and Inspection," EM 1110-2-3503, Washington, DC, (superseded).

__________. 1951 (May). "Dental Excavation and Concrete Backfill," EM 1110-2-3801, Washington, DC, (superseded).

__________. 1951 (May). "Guide Specifications Civil Works Construction," Tunnel Grouting, CE 1305.02, Washington, DC, (superseded).

__________. 1952 (Oct). "Guide Specification Civil Works Construction," Foundation Drilling and Grouting, CE 1305.01, Washington, DC, (superseded).

__________. 1959. "Guide Specifications Civil Works Construction," Foundation Drilling and Grouting, CE 1305.01, Amend. 1, May 64, Amend. 2, Oct 64, Washington, DC, 24 pp.

__________. 1959 (Nov). "Guide Specifications Civil Works Construction," Tunnel Grouting, CE 1305.02, Washington, DC, 20 pp.

__________. 1959 (Mar). "Specifications for Kettle Creek Dam," Baltimore District, Invitation No. CIVENG-18-020-59-8.

__________. 1963 (Aug). "Foundation Grouting - Field Technique and Inspection," EM 1110-2-3503, Washington, DC, 14 pp.

__________. 1965. "Periodic Inspection and Continuing Evaluation of Completed Civil Works Structures," ER 1110-2-100, Washington, DC.

__________. 1966 (July). "Foundation Grouting - Planning," EM 1110-2-3501, Washington, DC, 48 pp.

__________. 1966. "Quality Management," ER 1180-1-6, Washington, DC, (superseded).

__________. 1967. "Quality Management," ER 1180-1-6, Washington, DC, (superseded).

U. S. Army Corps of Engineers. 1970 (Apr). "Dental Excavation and Concrete Backfill," EM 1110-2-3505, Washington, DC, 2 pp.

____________. 1976 (Oct). "Modification and Claims Guide, Fixed Price Construction Contracts," EP 415-1-2, Washington, DC, 43 pp.

____________. 1978. "Bibliography on Grouting," WES MP C-78-8, Waterways Experiment Station, CE, Vicksburg, Miss.

____________. 1979. "Modification Impact Evaluation Guide," EP 415-1-3, Washington, DC, 70 pp.

____________. 1979. "Plans and Specifications," Longview Lake, Stage I Construction, Kansas City District, Kans.

____________. 1980. "Engineer Contracts Instructions," ER 1180-1-1, Washington, DC.

____________. 1980. "General Provisions Construction Contract," Washington, DC.

____________. 1982 (May). "National Program of Inspection of Non-Federal Dams," Final Report to Congress - "The National Dam Inspection Act of 1972," Section 5, Public Law 92-367, Office of the Chief of Engineers, 47 pp.

____________. 1983. "Contractor Quality Control," Lecture Notes for Resident Engineer Course, Ft. Worth, Tex.

____________. 1984. "Grouting Technology," EM 1110-2-3506, Washington, DC.

____________. 1981. "Construction Foundation Reports," ER 1110-1-1801, Washington, DC.

____________. 1968. "Survey of Potentially Dangerous Slides," EC 1110-2-68, Washington, DC.

____________, Missouri River Division. 1982. "Contracting Methods Study - MX Deep Basing," Prepared for AFRCE-MX through CEMXPA, Norton AFB, Calif., 104 pp.

U. S. Department of Defense. 1978. Armed Services Procurement Regulations, (DAR), Washington, DC.

APPENDIX I

SELECTED CASE HISTORIES

CONTENTS

APPENDIX I

SELECTED CASE HISTORIES

PROJECT A: JOHN MARTIN DAM

(This case history was developed with the assistance of Victor Huesinger and Jim McAdoo, Albuquerque District)

Location and Description of Project

A1. The John Martin Reservoir Project was authorized by the 1936 Flood Control Act under the title "Caddoa Reservoir," near Lamar in Colorado. The War Department Civil Appropriation Act of 1940 provided that the Caddoa Reservoir Project in Colorado and Kansas should be known as the John Martin Reservoir Project. The project is located on the Arkansas River in Bent County, Colorado, approximately 58 miles upstream from the Colorado-Kansas state line about midway between the cities of Lamar and Las Animas. The Project consists of a concrete gravity section, earth-fill embankments, gated spillway, outlet works, and Fort Lyon Protective Works dikes. The Dam in the floodplain, including the spillway section, has a length of approximately 4,000 ft with its crest at elevation 3880 ft, approximately 120 ft above the valley floor. The spillway crest elevation is 3840 ft and foundation elevation at the concrete section is 3730 ft. Wing dams on both abutments connect the main dam section to high ground and increase the overall length of the structure to approximately 2.6 miles (USACE 1939). The Caddoa Constructors, Caddoa, Colorado, was the prime contractor. The subcontractor for the drilling and grouting was the Jones Core Drilling Company of Dallas. The grouting was completed between 21 May 1941 and 31 December 1942, within the original contract period.

Geology

A2. The project is located near the western edge of the Great Plains Physiographic Province. The rock in the general vicinity consists of sandstones, shales, and limestones of Cretaceous age. The alluvium composing the floodplain of the Arkansas River and the terrace deposits north of the floodplain are of Quaternary age. The formations in the region are the Lykins of Triassic age, the Morrison of Upper Jurassic, the Purgatoire of Lower Cretaceous, and the Dakota, Benton, Niobrara, Pierre, Fox Hills, and Laramie of Upper Cretaceous age. At the damsite only the Dakota and Benton Formations are present. The major portion of the damsite is within the Dakota Formation which is composed of medium grained sandstones interbedded with shaly and silty sandstones, sandy and silty shales, and shales. The strata are thin bedded to massive and crossbedded. The sandstones are friable and lenticular in nature. The Benton Formation (Graneros shale), which outcrops on top of the north abutment, consists of a dark grey to black, sandy shale. The rock in the floodplain is covered with alluvium consisting of sands, gravels, boulders, silt, and clay. The south wing dam and concrete dam foundations are in the Dakota Formation which is about 475 ft thick. At the site, the Arkansas River has cut about 125 ft into the top of the Dakota, leaving a bluff 100 ft high on the left bank and a bluff 50 ft high on the right bank. The damsite is approximately on the axis of the Sierra Grande Arch and the strata exhibit a gentle northeast dip of about 15 ft to the mile. Two major joint systems were mapped, one striking N80°W, the other N10°E (near parallel to dam axis), both with vertical dip. Tests ran on samples parallel to bedding and normal to or at an angle of 55° with the bedding gave average coefficients permeability of 2×10^{-5} and 1.4×10^{-5} cm/sec, respectively.

Foundation Investigations

A3. Investigations consisted of field reconnaissance, borings, stripping and trenching, an exploration shaft, and seismic exploration. Eighty-five 2-in. core holes comprising 1495 ft in overburden and 3630 ft in rock were drilled by the Little Rock District. The Caddoa District drilled forty-four 2-in. holes totaling 595 ft in overburden and 2303 ft in rock. The total amount of 2-in. drilling was 2090 ft in overburden and 5933 ft in rock. Six holes were drilled diagonally. Three 6-in. holes were drilled for a total of 58 ft in overburden and 330 ft in rock. Two 36-in. holes were drilled for a total of 40 ft in overburden and 101 ft in rock. Twelve hand-excavated trenches and several dozer trenches were excavated and inspected. A 16-ft square sheet pile shaft was driven through 50 ft of alluvium to bedrock to determine feasibility of driving sheet piling and to determine its efficiency as a cutoff medium, to obtain undisturbed samples, to determine amount of leakage, and to inspect foundation rock. One hundred and eleven percussion drilled test holes were drilled approximately 10 ft deep into the foundation after rough excavation to confirm the foundation.

Technical Considerations

A4. The design of the structure provided for foundation drilling and grouting to reduce potential leakage. The grout curtain, beneath the structure, was angled upstream from the gallery and drain holes angled downstream were provided to reduce uplift. Some consolidation grouting was also required to grout riser pipes installed in the foundations to control water during concrete placement. No plans and specifications were available for review, but the bid abstract showed three items related to drilling and grouting. These items included 2-in. and 3-in. grout holes, 6-in. drain holes, and pressure grouting. Cement was Government furnished. The designer of the grouting program is unknown.

Contractual Considerations

A5. The contract for John Martin Dam was a firm fixed price contract awarded to the lowest bidder. Jones Core Drilling Company of Dallas was the subcontractor for drilling and grouting. The drilling and grouting were supervised and directed by Corps personnel, but the individuals involved for the contractor and the Corps are unknown. The specifics of the contract are also unknown. There were no claims in relation to drilling and grouting.

Drilling and Grouting

Concrete dam

A6. In order to reduce leakage and uplift pressures under the concrete dam, provisions were made to construct a grout curtain in the permeable foundation sandstone near the upstream side of the dam. To avoid having to drill through concrete, 3.5-in. pipes were set at 4-ft centers on the foundations and extended upward to the grouting gallery, except in Monoliths 40 to 43, inclusive, where they were extended to the operating gallery. The pipes were inclined to dip upstream at an angle of 15 deg from the vertical in a direction normal to the axis of the dam. This inclination made possible the intersection of a greater number of joints and at the same time moved the grout curtain nearer to the heel of the dam. Drilling of grout holes was done by rotary type drills powered by electric and air motors. The low grout consumption of the sandstone made stage grouting and the use of packers unnecessary.

A7. Grouting gravel drains and foundation risers. Pipes from the foundation riser systems and from each end of the gravel drains, placed in the upstream ends of certain monoliths for control of water during concrete placement, were extended to the grouting gallery for grouting. These, together with the exploratory core holes, were grouted prior to drilling the curtain grout holes in any area. The mixture used to grout the gravel drains consisted of two parts water to one part cement, by volume. Grout was forced into each gravel drain through the pipe leading to one end of the drain until it vented from the pipe set in the opposite end. The vent was then closed and grouting continued to refusal. The foundation riser systems were grouted with a 4:1 mixture and the exploratory core holes with a 6:1 mixture. All of this grouting was done at pressures of 35 to 45 psi.

A8. Low pressure curtain grouting. In accordance with provisions of the specifications and drawings alternate holes (8-ft centers) were designated as shallow or low pressure grout holes and drilled to a depth of 25 ft. These holes were drilled by 2-1/2-in. fishtail bits tipped with studeborium. (The low pressure holes were designated by the specifications as 2-in. holes, but the contractor elected to drill 2-1/2-in. holes, receiving, however, payment only for 2-in. drilling.) Low pressure curtain grouting was started 13 December 1941, and completed 2 May 1942. In general, the procedure was to drill and grout holes on 16-ft centers through several monoliths, then return and drill and grout the intermediate shallow holes. A 6:1 grout mixture was used and pressures ranged from 35 to 45 psi. Grout consumption was very low. Only 317 sacks of cement were required to grout the 201 low pressure holes, an average of 1.6 sacks of cement per hole.

A9. High pressure curtain grouting. The high pressure grout holes were drilled through the permeable foundation sandstone and through the relatively impervious silty sandstone into the underlying shale stratum on 8-ft centers. A few of the deep holes were fishtailed, but most of them were cored with 3-in. stellite or haystellite-set diamond-type bits. After all of the low pressure holes in an area had been grouted, deep high pressure holes were drilled on 32-ft centers. When the first deep holes had been grouted, a second set of deep holes was drilled and grouted, halving the intervals between the first holes. The remaining holes were drilled on 16-ft centers, but were separated by a previously grouted deep hole. The pressures used ranged from 50 to 130 psi, depending upon the height of the overlying structure at the time of grouting. In general, the grouting was done with 6:1 grout, but several holes were grouted with 10:1 grout in an attempt to increase the grout consumption. Pozzolan was added to the grout used in a number of holes in another effort to secure additional grout penetration. However, regardless of the mixture used, the amount of grout used per hole was only slightly more than equal to the volume of the hole. The 201 high pressure grout holes, averaging 57 ft in depth, consumed 663 sacks of cement, or an average of 3.3 sacks per hole. The high pressure grouting was done between 6 January 1942 and 4 June 1942.

A10. Quantities. The quantities of drilling and cement required to pressure grout the concrete dam foundation are tabulated as follows:

	Low Pressure	High Pressure
No. of holes	201	201
Drilling footage	5,045	11,467
Curtain grouting (sacks of cement)	317.6	663.0
Cement per hole (sacks)	1.58	3.30
Cement per foot of hole (sacks)	0.063	0.058
Exploratory core holes (sacks of cement)	40.2	
Gravel drains (sacks of cement)	46.7	
Foundation risers (sacks of cement)	106.7	
Total pressure grouting (sacks of cement)	1,174.2	

A11. Effectiveness. Because of the filtering effect of the sandstone in the foundation, the Portland cement grout used did not penetrate the foundation to provide an effective grout curtain. As a result, the flow through the foundation is considerably in excess of the flow originally anticipated. Experiments were conducted on samples of the foundation sandstone by the U. S. Bureau of Reclamation Laboratory at Denver, Colorado, to determine a suitable grout agent. From these experiments it was determined that cement or "solids in suspension" grouts are entirely inadequate, and that use of chemical "single shot" grouts offers the best solution of sealing the foundation (USACE 1943). Because of war conditions, however, further consideration of grouting was deferred indefinitely, and has not been done.

Earth dam

A12. Since the flow of ground water or reservoir leakage through the unconsolidated sand and gravel stratum forming the foundation for the earth dam was thought to be restricted and reduced by the steel sheet pile cutoff upstream, no provisions for grouting the earth dam foundation were made, except in that part of the foundation formed by the north abutment.

A13. North abutment consolidation grouting. Most of the cement used in grouting the north abutment was consumed by consolidation grouting of open joints and cracks uncovered during the final abutment cleanup. This grouting was done at intervals between 29 May 1941 and 27 June 1942. In general, the consolidation grouting was done with a 4:1 mixture and pressures of 10 to 20 psi. Where considerable grout was required, the mix was thickened. A few of the joints permitted grout to escape into the fill causing grout boils to appear on the surface. In such cases the mixture was thickened to 1:1 grout to seal the leaks. A 6:1 mixture and pressures ranging up to 80 psi were used in grouting a debris filled vertical joint extending entirely through the 25-ft sandstone member at the top of the abutment. This joint crossed the axis of the dam in a direction nearly normal to the dam axis. A filling of sand, silt and weathered shale was found tightly packed in the crack in the central one-third of the sandstone, and, because of the narrowness of the opening, it could not be entirely removed by blow-pipes. The upper and lower parts of the joint were comparatively free from detritus. Grout holes were drilled to intersect the joint near the bottom of the sandstone. Approximately 70 sacks of cement were used to grout this crack. Grout leaks appearing through and above the debris were stopped by caulking. The topmost abutment sandstone consumed 79 sacks of cement. The second sandstone required 44 sacks of cement for consolidation grouting. Four hundred and twelve sacks of cement were injected into the joints and cracks in the lower sandstone. Altogether, 535 sacks of cement were used in the consolidation grouting of the north abutment.

A14. North abutment curtain grouting. Since excavation had removed that part of the abutment rock most likely to take large quantities of grout, and all cracks and joints found during cleanup had been filled by consolidation grouting, it was thought that the abutment would offer practically no avenue for the passage of water other than through the pores of the sandstones. However, it was considered advisable to check the tightness of the rock by a series of high pressure grout holes. Five holes were fanned at various angles away from the abutment in a plane parallel to the axis of the dam. The holes were drilled in three stages, a stage being complete when a shale stratum was reached. At the completion of each drilling stage the hole was grouted. After an interval of two or three hours depending on the grout mixture used, the grout was flushed out of the hole and the drilling resumed. By drilling and grouting in stages, as described, the clogging of any joints, cracks or seams in the sandstone by shale cuttings was prevented. A packer was used to secure adequate coverage during the grouting of the lower stages with high pressures. Pressures up to 80 psi were used. A 6:1 mixture was used, except where leaks had to be sealed with thicker mixtures. A total of 135 sacks of cement was used to grout the 470 ft of 3-in. holes. The largest amount of grout for a single hole was 79 sacks.

South wing dam

A15. Curtain grouting. The sandstone forming the northern half of the south wing dam foundation varies from 40 ft to less than 15 ft in thickness and is underlain by a 10- to 20-ft layer of shale. The south wing dam grouting, therefore, was all done at low pressures, with the holes only penetrating the sandstone. Drilling was done with studeborium-tipped fishtail bits or, where core was required, with diamond bits and core barrels and after stripping off the overburden but before all the excavation had been completed.

A16. It was proposed to drill and grout holes through the sandstone caprock from the south abutment along the centerline of the south wing dam as far south as grout consumption warranted. Where considerable grout was taken, intermediate holes on 10-ft centers were drilled. The holes were 3-in. in diameter and were inclined 15 deg from the vertical, dipping in a direction parallel to the axis of the concrete dam. Existing exploratory core holes, where found, were cleaned and grouted. One hole was drilled into the silty sandstone underlying the concrete dam foundation sandstone to determine the tightness of the sandstone in the abutment below the caprock.

A17. The curtain grouting operations in the south wing dam foundation were carried out intermittently from 2 February 1942 to 15 June 1942. All holes were stop grouted, using packers and working from the bottom to the top of the hole. Three or four stops were used as required by the depth of the hole. Pressures ranged from 1 to 30 psi, according to the depth at which the packer was set below the surface. In most cases a pressure of 1 psi for each foot of depth was used. However, in the deeper holes where the packer for the first grouting stage was set at 20 ft, pressures up to 30 psi were used.

Grout mixtures varied from 6:1 to 0.75:1 by volume. Except in the topmost stage where the packer was set as near to the surface as possible, the starting mixture was 6:1. The top stage was usually started with 4:1 grout since the upper part of the sandstone was almost always badly cracked and broken. Many leaks occurred during the grouting of the last two stages because of the proximity of the packer to the surface and the broken character of the rock. These leaks were stopped by caulking or ponding whenever possible. However, frequently all attempts to stop the leaks were unsuccessful. In such cases, 1:1 grout was pumped into the hole at a low pressure until it vented and the hole was then abandoned.

A18. A total of 4950 sacks of cement was used during the curtain grouting operations in the south wing dam foundation, including the grouting of the exploratory core holes. A range in grout consumption per hole from less than one-half sack to 1365 sacks of cement was obtained. The total drilling for grouting in the south wing dam foundation was 2707 ft for a ratio of 1.8 sacks/ft.

Unexpected Geological Conditions Encountered During Construction

A19. There were no unexpected geological conditions encountered. However, grout takes in the sandstone foundation were not sufficient to effectively reduce the flow, as originally anticipated.

Evaluation of Grouting

A20. Even though the flow through the foundation sandstone was not reduced as much as anticipated, the grouting is considered to be adequate as flow into the gallery is within the design limitations of the pump system. A study for additional grouting by chemicals was deferred indefinitely at the time of construction and is not now considered essential. Grouting of the north abutment and south wing wall is considered adequate. Seepage was detected in 1955 near the junction of the south wing dam and the main dam was determined to be coming through the top 5 ft of sandstone. Grouting was considered to be of questionable value and was not performed.

Costs and Quantities

A21. Table A1 compares the Government estimate, bid, and actual quantities and costs (USACE 1940, 1943).

A22. Actual drilling quantities were 57 percent of the estimated quantities and actual drilling costs were 64 percent of the estimated cost (Government Estimated Quantities x bid unit cost). Actual pressure grouting was 27 percent of the estimated quantities and actual grouting costs were 27 percent of the estimated cost.

A23. Table A2 shows the statistics for the grout curtain.

Performance

A24. The performance of the grouting program has been monitored and evaluated under operational conditions by observation of drain hole flow into the gallery during O&M inspections, and periodic inspections of the dam safety program (USACE 1970). There has been no need for remedial grouting.

References

US Army Corps of Engineers. 1939. "Analysis of Design for Caddoa Dam and Reservoir," Section III, Geology, Caddoa District, Caddoa, Colo.

____________. 1940. "Abstract of Bids," Caddoa District, Caddoa, Colo.

____________. 1943. "Final Estimate," John Martin Reservoir Project, Albuquerque District, Albuquerque, N. Mex.

____________. 1943. "John Martin Dam and Appurtenant Works Completion Report," Contract No. W911-ENG-487, Albuquerque District, Albuquerque, N. Mex.

____________. 1970. "John Martin Periodic Inspection," Report No. 1, Albuquerque District, Albuquerque, N. Mex.

Table A1

Estimated and Actual Drilling and Grouting Quantities and Costs

Item	Description	Estimated Quantities	Estimated Unit Cost	Bid Unit Cost	Actual Quantities	Estimated Contract Cost	Actual Cost
14	Drill 2 in. holes	8,000 lin ft	0.678	1.50	5,097	$ 12,000.00	$ 7,645.50
15	Drill 2-1/2 in. Percus holes	135,000 lin ft	0.183	1.00	68,699	135,000.00	68,699.00
16	Drill 3 in. holes	16,000 lin ft	1.083	2.00	14,542	32,000.00	29,084.00
17	Drill 6 in. holes	6,000 lin ft	2.106	3.50	6,215	21,000.00	21,752.50
18	Drill 8 in. concrete cores	300 lin ft	7.132	10.00	255	3,000.00	2,550.00
		165,300 lin ft			94,800	$203,000.00	$129,731.00
19	Pressure grouting	25,000 cu ft	0.685	0.90	6,830	22,500.00	6,147.00
	Total cost drilling and grouting related items					$225,500.00	$135,878.00

Table A2

Grout Curtain Summary

	Low Pressure			High Pressure			Totals		
	Drilling lin ft	Grouting cu ft	Ratio sacks/ft	Drilling lin ft	Grouting cu ft	Ratio sacks/ft	Drilling lin ft	Grouting cu ft	Ratio sacks/ft
Concrete Dam	5,045	317.6	.063	11,467	663	.058	16,512	980.6	.059
North Abutment							470	135	.29
Southwing Dam							2,707	6,065.6	1.8
TOTALS							19,689	7,181.2	0.36

PROJECT B: NORFORK DAM

(This case history was developed with the assistance of Charlie Deaver, Little Rock District)

Location and Description of Project

B1. The Norfork Dam is located on the North Fork River in Baxter County, Arkansas, 4.8 miles upstream from the confluence with the White River. It is approximately 12.5 miles southeast of Mountain Home, Arkansas. It is a straight concrete gravity dam constructed for flood control and hydroelectric power. It is 2,631 ft long and 247 ft high above the lowest point in the foundation (Plate I-B1). It was constructed by the Little Rock District during the period from March 1941 to March 1945 (USACE 1945). Scheduled completion was April 1944, but several time extensions were allowed because of such things as weather and labor problems created by the war effort. The Utah Construction Company and Morrison-Knudson Company, Incorporated (a joint venture), were the prime contractors. The subcontractor for the drilling and grouting was Mott Core Drilling Company.

Geology

B2. The project is located on the southern flank of the Ozark Highlands, a structural dome centering in the St. Francis Mountains, 200 miles northeast. The relatively flat lying limestone strata have been gently folded and eroded into deeply cut valleys with narrow uplands. Foundation rocks at the site consist of bedded strata of the Everton, Powell, and Cotter formations of Ordovician age. The foundation rocks generally consist of dolomites and dolomitic limestones, occasionally sandy, and a few shale beds. Rock layers in the dam vicinity are generally near horizontal. The dam was constructed on a downthrown block between two major faults. Several minor faults occurred in the foundation rock and two major joint sets were present. Solution channels were encountered in the foundation, generally related to the small rock structures such as small folds or faults.

Foundation Investigations

B3. Foundation investigations consisted of core boring, trenching, and regional geological studies. A total of 18,256 ft of bedrock was drilled at four sites investigated, including 10,506 ft at the selected site. Average core recovery for drilling at the selected site was 97.4 percent. Cores of 2-1/8-in. diam were obtained from all borings, and all holes were pressure tested. A board of consultants reviewed the geotechnical data and foundation conditions. An experimental grouting program was performed in a limited area after overburden removal and prior to rock excavation to establish procedures.

Technical Considerations

B4. The plans and specifications (USACE 1941) described the work to be performed and the equipment to be used for the grout program which included some consolidation grouting and a grout curtain designed to reduce foundation leakage. Though some consideration was given to consolidation grouting, no extensive program was followed as foundation rock possessed no specific weakness that such grouting would correct. It was also thought that such a program, by restricting free drainage downstream of the grout curtain, might create undesirable uplift pressures. A small faulted area was drilled and grouted to test the need for consolidation grouting, but the small takes proved the area to be tight. Other consolidation grouting included grouting the open joints, seams, or solution channels in which pipe had been embedded prior to concrete placement. There was a changed condition clause in the construction contract. There was also a statement that quantities were approximate only and final quantities would be dependent upon the amount of work required as shown by information secured as the work progressed. There were five pay items for drilling core holes for grouting (different sizes and depths) and two items for placing grout (by cubic feet cement placed), one for up to 2,000 cu ft and the other over 2,000 cu ft. Cement was Government furnished. Core recovery was required. No item was included for pressure testing, but specifications provided for it as directed by the contracting officer. Very little was actually done. Pipe for consolidation grouting and drain holes was paid for.

Contractual Considerations

B5. The contract for Norfork Dam was a firm fixed price contract awarded to the lowest bidder. Mott Core Drilling Company was the subcontractor for drilling and grouting. Mr. Roy F. House was the resident engineer for the Corps and Mr. Raymond E. Whitla was the project geologist. The drilling and grouting were supervised and directed by Corps personnel. The specifications contained a clause stating that "The Government reserves the right to change the location and depth of the holes and to increase or decrease the quantities by any amount that may be necessary, if, in the opinion of the contracting officer, conditions require such modifications, and no change will be made in the applicable contract unit prices because of such modification." No major conflicts between the prime contractor and subcontractor or the Corps occurred and relations at the field and management level are inferred to have been professional and harmonious. The prime contractor did claim additional costs in connection with grouting as he contended that if the Government had required foundation consolidation grouting in advance of concrete operations (as he interpreted the contract), his unwatering problem would have been minimized. His claim was denied, he appealed, and the record of the final decision could not be located.

Drilling and Grouting Methods

B6. All grouting and core drilling were done by Mott Core Drilling Company. However, pipes through which the curtain grout holes were drilled and grouted, and all pipes placed in seams and in solution channels through which they were to be grouted after the foundation had been covered with concrete, were installed by the prime contractor. Grouting was performed after the concrete had reached a certain height (USACE 1944).

Drilling

B7. All curtain grout holes were 3 in. in diameter and drilled with diamond core drills. Core was required. Holes for drainage of the downstream dam foundation were 5 in. in diameter and drilled with shot core drills. The grout curtain holes were spaced on 4-ft centers, and drain holes downstream of the grout holes were spaced on 8-ft centers. Grout holes were inclined 10 deg upstream from the vertical, and drain holes were inclined 15 deg downstream from the vertical. Drills used in the gallery were equipped with 440-v electric motors.

Washing and pressure testing

B8. No separate item was included for pressure testing, but the contractor was required to furnish the necessary equipment to make such tests as directed by the contracting officer. The costs were to be included in the various prices bid for drilling.

Grouting mixtures

B9. All grouting was done with a mixture of Portland cement and water. The cement was furnished by the Government. Mixtures ranged from one consisting of six parts water to one part cement by volume to one consisting of three parts water to four parts of cement by volume. Most of the holes that were grouted commenced with a mixture of four parts water to one part cement.

Pressure

B10. Pressures were determined for the most part on the basis of one pound per square inch pressure for each foot of rock and/or concrete above the zone being grouted. This was considered a safe rule to avoid heaving or otherwise disturbing the rock when uplift gages were not used. Higher pressures were used for experimental grouting, grouting solution channels, and for the last rounds of grouting the cut-off curtain. Pressures ranged from 5 to 300 psi. The specifications provided for a maximum of 250 psi and the expectation that, generally, 150 psi would be required in the deeper sections, while lower pressures would be used for upper zones.

B11. The higher pressure of 300 psi was used with the verbal consent of the subcontractor to grout the bottom zones of six of the curtain grout holes. Based on the expected 150 psi requirement, the contractor protested the higher grout pressures. The contractor was directed to accept the interpretation allowing the 250 psi until the decision was received from the district office. A reply was never received.

Refusal rate

B12. The refusal rate set in the specifications required the hole to be considered grouted to refusal when the rate of grout take was less than one cubic foot in 10 min. This refusal rate was generally followed for all the grouting of Norfork Dam.

Field procedures

B13. Curtain grout holes had a maximum depth of 100 ft in the right abutment and penstock sections and 150 ft in the spillway and left abutment sections (Plate I-B2). The average depth was 79.4 ft. The holes were drilled and grouted by the split spacing method, generally beginning with 48-ft centers, then 16, 8 and 4 ft, respectively. Occasionally, it was necessary to split between the 4-ft spacing. All the holes were grouted in zones by using a grout stop or packer. The bottom zones thus were grouted first and, as each zone was completed, the packer was raised to grout the successively higher zones. Each hole was divided into zones on the basis of its depth. Each zone represented a 30 to 40-ft section of each hole. Zones of over 40 ft were avoided as much as possible. Grouting of the primary, secondary, and tertiary holes (48, 16, and 8 ft spacing) was started with a 4 to 1 mixture, and the remaining splits were started with a 6 to 1 mixture. The grout mixture was changed to a thicker mixture on some holes after takes continued for some time or when the hole took grout so freely that the desired grout pressure could not be obtained with the starting mixture. The determination as to when to change the mixture and how much change was left to the judgment of the grout inspector.

Equipment

B14. The specifications required the contractor to provide a grout mixer, and sump, a water tank for auxiliary water supply, two duplex piston displacement grout pumps (for up to 250 psi), suitable air compressors, water meter reading to nearest 0.1 cu ft, and other auxiliary equipment such as hoses, gages, valves, packers--all subject to the approval of the contracting officer.

Grout takes

B15. Total cement for the curtain grouting amounted to 13,748.6 cu ft or about 0.25 cu ft of cement per foot of hole, exclusive of backfill.

Unexpected Geological Conditions Encountered During Construction

B16. There were no unexpected geological conditions encountered. As mentioned, some experimental grouting was performed but with minor takes. Additional exploration and geological information was obtained during the course of the contract since core was required from the grout holes.

Evaluation of Grouting

B17. The grouting program resulted in a relatively tight foundation, was judged to be adequate after construction, and is still judged to be adequate. The grouting of the solution cavities, seams, joints, and the curtain was adapted to the geology and project design and was anticipated prior to construction.

Costs and Quantities

B18. Actual drilling quantities were 5 percent under estimated drilling, and actual grouting quantities were 71 percent under estimated quantities. Total drilling cost was $191,174, and total grouting cost was $36,687 for a total of $227,861. Table B1 compares the Government estimate, bid, and actual quantities and costs.

Performance

B19. The performance of the grouting program was evaluated by exploratory core holes and the effectiveness evaluated by monitoring actual inflow into the gallery from the drain holes by continuing observation since the project became operational. The most recent periodic inspection report (USACE 1978) concludes that the grout curtain is functioning as designed. There has been no need for remedial grouting.

References

US Army Corps of Engineers. 1941. "Plans and Specifications," Contract No. W-777-ENG-875, Little Rock District, Little Rock, Ark.

___________. 1944. "Report of Grouting and Drainage (Norfork Dam)," Little Rock District, Little Rock, Ark.

___________. 1945. "Norfork Dam, Completion Report on Construction of Dam," Contract No. W-777-ENG-875, Little Rock District, Little Rock, Ark.

___________. 1978. "Norfork Dam, Report of Periodic Inspection," No. 4, Little Rock District, Little Rock, Ark.

Table B-1

Estimated and Actual Drilling and Grouting Quantities and Costs

Government Estimate				Bid	Actual	
Item	Description	Quantities	$ Unit Cost	$ Unit Cost	Quantities	$ Cost
11	Drilling 3 in. holes (0-80 ft)	13,000 lin ft	1.50	2.85	16,229.6	42,254.36
12	Drilling 3 in. holes (0-40 ft)	23,000 lin ft	1.80	2.50	27,213.2	68,033.00
13	Drilling 3 in. holes (40-100 ft)	20,000 lin ft	1.80	2.60	24,352.2	63,315.72
14	Drilling 3 in. holes (100-150 ft)	1,000 lin ft	1.81	2.85	3,611.2	10,291.92
15	Drilling 3 in. holes (0-40 ft)	20,000 lin ft	1.40	2.00	1,639.5	3,279.00
		77,000 lin ft			73,045.7	191,174.00
19	Pressure Grouting (0-20,000 cu ft)	20,000 cu ft	0.70	1.70	20,000	34,000.00
20	Pressure Grouting (over 20,000 cu ft)	40,000 cu ft	0.60	0.60	4,479.37	2,687.62
					24,479.37	36,687.61

Summary

Total quantity of cement for curtain grouting	13,748.6 sacks
Number of holes grouted	706
Average depth of hole in rock	79.4 feet
Quantity cement per foot of hole	0.25 sacks

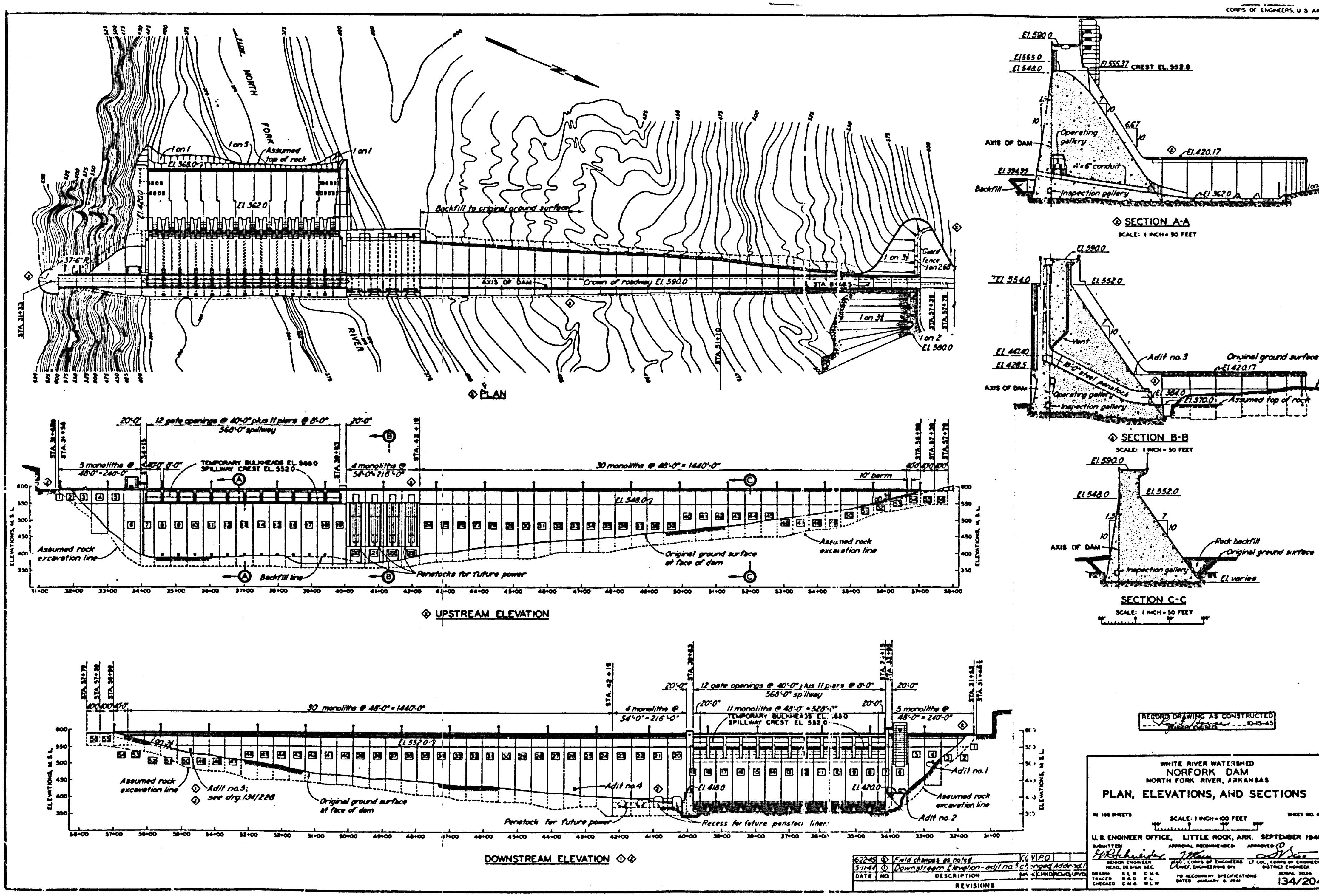

CORPS OF ENGINEERS, U.S. ARMY
PLAN
Axis of dam
Crown of roadway El. 590.0
Backfill to original ground surface
Assumed top of rock
NORTH FORK RIVER
UPSTREAM ELEVATION
12 gate openings @ 40'-0" plus 11 piers @ 8'-0"
568'-0" spillway
5 monoliths @ 48'-0" = 240'-0"
4 monoliths @ 54'-0" = 216'-0"
30 monoliths @ 48'-0" = 1440'-0"
TEMPORARY BULKHEADS EL. 566.0
SPILLWAY CREST EL. 552.0
10' berm
Assumed rock excavation line
Original ground surface at face of dam
Backfill line
Penstocks for future power
ELEVATIONS, M.S.L.
DOWNSTREAM ELEVATION
11 monoliths @ 48'-0" = 528'-0"
Adit no. 1
Adit no. 2
Adit no. 3; see drg. 134/228
Adit no. 4
Penstock for future power
Recess for future penstock liner
SECTION A-A
SCALE: 1 INCH = 50 FEET
Operating gallery
Inspection gallery
Backfill
SECTION B-B
SCALE: 1 INCH = 50 FEET
Adit no. 3
Original ground surface
Assumed top of rock
Operating gallery
Inspection gallery
SECTION C-C
SCALE: 1 INCH = 50 FEET
Rock backfill
Original ground surface
Inspection gallery
El. varies
RECORD DRAWING AS CONSTRUCTED 10-15-45
WHITE RIVER WATERSHED
NORFORK DAM
NORTH FORK RIVER, ARKANSAS
PLAN, ELEVATIONS, AND SECTIONS
SCALE: 1 INCH = 100 FEET
U.S. ENGINEER OFFICE, LITTLE ROCK, ARK. SEPTEMBER 1940
REVISIONS
134/204

PLATE I-B1


20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56
These holes became plugged with debris after they were drilled. The lower sections of the holes were not cleaned out.
Grouted together from same header. 5.8 Sks
Grouted together from same header. 39.4 Sks
Grouted together from same header. 1.6 Sks
These holes became plugged with debris after they were drilled. The lower sections of the holes were not cleaned out.
Plugged with grout that leaked into this hole from hole 12-36-1
NORFORK DAM
NORTH FORK RIVER, ARKANSAS
GROUT DATA FOR
CURTAIN-GROUT HOLES
SCALE OF FEET
0 20 40
SEPTEMBER 1944
SERIAL 3286
F(1)134/829
PLATE I-B2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37
Plugged with grout that leaked into this hole from hole 12-8-7.
Plugged with grout that leaked into this hole from hole 12-12-10.
These holes became plugged with debris after they were drilled. The lower sections of the holes were not cleaned out.
Grouted together from same header. 3.8 Sks
Grouted together from same header. 39.4 Sks
Grouted together from same header. 1.6 Sks
These holes became plugged with debris after they were drilled. The lower sections of the holes were not cleaned out.

PROJECT C: ALLATOONA DAM

(This case history was developed with the assistance of Jack Bryan, Mobile District)

Location and Description of Project

C1. The Allatoona Dam is located on the Etowah River in Bartow County, Georgia, approximately 5 miles east of the city of Cartersville and 35 miles northwest of Atlanta (USACE 1941). It is a curved, concrete, gravity dam with a maximum height of about 200 ft and a total length of 1231 ft. The adjacent powerhouse will accommodate three 36,000 kw units and a 2,000 kw service unit. One of the main units is to be installed at a future date. The project is a multipurpose flood control and power project. Plate I-C1 shows the general layout and boring plan. The dam was constructed by the Mobile District during the period 1946 to 1949. The prime contractor was National Constructors, Incorporated; the subcontractor for drilling and grouting was Continental Drilling Company.

Geology

C2. The Etowah flows almost due west at the damsite which is situated in a gorge formed by a spur of Pine Mountain on the north and Vineyard Mountain on the south. It is within but near the eastern border of the Appalachian Valley and Ridge province, approximately 400 ft downstream from the contact with the Piedmont Plateau. Rocks of the Valley and Ridge province are folded Cambrian and younger sedimentary and meta sedimentary formations, and those of the Piedmont are generally Pre-Cambrian metamorphic rocks of complex structure and stratigraphy. The damsite itself is entirely underlain by the Weisner formation of Cambrian age. The formation consists of muscovite schist with random beds of massive quartzite, metasiltstone and conglomerate, and less frequently with beds of crystalline dolomite and limestone. The foundation rocks occur on the eroded limb of an overturned isoclinal fold. The beds strike generally parallel to the axis of the dam and dip 45 to 65 deg in an upstream direction. Innumerable small faults, folds, and joints were encountered at the site and are attributed to the stress history of the site.

Jointing was most intense and closely spaced in the quartzites, resulting at times in shattered zones. The less competent rocks were more massive, having yielded to dynamic stress by deformation rather than fracturing. Little jointing was noted in the schist; however, interestingly the curtain grouting resulted in less grout takes in the shattered quartzite than in the relatively massive schist. Other geologic phenomena considered in design and construction included sheet or relief joints and solutioning of carbonate rocks along faults and joints. These features resulted in additional excavation and backfill in the powerhouse and stilling basin areas.

Subsurface Investigations

C3. Preconstruction investigations prior to completion of the design report included 141 small diameter core borings and five large (36-in.) diameter calyx holes (USACE 1944). Thirteen additional small diameter core borings were added immediately before and continuing until two months after construction began. They were in the stilling basin for the purpose of evaluating a solution channel revealed by previous drilling. Other drilling was done during construction to evaluate conditions in the south abutment and powerhouse areas. As a result, two concrete monoliths were eliminated in the south abutment due to a high sound rock line. The powerhouse construction borings consisted of 40 holes with an aggregate depth of 3033 ft. They were used to develop foundation sections determining the need and amount of dental excavation necessary for an adequate powerhouse foundation. Miscellaneous jackhammer holes were used occasionally to determine the extent and depth of foundation weathering.

C4. Design of the subsurface investigation program for Allatoona Dam apparently gave little consideration to grouting design details as it was felt that investigations to determine an adequate foundation for the structure would also be useful in planning the grouting program. In addition, the foundation would be mapped in detail prior to grouting and the grouting itself was considered exploratory in nature. Also, "To determine just what might be expected in grout quantities, and to plan the best possible grouting procedure with respect to depth, spacing, and stages, a test section in what was considered to be the portion of the foundation underlain by the most highly jointed and pervious rocks (Monoliths 12, 13, 14 and 15) was selected for initial treatment" (Conn 1949).

Grouting Design

C5. A tentative program of consolidation and curtain grouting was presented in the plans and specifications for bidding purposes.

Consolidation grouting

C6. After final exposure and examination of the foundation, consolidation grouting of observed cracks and fissures of sufficiently large areal extent was planned. A 1-in. grout pipe was inserted into the crack and extended to the gallery. These pipes were installed more profusely upstream of the curtain since drainage was not desired. The pipes were then washed and grouted from the gallery coincidental with the curtain grouting, using similar procedures, mixtures and pressures. Based on exploratory drilling, it was also planned to treat other areas by consolidation grouting. They were: a deeply weathered area of Monoliths 11, 12, 13 and 14; a cavern under the south portion of the stilling basin; solution channels in the north half of the powerhouse foundation; and weathering under the north downstream slabs of the stilling basin. When these areas were exposed by excavation, it became apparent that grouting alone would not be a satisfactory treatment. Each area would have to be treated individually by excavation, dental treatment, consolidation grouting, or a combination of the three. Consequently, the actual amount of consolidation grouting in these areas was reduced to just the downstream third of Monolith 14 and a small amount in the powerhouse to fill small spaces not reached by concrete backfill and small voids caused by shrinkage of the backfill.

Curtain grouting

C7. The geology of the damsite and reservoir area was recognized as being favorable in regards to leakage and seepage potential. However, open joints and solutioning were identified during project investigations, and it was considered prudent to require systematic grouting. Three inch curtain grout pipe were required in the concrete dam extending from the foundation to the gallery on 5-ft centers. Primary holes on 20-ft spacing were specified with splits to be directed. The vertical grout curtain was planned beneath the full extent of the concrete dam but did not extend into the abutments beyond the dam. The design was tentative with details to depend on a test section to be grouted by the contractor as his initial treatment.

C8. "The program as executed throughout the entire cutoff consisted of drilling, washing, and grouting first stage holes on 20-ft centers; split spacing with similar holes, making 10-ft centers; and finally splitting the 10-ft interval, providing a first stage curtain 25 ft deep on 5-ft centers . . . Whenever an unusually large grout take was encountered in a first stage hole, or group of holes, a second stage was drilled to 50 ft, and if a comparatively large take was encountered in the second stage, a third stage was drilled to 75 ft. In any case, at least one hole in each monolith was drilled as a check hole to second stage depth" (Conn 1949). A few splits to 2-1/2-ft centers were required in Monolith 26. Plates I-C2 and I-C3 show the as-built grout curtain.

Contractual Considerations

Contract

C9. The contract for Allatoona Dam was a firm fixed price contract awarded to the lowest responsible bidder. A single contract was used for the entire dam. Mr. Charles A. Jackson was resident engineer for the Corps, and William V. Conn was the project geologist. Mr. W. N. Evans was project manager for National Constructors, Incorporated, in the early stages and was later succeeded by Mr. K. L. Parker. The foreman for Continental Drilling Company was Mr. J. C. Myrick.

Specification drilling and grouting requirements

C10. The specifications required rotary diamond drills for drilling the 1-1/2-in.-diam grout holes. Percussion drills were prohibited. No core was required. The split spacing, stage grouting method was required with the exact location, depth, direction, interval between holes, and order of drilling and grouting to be determined in the field by the contracting officer. All holes were to be thoroughly washed and pressure tested prior to grouting. Grouting pressures and mixtures were to be as directed. Specified mixtures consisted of cement and water with water cement ratios to range between 4 and 0.6.

C11. Specified grouting equipment included a mechanically agitated mixer and sump, water tank, air-driven duplex slush pump, and suitable gages, pressure hoses, supply lines and valves--all subject to approval of the contracting officer.

C12. The contract specifications (USACE 1946) contained the following clause: "For the purpose of canvassing bids, a tentative program for drilling grout holes and grouting the foundations of the dam is shown on the drawings and outlined in the specifications. The Government reserves the right, however, to alter the location and depth of the grout holes, to vary the amount of grout, and to decrease by 50 percent or increase by 100 percent the total estimated footage of grout hole drilling, and no change will be allowed in the contract unit price because of such alterations."

C13. The estimated quantities (Table C1) for drilling and grouting were 25,600 lin ft and 18,000 sacks, respectively. Actual quantities were 13,225 lin ft and 3,000 sacks. Since these quantities varied within the limits of the above clause, no claim ensued and no adjustment was made to the contract unit prices. Table C-2 shows contract bid prices for drilling and grouting.

C14. It is interesting to note the following comment from the foundation report (Conn 1949): ". . . wherever possible, drilling and grouting quantities in the specifications should be left entirely open. Tentative estimates can be made for the purpose of canvassing bids, but the right should be reserved by the Government to increase or decrease the quantity--not merely 100 percent, but by any amount which may be required." It became standard practice for the Corps contracts to do just that, i.e., reserve a right to vary drilling and grouting quantities by any amount. The practice worked quite well for two decades, however, since 1978, it has been challenged legally with increasing frequency.

Contract management

C15. No contract management or administration problems relative to grouting surfaced during this study. No grouting claims were filed. The underrun of drilling and grouting quantities reduced the cost of grouting by approximately $83,000 or 64 percent. The impact of this reduction on the grouting subcontractors is difficult to assess, however, since the contractual arrangements between the prime and subcontractors are unknown.

Drilling and Grouting Methods

Drilling

C16. All grout holes were 1-1/2 in. in diameter, vertical, and were drilled with pneumatic drills from the gallery. The contractor elected to use diamond coring bits rather than plug bits, however, he was not required to save any core. Percussion drills were prohibited by the specifications.

Washing and pressure testing

C17. Washing and pressure testing were required prior to grouting, however, the procedure was of little value since interhole connections were rare and groutable openings contained little filling material to be washed. The procedure did provide an indication of how the hole would be expected to act upon being grouted and was therefore used throughout the program.

Grouting mixtures

C18. All grout was composed of two ingredients: water and cement. The specified range of water-cement ratios was 4 to 0.6. ". . . the normal procedure in grouting was to begin with a water-cement ratio of 3, which ordinarily was used until the hole was grouted to refusal. A few holes were encountered where it was necessary to thicken the mixture to a water-cement ratio of 1, or, if water pressure testing had indicated an extremely open hole, grouting might be started with a ratio of 2 and later reduced to 1. The use of these thicker mixtures, however, was the exception rather than the rule. In the early stages of the grouting program, some experimenting was done with a water-cement ratio of 4 in an attempt to increase grout quantities, but it was found that the excessive shrinkage associated with such a thin mixture would make the effectiveness of the treatment extremely doubtful" (Conn 1949).

Pressure

C19. The rule of thumb of 1 psi per foot of rock or concrete overburden was used as the maximum allowable pressure for grouting and pressure testing. Specifications required the concrete dam to be at least 100 ft high before grouting was permitted. This allowed sufficiently high pressures to insure penetration of small cracks and fissures.

Field procedures

C20. Split spacing, stage grouting procedures were used. Primary holes were on 20-ft centers with splits down to 5-ft centers for stage 1 being mandatory. Further splits to 2-1/2-ft centers were made in rare cases based on grout takes. Stage 1 was from 1 to 25 ft deep. If stage 1 holes took a relatively large amount of grout, a second stage was grouted to 50 ft, and if a large take was encountered in stage 2, a third stage was grouted to 75 ft. Grout hole locations, depths, angles, order of drilling and grouting, pressures, and grout mixtures were all as directed in the field by the contracting officers' representative. No special procedures for backfilling grout holes were indicated.

Grout take

C21. Grout takes were generally very small, averaging less than 0.1 sack per linear foot of hole. The majority of the holes took little or no grout, however, there were a number of holes that took 20 to 40 sacks (Plates I-C2 and I-C3). It was concluded that the holes which took over 20 sacks indicated the existence of areas which needed to be treated, and detection of these areas was only possible by drilling the entire curtain. Information on water pressure test results was not available during this study, therefore, no comparison can be made of water and grout takes.

Refusal criteria

C22. No refusal criteria were specified or given in the foundation report.

Records

C23. According to the specifications (USACE 1946) "The Contracting Officer will keep records of all grouting operations, such as log of the grout holes, results of washing and pressure testing operations, time, mix, pressure, rate of pumping, amount of cement for each change in water-cement ratio, and other data as deemed by him to be necessary. The Contractor shall furnish all necessary assistance and cooperation to this end."

Unexpected Geological Conditions Encountered During Construction

C24. No major unexpected geological conditions were encountered during construction. Several areas where foundation difficulties were anticipated were explored in greater detail (Para. 3). After exposure and inspection of these areas and evaluation of the additional explorations, design measures were adopted to obtain a satisfactory foundation. There was a significant underrun of grouting quantities, however, no claims resulted.

Evaluation of Grouting

C25. The grouting program for the Allatoona project is considered adequate even by present day standards. The program was well adapted to the geology and project design.

Costs (Drilling Grout Holes and Pressure Grouting)

Government Estimate	$129,164.50
Contractors Bid	130,355.00
Actual	46,917.50 ($15.64/$ft^3$)

NOTE: Does not include drain hole and exploratory drilling.

Performance

C26. The grout curtain performance is considered good. There have been no seepage problems since construction (Jack Bryan, personal communication, 1983).

References

US Army Corps of Engineers. 1941. "Allatoona Dam Definite Project Report," Mobile District, Appendix C - Geology, p. 6.

____________. 1944. "Allatoona Dam Analysis of Design," Mobile District.

____________. 1946. "Allatoona Dam Specifications," Mobile District.

Conn, William V. 1949 (Apr). "Final Foundation Report, Allatoona Dam," Powerhouse and Appurtenant Work. U. S. Army Corps of Engineers, Mobile District, p. 51.

Personal Communication, 1983, Jack Bryan, Chief, F&M Branch, Mobile District.

Table C1

Government Estimate Allatoona Grouting

Item No.	Schedule of Bid Items	Quantities	Unit	Unit Cost	Amount
6	Pressure Grouting, Consolidation	9,000	sack of cement	1.75	15,750.00
7	Pressure Grouting, Curtain	9,000	sack of cement	1.75	15,750.00
8a	Drilling 1-1/2-in. Grout Holes, Consolidation	2,500	lin ft	2.70	6,750.00
8b	Grouting, First Stage Drilling 1-1/2-in. Grout Holes, Consolidation Grouting, Second Stage	4,100	lin ft	3.10	12,710.00
8c	Drilling 1-1/2-in. Grout Holes, Consolidation Grouting, Third and Succeeding Stages	1,000	lin ft	3.96	3,960.00
9a	Drilling 1-1/2-in. Grout Holes, Curtain Grouting, First Stage	5,000	lin ft	3.13	15,650.00
9b	Drilling 1-1/2-in. Grout Holes, Curtain Grouting, Second Stage	6,500	lin ft	3.80	24,700.00
9c	Drilling 1-1/2-in. Grout Holes, Curtain Grouting, Third and Succeeding Stages	6,500	lin ft	4.85	31,525.00
13	3-in. Black Steel Grout Pipe	3,250	lin ft	0.60	1,950.00
14	3-in. Cast Iron Screw Caps	210	ea	1.95	409.50

Table C2

Bid Price Allatoona Grouting

Item No.	Estim. Quan.	Unit	Description	Unit Price	Amount
6	9,000	sack of cement	Pressure Grouting, Consolidation	3.50	31,500.00
7	9,000	sack of cement	Pressure Grouting, Curtain	3.50	31,500.00
8a	2,500	lin ft	Drilling 1-1/2-in. Grout Holes, Consolidation Grouting, First Stage	2.50	6,250.00
8b	4,100	lin ft	Drilling 1-1/2-in. Grout Holes, Consolidation Grouting, Second Stage	2.50	10,250.00
8c	1,000	lin ft	Drilling 1-1/2-in. Grout Holes, Consolidation Grouting, Third and Succeeding Stages	2.50	2,500.00
9a	5,000	lin ft	Drilling 1-1/2-in. Grout Holes, Curtain Grouting, First Stage	2.50	12,500.00
9b	6,500	lin ft	Drilling 1-1/2-in. Grout Holes, Curtain Grouting, Second Stage	2.50	16,250.00
9c	6,500	lin ft	Drilling 1-1/2-in. Grout Holes, Curtain Grouting, Third and Succeeding Stages	2.50	16,250.00
13	3,250	lin ft	3-in. Black Steel Grout Pipe	1.00	3,250.00
14	210	ea	3-in. Cast Iron Screw Caps	.50	105.00

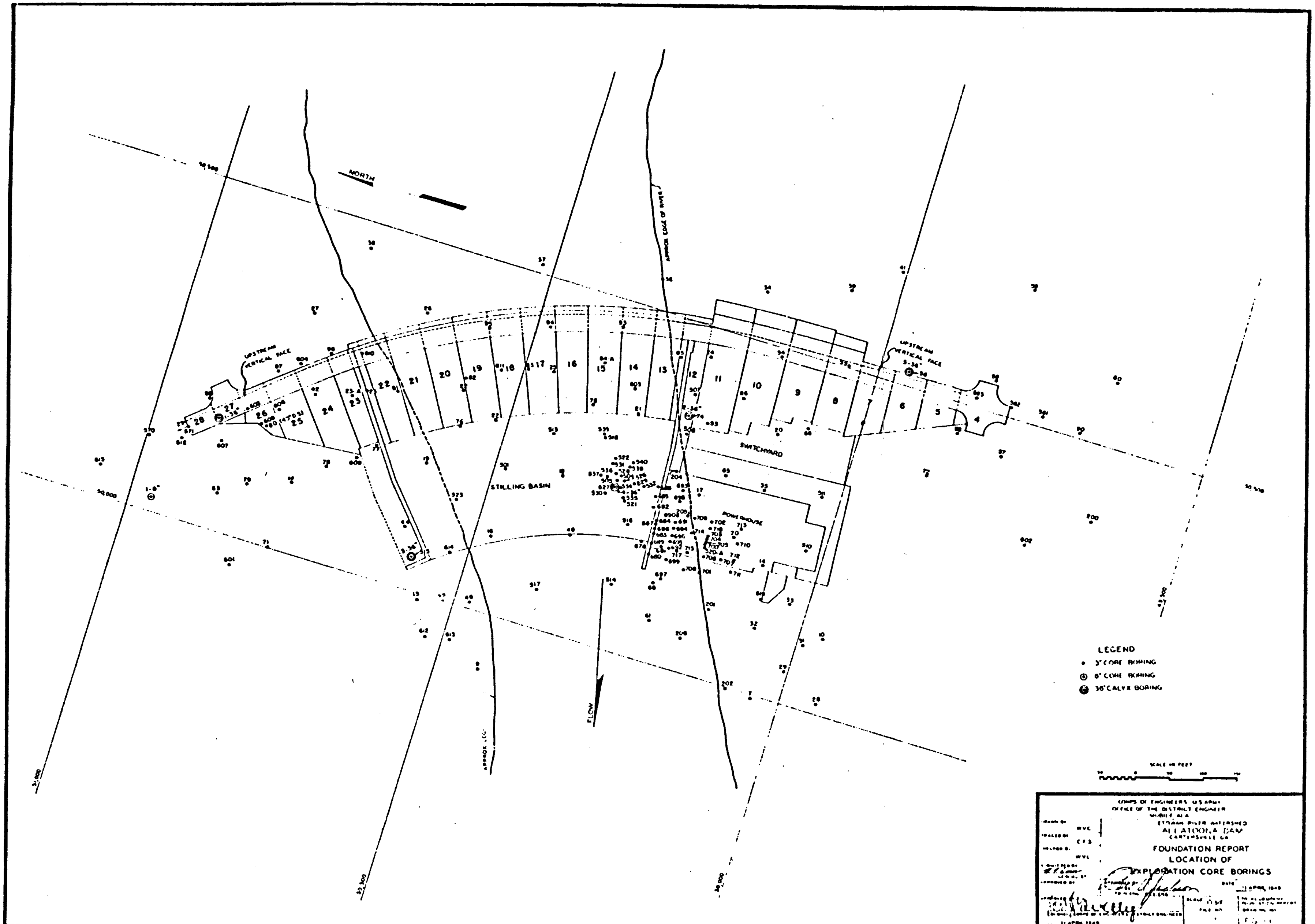

NORTH
UPSTREAM VERTICAL FACE
STILLING BASIN
SWITCHYARD
POWERHOUSE
FLOW
LEGEND
3" CORE BORING
8" CORE BORING
36" CALYX BORING
SCALE IN FEET
FOUNDATION REPORT
LOCATION OF
EXPLORATION CORE BORINGS

PLATE I-C1

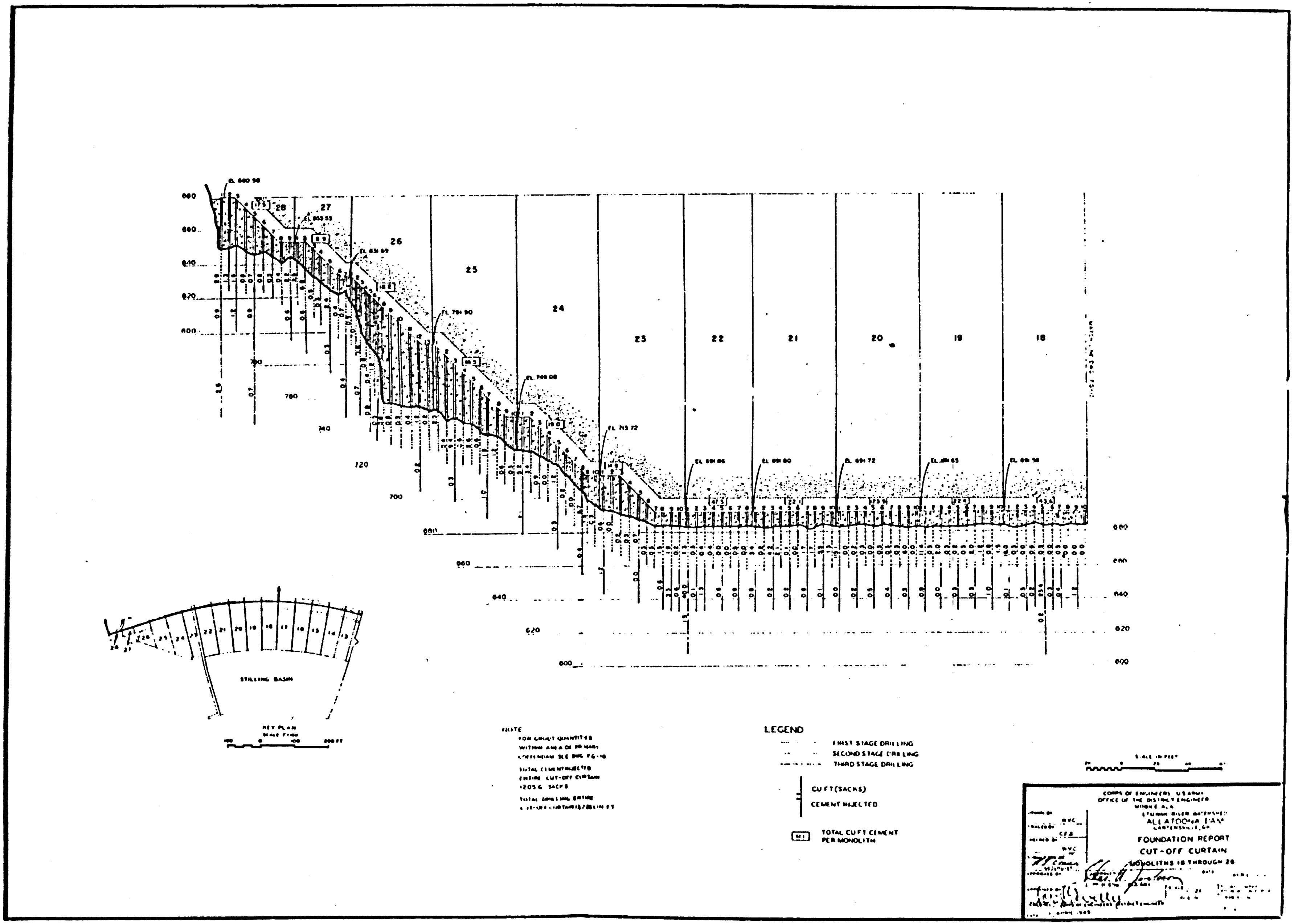

28
27
26
25
24
23
22
21
20
19
18
STILLING BASIN
LEGEND
FIRST STAGE DRILLING
SECOND STAGE DRILLING
THIRD STAGE DRILLING
CU FT (SACKS)
CEMENT INJECTED
TOTAL CU FT CEMENT PER MONOLITH
NOTE
TOTAL CEMENT INJECTED ENTIRE CUT-OFF CURTAIN 12056 SACKS
CORPS OF ENGINEERS U.S. ARMY
OFFICE OF THE DISTRICT ENGINEER
ALLATOONA DAM
FOUNDATION REPORT
CUT-OFF CURTAIN
MONOLITHS 18 THROUGH 28

PLATE I-C2

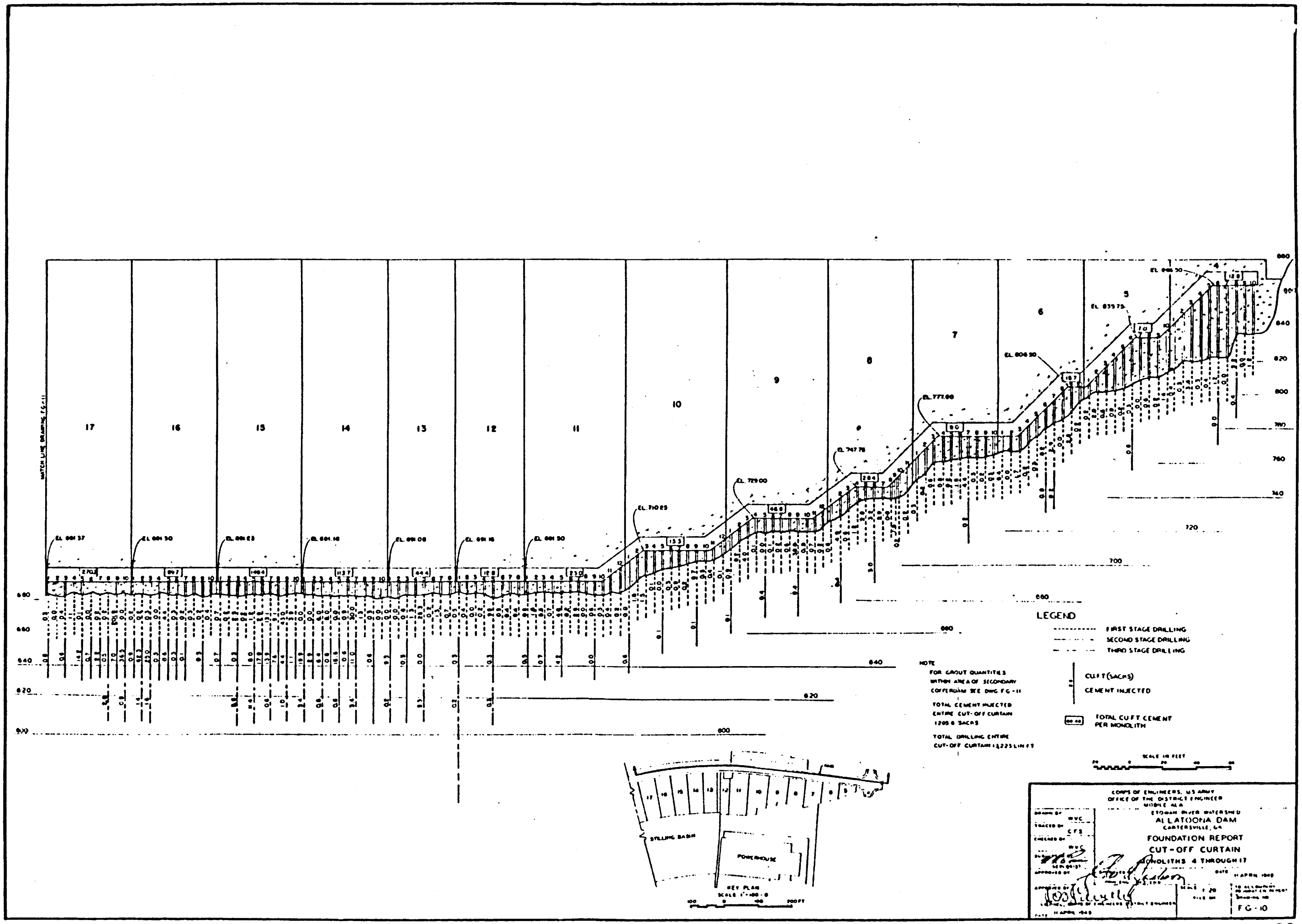

LEGEND
FIRST STAGE DRILLING
SECOND STAGE DRILLING
THIRD STAGE DRILLING
CU FT (SACKS) CEMENT INJECTED
TOTAL CU FT CEMENT PER MONOLITH
NOTE
FOR GROUT QUANTITIES WITHIN AREA OF SECONDARY COFFERDAM SEE DWG FG-11
TOTAL CEMENT INJECTED ENTIRE CUT-OFF CURTAIN 1205.6 SACKS
TOTAL DRILLING ENTIRE CUT-OFF CURTAIN 13225 LIN FT
STILLING BASIN
POWERHOUSE
KEY PLAN
CORPS OF ENGINEERS, US ARMY
OFFICE OF THE DISTRICT ENGINEER
MOBILE ALA
ETOWAH RIVER WATERSHED
ALLATOONA DAM
CARTERSVILLE, GA
FOUNDATION REPORT
CUT-OFF CURTAIN
MONOLITHS 4 THROUGH 17
11 APRIL 1949
FG-10

PLATE I-C3

PROJECT D: HARTWELL DAM

(This case history was developed with the assistance of Earl Titcomb, Savannah District)

Location and Description of Project

D1. The Hartwell Dam is located on the Savannah River Georgia/South Carolina, approximately 100 miles east northeast of Atlanta, Georgia. The dam consists of embankment sections (each approximately 1-1/2 miles long on both the Georgia (southeast) and South Carolina (northwest) sides of the river, and a concrete dam in the river section consisting of a left nonoverflow section, spillway, powerhouse, and right nonoverflow section. It is a multipurpose flood control and power project (Plate I-D1). The dam was designed by the Savannah District and constructed from 1955 to 1960.

Geology

D2. The Hartwell Dam and Reservoir are situated in the Piedmont Physiographic Province. The region is characterized by flat-topped hills and ridges separating wooded slopes which plunge sharply into steep graded tributaries of the main rivers. Rock types in the region are principally schists, gneisses, and granites of Pre-Cambrian age. Regional structure strikes N30°E. The Tugaloo, Seneca and Savannah Rivers cut across the structure, but many of the tributaries follow structural trends. In general, similar rock types exist along the strike of the fold axes while the principal changes of rock types are at right angles to the structure. Few faults have been identified in the area.

D3. The dominant rock type at the damsite is biotite granite gneiss. In its unweathered state it is hard, moderately jointed, and contains a considerable variation in percentage of its major constituents--biotite, quartz and feldspar. No appreciable faulting was recognized in the damsite area prior to construction although slickensided drill cores were recovered, and a shear zone was suspected along the Georgia abutment. Several joint systems have been recognized in the damsite area. The surface outcrops have revealed several systems in which the individual joints could be followed only short distances. Aerial photographs revealed the presence of one strong joint system which had not been readily recognized in the field. A set of joints strikes N80°E and passes through the Georgia abutment of the upper axis and the South Carolina abutment of the lower axis. Another set of joints strikes N60°W and intersects a concentration of the N80°E joints at the Georgia abutment of the upper axis. A deeply weathered zone coincides with the intersection of these two joint concentrations. The deeply weathered zone in the South Carolina abutment of the lower axis lies along the N80°E concentration and may be the result of weathering along these joints. A basalt dike in the river was intruded along one of the N60°W joints. Strike joints or flow cleavages which strike parallel to the banded structure are by far the most plentiful. Numerous other joints striking parallel to the structure and dipping at various angles were also noted. Still another principal set of jointing is near horizontal, approximately parallel to the ground surface (USACE 1951).

Subsurface Investigations

D4. Preconstruction investigations for Hartwell Dam were carried out at three sites to select the most economical site and type of dam. The selected site was investigated in detail with vertical and directional core borings, water pressure testing, and various types of soil borings and tests. Plate I-D2 shows the foundation exploration for the concrete dam contract. Based on water takes during pressure testing of the jointed sound rock, it was concluded that a grout curtain would be necessary. Anticipated grout takes at the time the Definite Project Report (USACE 1951) was published were in the range of 0.25 to 0.5 sacks of cement per foot of grout hole. The grout curtain would extend beneath the concrete dam and the core trench beneath both embankment sections.

Grouting Design

D5. The grout curtain as designed and constructed beneath the embankment sections consisted of a single line with first zone holes on 10-ft centers and second zone holes on 20-ft centers. The first zone was to a depth of 20 ft in rock and the second zone to a depth of 40 ft in rock. The concrete dam contract required embedded pipe for grout holes on 4-ft centers. Grout holes were required on 4-ft centers for the first zone, 8-ft centers for the second zone, and 16-ft centers for the third zone. Depths of the zones were 25, 50 and 75 ft, respectively. Split spacing, stage grouting procedures were required by both contracts, and each grout hole was pressure tested prior to grouting. Consolidation grouting was required in the foundation when it was determined by the Contracting Officer's representative that joints or fractures needed additional treatment. Pipes were installed in the joints or fractures and later extended to the gallery for grouting in conjunction with the grout curtain. Plates I-D3 and I-D4 show details of grouting design.

Contractual Considerations

Contracts

D6. Two separate contracts were used for construction of the Hartwell Dam, one for the embankment sections and one for the concrete dam. Grouting was included in both contracts. The project was designed and constructed under the supervision of Savannah District, USACE, Savannah, Ga. The grout curtain was designed by Messrs. R. L. Wilson and L. E. Jackson. Mr. Ross Wylie was resident engineer during construction of earth embankments, including cutoff trench and grout curtain. Mr. Charles A. Jackson was resident engineer during construction of the remaining works, including the concrete dam. Mr. Lawson E. Jackson was the project geologist in charge of foundation work including grouting during the construction of the concrete dam. The general contractor for the earth embankments was Mr. M. R. Thomason. Mr. John Thomason was the project manager. The subcontractor for drilling and grouting was Cunningham Core Drilling and Grouting Corporation, Mr. Howard Rimer, Foreman. Inspection of foundation treatment was done by Mr. John LeRoy and Mr. Hugh Montgomery. The general contractor for the concrete dam and appurtenant works was Hartwell Dam Contractors, a combination of Guy F. Atkinson Company, Ostrander Construction Company, and Soo Contractors, Inc. Mr. Roy Atkinson, Jr., was project manager during the initial stage of construction, and succeeded by Vernon R. Bradley. Subcontractor for drilling and grouting was Continental Drilling Company, Mr. Leo Broadrick, Foreman.

Specification drilling and grouting requirements

D7. The specifications for both contracts allowed either percussion or rotary drills for grout holes and required the holes to have a minimum 1-3/8-in. diam at the point of maximum penetration. The type of bit was optional. The concrete dam contract specified embedded pipe for grout and drain holes but allowed the option of drilling through the concrete.

D8. The split spacing, stage grouting method was required by both contracts. Grout holes were required to be thoroughly washed under pressure and pressure tested immediately prior to grouting. Grouting pressures, procedures, and mixtures were to be as directed. The specified range of water cement ratios was from 3 to 0.6 in both contracts and the anticipated range of grouting pressures was given as from 10 to 100 psi. A circulating grout system was required.

D9. Equipment specified in both contracts included mechanical mixer and sump, two air driven slush pumps and valves, gages, pressure hoses, tools and accessories as may be necessary.

D10. Bid items were not subdivided and exempted from variations in estimated quantities provisions by a special provisions paragraph, but the technical provisions contained the following: "The Government reserves the right to increase by as much as 100 percent or to eliminate any part of the entire drilling and grouting program should conditions indicate this as being desirable, and the contractor will not be allowed any increase in the unit prices bid in the schedule for drilling and grouting by reason of any changes in the amount of work or materials actually involved" (USACE 1956 and USACE 1955). A separate bid item was included in both contracts for mobilization and demobilization for drilling and grouting.

D11. Estimated quantities for drilling and grouting are shown in Tables D-1 and D-2. For the concrete dam contract, Portland cement in grout was an undetermined part of the total quantity of Portland cement for the dam. For this study, it is assumed that the estimated quantity of Portland cement in grout was 12,600 cu ft, equal to that shown for item 18, Pressure Grouting. Estimated drilling quantity for this contract was 20,000 lin ft. Estimated quantities for drilling and grouting for the embankment contract were 12,400 lin ft and 7,000 cu ft, respectively. Actual quantities were as follows:

Embankment contract:	drilling -- 6,458 lin ft; grouting 791.1 cu ft
Concrete dam contract:	drilling -- 22,969 lin ft; grouting 4,221 cu ft
TOTAL:	drilling -- 29,427 lin ft; grouting 5,012.1 cu ft

As can be seen, drilling quantities were slightly over the estimate, but actual grouting quantities were only 26 percent of the estimate. There were no claims or adjustments to contract unit prices for grouting.

Contract management

D12. No contract management or administration problems were revealed during this study; however, insufficient data were available to make an assessment. Government/Contractor field and management relations relative to grouting were reported to be very good during the concrete dam contract (personal communication, Mr. Lawson E. Jackson, 13 May 1983).

Drilling and Grouting Methods

D13. The following is taken directly from the Hartwell Dam Foundation Report (USACE 1960). See Tables D-3 through D-5 for as-built quantities of the grouting at Hartwell Dam.

Consolidation grouting

D14. During the course of foundation preparation, cracks or crevices were sometimes noted which prompted additional treatment. Often, where the condition was not conducive to being corrected or improved by further removal, it was deemed advisable to provide for future grouting of these areas. Therefore, pipe was installed in these fissures or crevices and brought up above that placement and later extended to the gallery. With the exception of those in monolith 8, which were 16-in. pipe, later reduced to 1 in., the pipe was 1 in. In monolith 24 in addition to the pipe installed in a seam, two holes were drilled with a wagon drill from the final surface of the foundation to intersect the seam away from the cut, with pipe then being run from the drill hole to the inspection gallery. Those were later grouted in conjunction with the cutoff curtain at comparable pressures and mixtures. Generally, two pipes were installed as a unit in a local area to provide for relief and to serve as a telltale in the event that grout return was noted flowing from one while grouting the other. In that event the return pipe was capped and grouting proceeded to refusal. Only a limited number of these were required. Also included in the tables is a summary of grout quantities for consolidation grouting. It is noted that the grout take, generally, for these holes are relatively small and in some instances, as in monolith 24, there was no take. As the curtain grouting was done first it is quite probable that in these instances, these areas were grouted with the curtain grouting. This would appear to be true especially for monolith 24 as the area to be treated was relatively low and the attitude of the seam was such that the grout curtain beneath the gallery would intersect this zone, as extended, at depth.

Curtain grouting - cutoff
trench, previous contract

D15. The plans and specifications for the earth embankment provided for excavation of a cutoff trench into firm rock with a grout curtain to be grouted from this elevation, prior to placement of impervious backfill. Since this was done prior to the writers' presence, only a brief discussion is included herein. It was thought, however, that the inclusion of a profile and summary of grout quantities, which are included in this report, would be desirable in completing the overall picture of the grout curtain. On the Georgia embankment, the cutoff trench extended on embankment stations from Station 93+00 to Station 111+10 and on the South Carolina embankment from Station 132+00 to Station 136+10. The grout pattern consisted generally of first zone holes on 10-ft centers and second zone holes on 20-ft centers. The first zone was to a depth of 20 ft in rock and the second zone to a depth of 40 ft in rock. The split spacing, stage grouting method was used and, where it was deemed desirable, additional holes, including angle holes were used. Some holes were carried to a greater depth as a check. The exploratory holes were grouted for full depth in one operation during regular grouting. Pressures varied according to field conditions but generally were 25 psi in the first zone and 40 psi in the second zone. Drilling was done with Air-Trac Gardner-Denver percussion drills. Mixtures varied according to conditions, and surface breakouts were at times profuse requiring caulking and packer grouting.

Curtain grouting, concrete dam

D16. The plans and specifications called for a grout curtain under the concrete dam to be drilled and grouted from the inspection gallery, and generally for the holes to be on 4-ft centers for first zone, 8-ft centers for second zone, and 16-ft centers for third zone. It was anticipated that the depths in rock for each zone would be 25, 50, and 75 ft, respectively, for first, second, and third zones. This proposed pattern was suggested as a result of studies made of core and pressure testing during the exploration phases. As the contractor elected to install pipe from the foundation up to the gallery floor, it was necessary to firmly establish the spacing of the proposed holes in the relatively early stages of construction. After inspection of the final foundation, it was decided that the proposed spacing generally suited the foundation conditions and pipe was installed at 4-ft centers for future grouting. It was recognized that the numerous steeply dipping joints cutting nearly perpendicular across the axis of the dam could possibly provide passage for the water under the dam. It is believed, however, that this grouting pattern was effective in intercepting these joint planes, due to the relative close spacing and the angle of the grout holes. In most instances they were angled upstream 15 deg from the vertical and were normal to the axis of the dam. Since no joints were exactly normal to the axis of the dam, the attitude of the holes should be conducive to interception of the zones. Close observations were made in this vicinity after final preparation of the foundation and after installation of the pipe to check the effectiveness of the pipe in relation to the features of the foundation. In a few instances, one or more lifts of concrete were placed and then the pipe installed in concrete up to the gallery floor. This condition was generally restricted to areas of relatively steep slopes with the gallery floor several feet above the foundation.

D17. Holes were drilled following the split spacing method and stage grouting procedures used. Within any zone, when there was a marked water loss or flow, drilling was stopped and that hole grouted to refusal before completing that zone. Both water loss and flow were encountered, and often the flow, when encountered, was of moderate proportions. This was especially true in the river section after closure. Moreover, along a given section these holes within that series would show a connection to other holes. The holes on 16-ft centers or first series were first drilled and grouted to 25 ft, followed by those on 8-ft centers or second series, then by those on 4-ft centers or third series, thereby completing first zone grouting. The first series holes were then drilled and grouted to 50 ft, followed by second series holes to 50 ft. Then the first series was advanced to 75 ft and grouted, thus completing the grouting for that section. The same general procedure was used throughout the grouting program. In certain areas of high grout take adjacent holes were deepened to check the hole of high take and a few holes were drilled to a depth of 100 ft. Pressures used generally conformed to the rule of thumb of 1 lb for each foot of hole although some variance in this method occurred when conditions indicated higher or lower pressure was desirable.

Mixtures varied from a water cement ratio of 4:1 to 0.6:1. It was found that a mixture of 3:1 generally was adequate and better results were obtained by use of this mixture. If the hole started taking considerable quantities, the mixture was thickened by degrees, until refusal was met. Occasionally this resulted in a mixture of 0.6:1. In certain sections of the South Carolina abutment a mixture of 4:1 was used quite effectively.

D18. The contractor entered this phase of the construction in May 1959 and completed the program in March 1960. Concrete had reached full height, or nearly so, in each section prior to pressure grouting. Grout holes were drilled with pneumatic rotary drills. Early in the program holes were drilled with plug bits and coring bits to determine the one best suited for conditions at the site. The decision based on this study indicated to the contractor that the coring bits were more satisfactory and economical, so practically the entire drilling was accomplished by use of coring bits. The drilling, pressure testing, and grouting were done in accordance with the plans and specifications.

D19. After grouting the first section to full depth on 4-ft centers, it was decided to follow this pattern for the entire length of the curtain to insure against leakage through any of the joints. In retrospect, this spacing in the South Carolina abutment would appear to reflect an extremely conservative procedure; however, the proof of the effective foundation conditions, as regards leakage, is reflected by the grout take, necessarily requiring the drilling and grouting of each hole.

D20. The split spacing method proved effective in a gradual buildup of each zone as, generally, the highest take was realized in the first series, followed by second and third. This was especially true in those areas, usually in the river section, where apparent sheet joints occurred, thereby offering a path for the grout along the axis, often resulting in grout return to the gallery through an adjacent hole in this series.

D21. The abutments and certain sections of the river generally had a higher grout take in the first zone, followed by less in the second and third zones. This would appear to be normal and is about as was anticipated in the planning. However, certain sections in the river appeared to be remarkably tight in the first zone, with increased take in the second or even third zone. Quite a number of these holes would show a connection to other holes in that series marked by grout return in the gallery. These holes were capped, after grout of the same consistency of that being pumped emerged, and the hole grouted to refusal. Then the hole that had showed the return was grouted and so on until the section had been grouted completely. This would indicate some relatively deep lying sheet joints or other structural features of rather extensive areal proportions. Although core was not required, and no effort made to keep it in order, observation of the broken pieces would at times reveal quartz lenses or stringers of moderate proportions, but generally fresh and hard. It is possible that these lenses or stringers, and perhaps even other structures, are a reflection on a gross scale of the foliated gnessic rock, following the general trend of the local banding, along which some parting has taken place, providing avenues of leakage. Several of these were observed on the foundation surface in various stages of weathering, generally following the structure and generally dipping in an upstream direction. The special pipe for grouting in monolith 17 was placed in a fissure associated with this type structural characteristic. Another observation noted suggested that the grout usually followed smooth well defined planes, such as distinct joint planes, more readily than it did through zones of weathering. Although holes drilled in weathered rock were at a minimum, the condition did exist at certain localities. Monolith 6 had some slightly weathered rock associated with a joint, but the grout take was not as high as expected for such a condition.

D22. A portion of the cutoff trench under the Georgia embankment and the South Carolina embankment were included in this contract and drilled and grouted by same methods and procedures as described above. A summary of grout quantities for grouting under this contract is shown in Tables D-3 through D-5. Those quantities for the cutoff trenches are only for the main dam contract. The sheets show the grout take by zones and by series with totals for both. The first series refers to holes drilled on 16-ft centers (those grouted first for any zone), the second series for those drilled on 8-ft centers (those grouted second for any zone), and the third series for those drilled on 4-ft centers (those grouted last for any zone). Also included is a summary sheet showing total quantities for drilling and grouting for the entire job (Table D-5).

Drain holes

D23. Relief of uplift under the foundation caused by seepage of water from upstream was provided for by 3-in. drain holes on 12-ft centers drilled

30 ft into the rock. Due to the impervious nature of this rock type, it would appear that seepage would be restricted to those areas along joints or cracks and therefore this pattern was deemed adequate. The drain holes are downstream of the grout curtain, angled 15 deg from the vertical in a downstream direction, normal to the axis of the dam. These holes were drilled through pipe set in the concrete by pneumatic rotary drills with a coring bit.

D24. Several of the holes when drilled had a small flow of water from them. These occurred generally in the low areas adjacent to the abutments and in areas of the river section. Most of these were thought to be ground water from the relatively higher abutment sections above them, and no increase in flow was noted during April 1960 when the reservoir level increased from 521.6 to 546.6. Some of the river holes did show an increase however during this same period. No real study can be made until water is stored to project level. The effectiveness of the grout curtain at this time, however, can be demonstrated in that water flow from the drain holes in the river section, drilled after grouting, at the approximate location of grout holes which showed moderate flow, is, when present, only a fraction of that noted in the grout holes.

Unexpected Geological Conditions Encountered During Construction

D25. No major adverse unexpected conditions were encountered during construction. The underrun of placing grout quantities did not result in a claim or price adjustment.

Evaluation of Grouting

D26. Little data were available during this study on grouting beneath the embankment. The grouting for the concrete dam is considered adequate. The program was well adapted to the geology and project design.

Costs (Drilling and Grouting)

D27. Cost data were not available to this study, except for the bid prices shown on Table D-1. Since there were no claims, these data were used, along with actual quantities for drilling and grouting for analyzing grouting costs for the embankment contract (Part IV). Summary of costs are as follows: Contractors Bid--$61,236; Actual--$23,664.

Performance

D28. No data were available to evaluate post construction performance.

References

US Army Corps of Engineers. 1951. Appendix III, Geology, Definite Project Report, Hartwell Reservoir, Savannah District.

____________. 1955. Technical Provisions for Foundation Drilling and Grouting, Hartwell Dam Earth Embankment, Savannah District.

____________. 1956. Plans and Contract Technical Provisions for Foundation Drilling and Grouting, Hartwell Concrete Dam, Savannah District.

____________. 1960. Foundation Report, Hartwell Dam, Chapters IX, X, and XI, w/Plates, Savannah District.

Personal communication, 1983, Lawson E. Jackson, Division Geologist, Southwestern Division.

Table D1

Estimated Drilling and Grouting Quantities - Earth Embankments

Hartwell Dam

Description	Estimated Quantity	Unit	Unit Price	Estimated Amount
Mobilization and Demobilization for Drilling and Grouting	job	lump sum		$ 1,700.00
Drilling Grout Holes	12,400	lin ft	$2.30	$28,520.00
Pipe for Grout Holes	2,700	lb.	$0.58	$ 1,566.00
Portland Cement in Grout	7,000	cu ft	$1.55	$10,850.00
Placing Grout	7,000	cu ft	$2.30	$16,100.00
Connections to Grout Holes	500	ea.	$5.00	$ 2,500.00

Table D2

Estimated Quantities for Drilling and Grouting

Hartwell Concrete Dam

Description	Estimated Quantity	Unit	Unit Price	Estimated Amount
Mobilization and Demobilization for Drilling and Grouting	job	lump sum		
Pressure Grouting	12,600	cu ft		
Connection to Grout Holes	525	ea.	$5.00	$2,625.00
Drilling EX (1-1/2 in.) Grout Holes	20,000	lin ft		

Table D3

Consolidation Grouting

Summary of Grout Quantities

Hole No.	Location	Bags
SP8-1	Monolith 8	1.5
SP8-2	Monolith 8	55.0
SP8-3	Monolith 8	0.3
SP10-1	Monolith 10	0.0
SP10-2	Monolith 10	0.0
SP15-1	Monolith 15	0.1
SP15-2	Monolith 15	7.3
SP17-1	Monolith 17	2.4
SP17-2	Monolith 17	0.4
SP24-D2	Monolith 24	0.0
SP24-D1	Monolith 24	0.0
SP24-1	Monolith 24	0.0
SP24-2	Monolith 24	0.0

TOTAL CONSOLIDATION GROUTING - 67.0 Bags

Table D4

Pressure Grouting - Cutoff Curtain

Summary of Grout Quantities

Location	Zone	Bags by Series			Bags by Zones
		1	2	3	
Georgia	1	29.0	36.1	2.0	67.1
Cutoff	2	8.0	39.0		47.0
Trench	3	5.6			5.6
	Total	42.6	75.1	2.0	119.7
Monolith 1	1			6.8	6.8
	2		1.9		1.9
	3	0.3			0.3
	Total	0.3	1.9	6.8	9.0
Monolith 3	1	20.0	0.9	3.0	23.9
	2	2.0	1.1		3.1
	3	3.8			3.8
	Total	25.8	2.0	3.0	30.8
Monolith 4	1	8.9	0.2	2.3	11.4
	2	0.3	0.6		0.9
	3	0.7			0.7
	Total	9.9	0.8	2.3	13.0
Monolith 5	1	14.5	0.0	4.6	19.1
	2	0.3	0.7		1.0
	3	0.4			0.4
	Total	15.2	0.7	4.6	20.5
Monolith 6	1	6.2	9.5	6.4	22.1
	2	2.0	0.5		2.5
	3	0.5			0.5
	Total	8.7	10.0	6.4	25.1
Monolith 7	1	3.4	1.4	9.0	13.8
	2	15.3	4.4		19.7
	3	16.0			16.0
	Total	34.7	5.8	9.0	49.5
Monolith 8	1	2.4	2.6	2.5	7.5
	2	3.6	10.8		14.4
	3	0.3			0.3
	Total	6.3	13.4	2.5	22.2

(Continued)

Table D4 (Continued)

Location	Zone	Bags by Series			Bags by Zones
Monolith 9	1	22.2	9.0	6.2	37.4
	2	39.8	6.1		45.9
	3	70.2			70.2
	Total	132.2	15.1	6.2	153.5
Monolith 10	1	38.8	2.5	6.5	47.8
	2	21.9	29.2		51.1
	3	112.0			112.0
	Total	172.7	31.7	6.5	210.9
Monolith 11	1	45.2	3.5	1.3	50.0
	2	34.6	1.6		36.2
	3	4.9	0.2		5.1
	4	0.5			0.5
	Total	85.2	5.3	1.3	91.8
Monolith 12	1	50.0	1.2	2.2	53.4
	2	82.8	2.4		85.2
	3	54.8	1.7		56.5
	4	4.0			4.0
	Total	191.6	5.3	2.2	199.1
Monolith 13	1	28.3	0.8	1.5	30.6
	2	15.6	7.6		23.2
	3	13.2	1.2		14.4
	Total	57.1	9.6	1.5	68.2
Monolith 14	1	63.7	35.8	3.0	102.5
	2	61.9	27.0		88.9
	3	33.1			33.1
	Total	158.7	62.8	3.0	224.5
Monolith 15	1	41.3	37.9	75.3	154.5
	2	0.9	1.0		1.9
	3	0.9			0.9
	Total	43.1	38.9	75.3	157.3
Monolith 16	1	014	0.2	0.3	0.9
	2	175.0	2.2		177.2
	3	0.7			0.7
	Total	176.1	2.4	0.3	178.8

(Continued)

Table D4 (Continued)

Location	Zone	Bags by Series			Bags by Zones
Monolith 17	1	44.0	4.8	142.6	191.4
	2	94.7	49.4		144.1
	3	91.3			91.3
	Total	230.0	54.2	142.6	426.8
Monolith 18	1	3.0	1.2	1.5	5.7
	2	52.3	3.8		56.1
	3	1.0			1.0
	Total	56.3	5.0	1.5	62.8
Monolith 19	1	0.6	0.0	0.2	0.8
	2	53.3	3.9		57.2
	3	4.1			4.1
	Total	58.0	3.9	0.2	62.1
Monolith 20	1	0.4	39.0	1.3	40.7
	2	55.5	6.5		62.0
	3	15.3			15.3
	Total	71.2	45.5	1.3	118.0
Monolith 21	1	8.0	5.4	20.0	33.4
	2	26.5	4.3		30.8
	3	1.5			1.5
	Total	36.0	9.7	20.0	65.7
Monolith 22	1	168.7	25.3	15.4	209.4
	2	109.0	55.1		164.1
	3	150.1			150.1
	4	1.2			1.2
	Total	429.0	80.4	15.4	524.8
Monolith 23	1	15.6	1.3	3.6	20.5
	2	107.7	36.6		144.3
	3	13.6			13.6
	Total	136.9	37.9	3.6	178.4
Monolith 24	1	1.9	7.9	1.9	11.7
	2	128.3	5.8		134.1
	3	172.6			172.6
	Total	302.8	13.7	1.9	318.4
Monolith 25	1	10.8	0.9	1.6	13.3
	2	73.3	2.6		75.9
	3	5.5			5.5
	Total	89.6	3.5	1.6	94.7

(Continued)

Table D4 (Continued)

Location	Zone	Bags by Series			Bags by Zones
Monolith 26	1	0.3	0.5	1.6	2.4
	2	77.3	1.3		78.6
	3	214.6			214.6
	Total	292.2	1.8	1.6	295.6
Monolith 27	1	10.8	5.8	2.5	19.1
	2	160.0	0.8		160.8
	3	43.5			43.5
	Total	214.3	6.6	2.5	223.4
Monolith 28	1	6.4	0.9	3.8	11.1
	2	1.0	0.8		1.8
	3	1.2			1.2
	Total	8.6	1.7	3.8	14.1
Monolith 29	1	4.5	2.0	1.6	8.1
	2	4.0	1.0		5.0
	3	8.6			8.6
	Total	17.1	3.0	1.6	21.7
Monolith 30	1	25.0	0.0	6.1	31.1
	2	1.9	6.0		7.9
	3	31.3			31.3
	Total	58.2	6.0	6.1	70.3
Monolith 31	1	13.3	2.4	0.6	16.3
	2	0.7	1.2		1.9
	3	0.2			0.2
	Total	14.2	3.6	0.6	18.4
Monolith 32	1	1.7	0.6	0.6	2.9
	2	0.2	0.0		0.2
	3	0.3			0.3
	Total	2.2	0.6	0.6	3.4
Monolith 33	1	0.0	0.0	0.6	0.6
	2	0.0	0.4		0.4
	3	0.1			0.1
	Total	0.1	0.4	0.6	1.1
Monolith 34	1	0.0	0.1	0.4	0.5
	2	0.0	0.4		0.4
	3	1.0			1.0
	Total	1.0	0.5	0.4	1.9

(Continued)

Table D4 (Concluded)

Location	Zone	Bags by Series			Bags by Zones
Monolith 35	1	0.0	0.0	0.9	0.9
	2	0.0	0.2		0.2
	3	0.1	0.2	0.9	1.2
	Total	0.1	0.2	0.9	1.2
Monolith 36	1	0.0	0.0	0.1	0.1
	2	0.2	0.2		0.4
	3	0.1			0.1
	Total	0.3	0.2	0.1	0.6
Monolith 37	1	0.0	0.3	0.9	1.2
	2	7.1	0.8		7.9
	3	1.5			1.5
	Total	8.6	1.1	0.9	10.6
Monolith 38	1	0.0	0.0	0.0	0.0
	2	0.3	0.4		0.7
	3	0.1			0.1
	Total	0.4	0.4		0.8
Monolith 39	1	0.0	0.0	0.0	0.0
	2	0.0	0.1		0.1
	3	0.1			0.1
	Total	0.1	0.1	0.0	0.2
Monolith 40	1	0.1	0.5	0.2	0.8
	2	0.4	0.3		0.7
	3	0.0			0.0
	Total	0.5	0.8	0.2	1.5
South Carolina Cutoff Trench	1	0.7	12.0	0.3	13.0
	2	1.0	1.0		2.0
	3	0.0			0.0
	Total	1.7	13.0	0.3	15.1

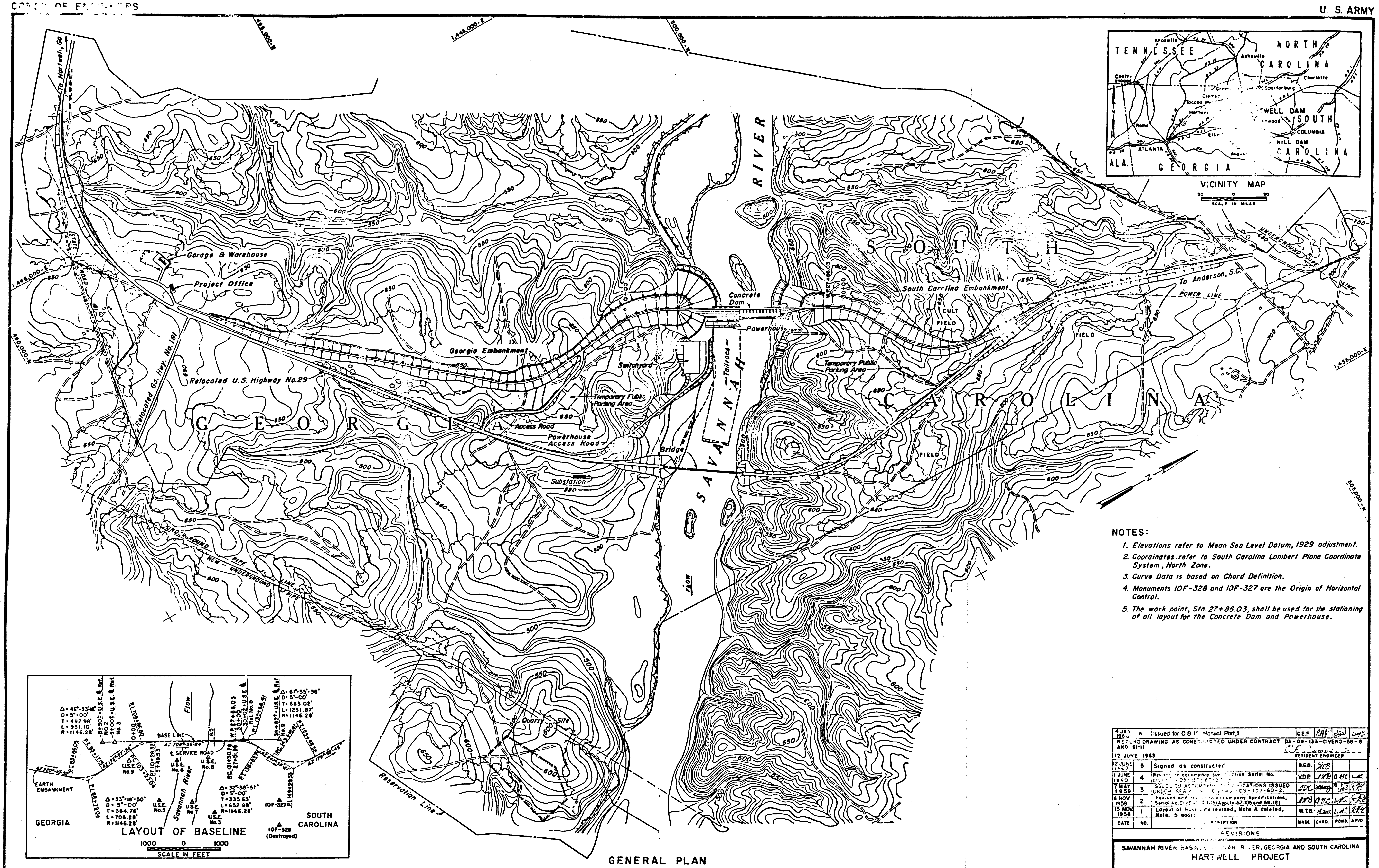
Table D5

Summary of Drilling and Grouting - Totals

(Exclusive of Consolidation Grouting)

Description	Ft Drilled	Bags	Bags/Lin Ft of Hole
Georgia Embankment (Previous Contract)	5,270.0	664.6	0.126
South Carolina Embankment (Previous Contract)	1,188.0	124.5	0.106
SUBTOTAL	6,458.0	791.1	0.123
Concrete Dam & Cutoff Trench	22,969.0	4,105.4	0.179
Backfill	--	115.6	--
SUBTOTAL	22,969.0	4,221.0	0.179
TOTAL (Complete Curtain Grouting)	29,427.0	5,012.1	0.166*

* Exclusive of Backfill



NOTES:

1. *Elevations refer to Mean Sea Level Datum, 1929 adjustment.*
2. *Coordinates refer to South Carolina Lambert Plane Coordinate System, North Zone.*
3. *Curve Data is based on Chord Definition.*
4. *Monuments IOF-328 and IOF-327 are the Origin of Horizontal Control.*
5. *The work point, Sta. 27+86.03, shall be used for the stationing of all layout for the Concrete Dam and Powerhouse.*

COORDINATES			
STATION	NORTH	EAST	REMARKS
℄ 0+00	497,544.30	1,449,407.28	℄ 8.5' up str. of ℄ of ser. rd.
℄ 30+00	500,169.68	1,450,858.96	do
P.I. 88+79.03	495,850.87	1,449,710.70	
P.I. 106+86.80	497,701.99	1,449,503.91	
P.I. 135+66.41	500,242.25	1,450,908.80	
P.I. 149+99.53	500,932.81	1,452,185.39	

COORDINATES			
MON.	NORTH	EAST	ELEV.
U.S.E. No. 3	498,565.23	1,452,177.30	
U.S.E. No. 5	497,396.71	1,451,116.52	481.04
U.S.E. No. 6	498,367.96	1,450,403.58	485.68
U.S.E. No. 7	498,159.58	1,451,606.37	481.87
U.S.E. No. 8	499,144.10	1,450,752.42	483.21
U.S.E. No. 9	497,210.17	1,449,772.40	648.87
IOF-327	500,255.42	1,452,752.88	
IOF-328	499,937.06	1,453,346.28	(Destroyed)

RECORD DRAWING AS CONSTRUCTED UNDER CONTRACT DA-09-133-CIVENG-58-5 AND 61-11
12 JUNE 1963 — RESIDENT ENGINEER

DATE	NO.	DESCRIPTION	MADE	CHKD.	RCMD.	APVD.
4 JAN 196[illegible]	6	Issued for O & M Manual Part, I	C.E.F.			
12 JUNE 1963	5	Signed as constructed.	B.G.D.			
1 JUNE 1960	4	Revised to accompany specification Serial No. [illegible]	V.D.P.			
7 MAY 1959	3	ISSUED TO ACCOMPANY SPECIFICATIONS ISSUED UNDER SERIAL NO. [illegible]-60-2.				
6 NOV. 1958	2	Revised and issued to accompany Specifications, Serial No. [illegible] Appl'n 57-105 and 59-18)				
15 NOV. 1956	1	Layout of Base Line revised, Note A deleted, Note 5 added	W.T.B.			

REVISIONS

SAVANNAH RIVER BASIN, SAVANNAH RIVER, GEORGIA AND SOUTH CAROLINA

HARTWELL PROJECT

PROJECT LOCATION AND SITE MAP

SCALE: AS SHOWN

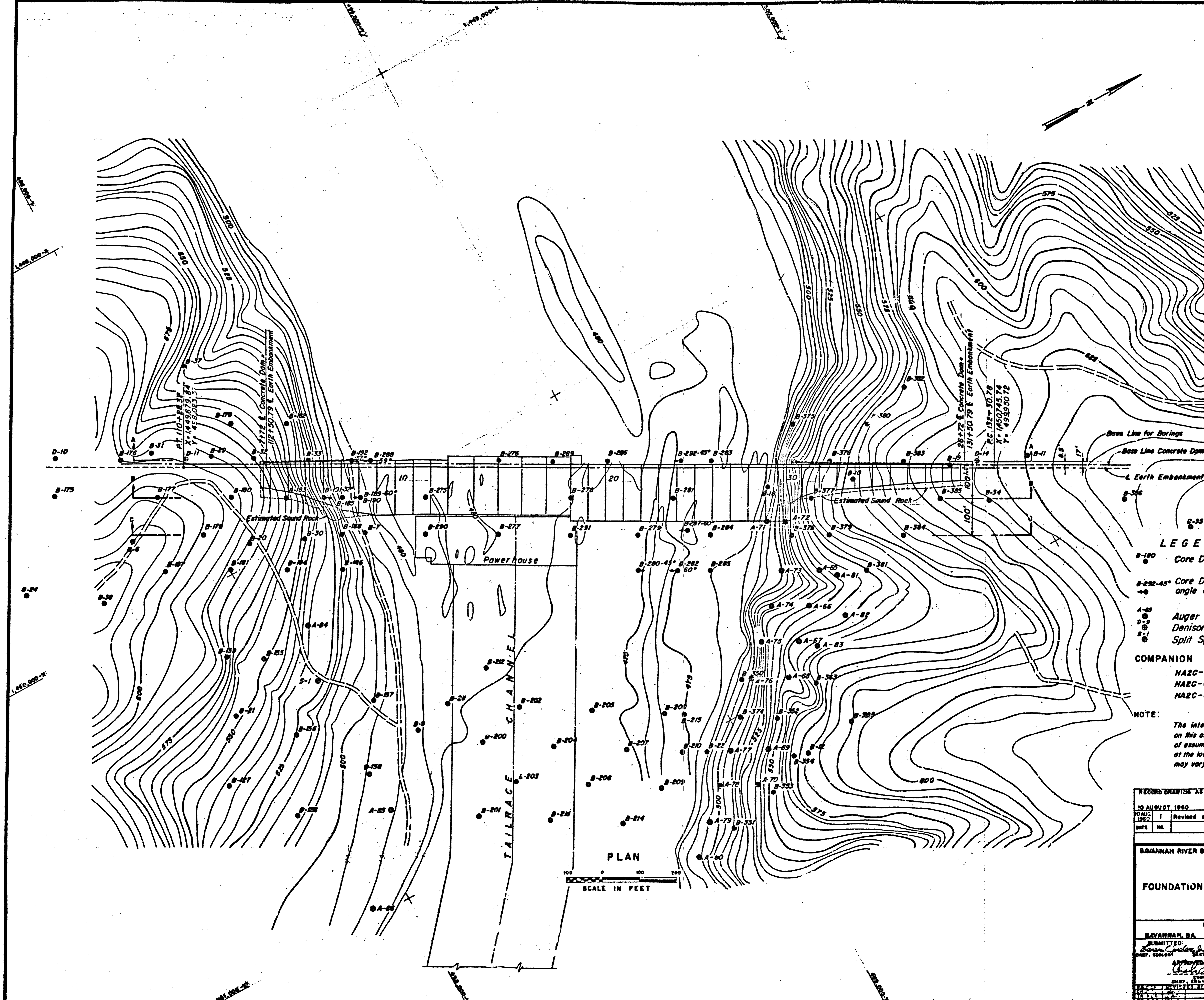
CORPS OF ENGINEERS, U.S. ARMY
SAVANNAH DISTRICT
SAVANNAH, GA. 15 OCTOBER 1956

SUBMITTED: CHIEF, STRUCTURAL SECTION
APPROVAL RECOMMENDED: CHIEF, DESIGN BRANCH
APPROVED: ENGINEER, CHIEF, ENGINEERING DIVISION
APPROVED: COL., CORPS OF ENGINEERS, DISTRICT ENGINEER

DR. / CH. / TR. / CH. — REVIEWED BY

TO ACCOMPANY SPECIFICATIONS ISSUED UNDER SERIAL NO. CIVENG 09-133-57-105

FILE NO. HA2C-022.6



LEGEND

- B-190 Core Drill Hole (Vertical)
- B-292-45° Core Drill Hole including direction and angle of hole. Degrees with vertical.
- A-65 Auger Borings
- D-9 Denison Drill Hole
- S-1 Split Spoon Penetration

COMPANION DRAWINGS:

HA2C-026
HA2C-027
HA2C-028

NOTE:

The interpretations of subsurface conditions as contained on this and companion drawings listed above are diagrams of assumed geologic conditions as determined from borings at the locations indicated, and rock profiles and composition may vary locally between borings from that shown.

RECORD DRAWING AS CONSTRUCTED UNDER CONTRACT DA-09-133-CIVENG-58-8
RESIDENT ENGINEER
10 AUGUST 1960

DATE	NO.	DESCRIPTION	MADE	CHKD.	RCMD.	APVD
10 AUG. 1960	1	Revised as constructed				

REVISIONS

SAVANNAH RIVER BASIN, SAVANNAH RIVER, GEORGIA AND SOUTH CAROLINA

HARTWELL PROJECT
CONCRETE DAM

FOUNDATION EXPLORATION-PLAN AND SECTIONS
SHEET 1 OF 4

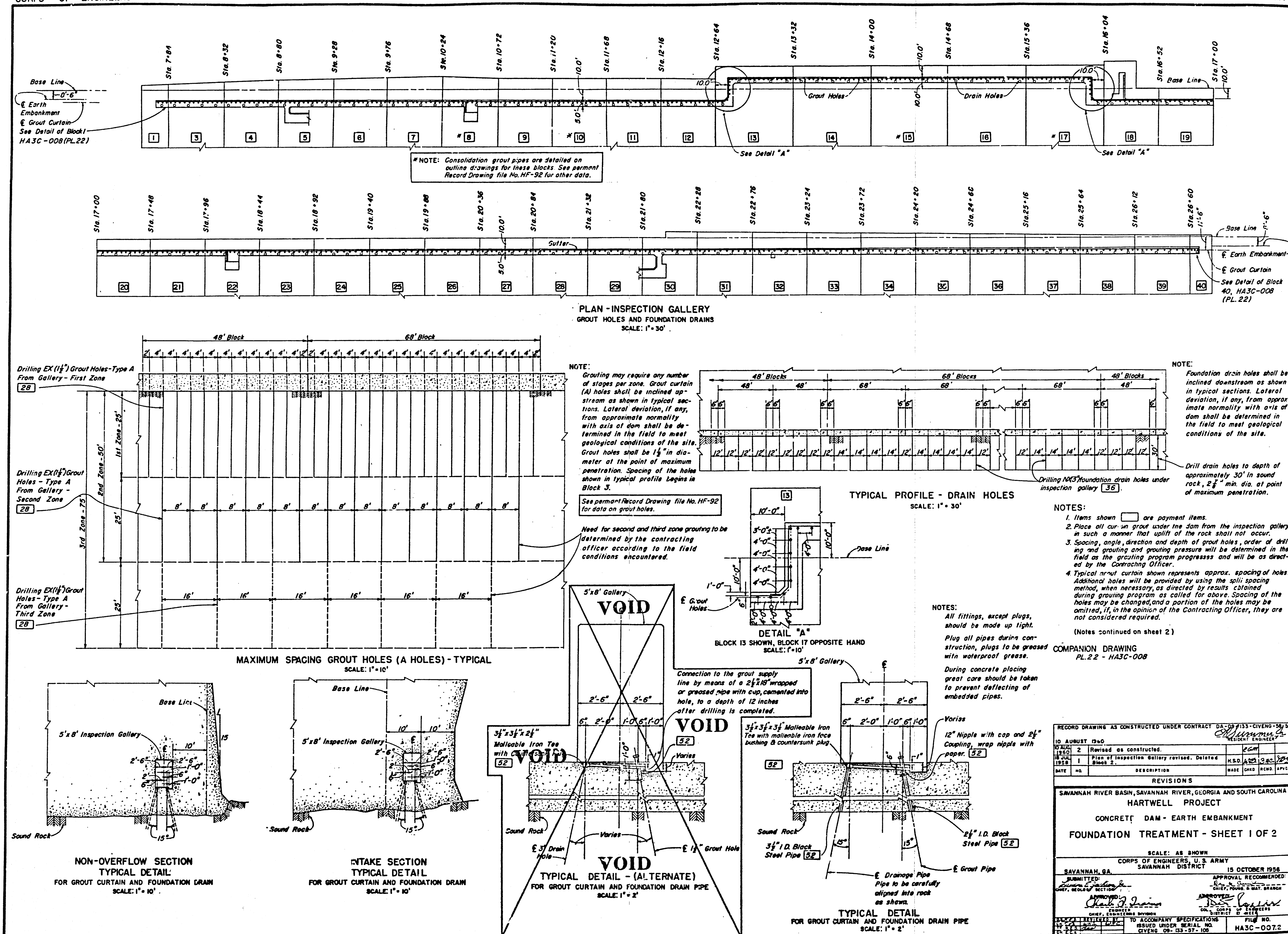
SCALE: AS SHOWN

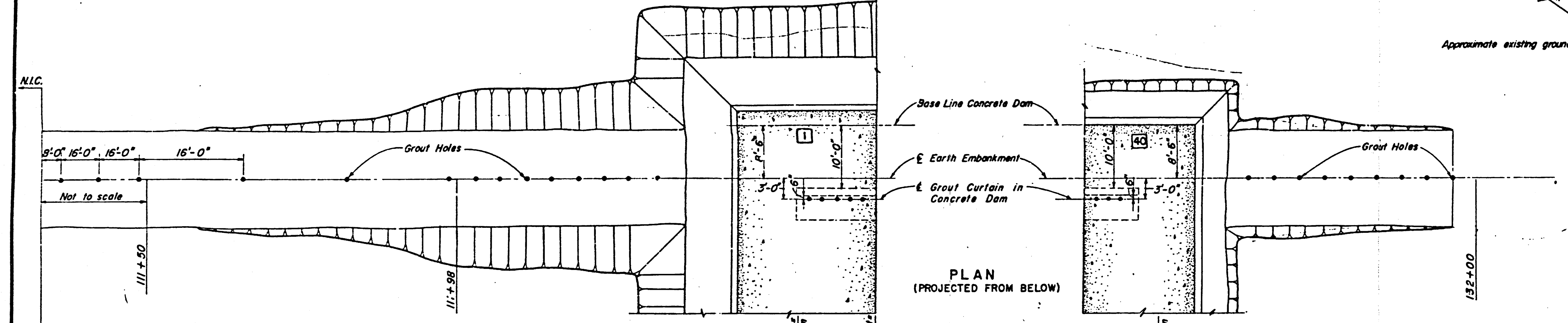
CORPS OF ENGINEERS, U.S. ARMY
SAVANNAH DISTRICT
SAVANNAH, GA. 15 OCTOBER 1956

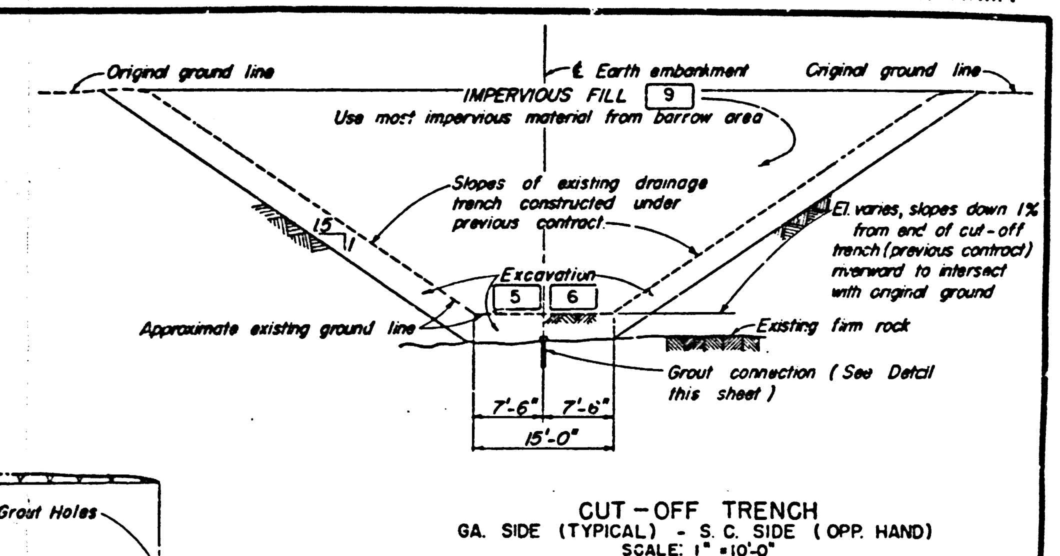
SUBMITTED: CHIEF, GEOLOGY SECTION
APPROVAL RECOMMENDED: CHIEF, FOUND. & MAT. BRANCH
APPROVED: ENGINEER, CHIEF, ENGINEERING DIVISION
APPROVED: COL., CORPS OF ENGINEERS, DISTRICT ENGINEER

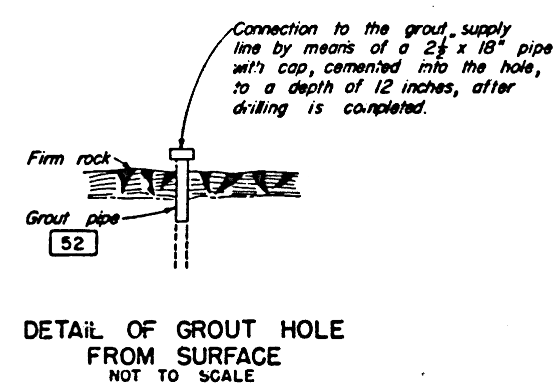
TO ACCOMPANY SPECIFICATIONS ISSUED UNDER SERIAL NO. CIVENG 09-133-57-105

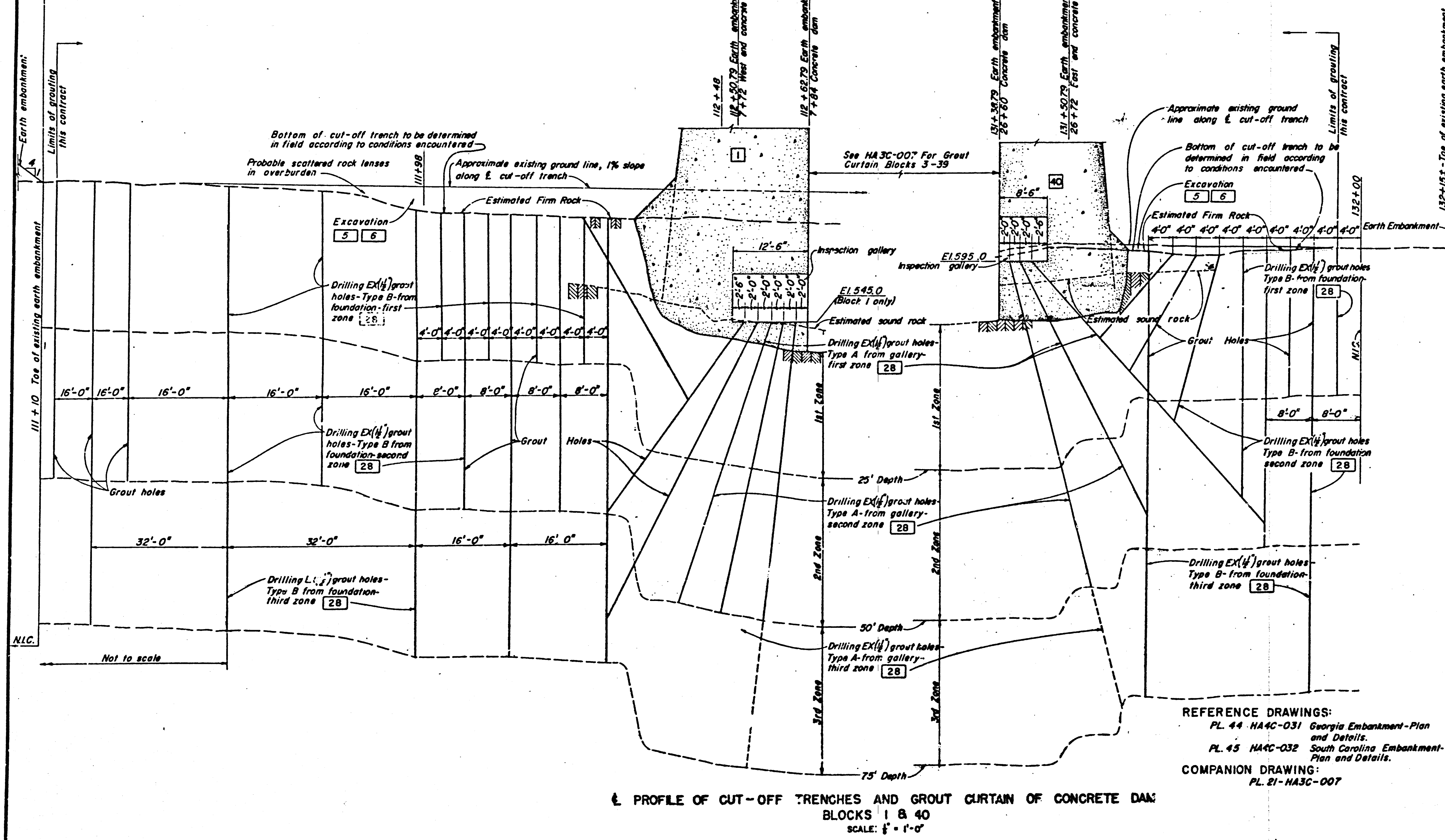
FILE NO. HA2C-025.1


PLAN - INSPECTION GALLERY
GROUT HOLES AND FOUNDATION DRAINS
SCALE: 1" = 30'
* NOTE: Consolidation grout pipes are detailed on outline drawings for these blocks. See permanent Record Drawing file No. HF-92 for other data.
Base Line
℄ Earth Embankment
℄ Grout Curtain
See Detail of Block 1 HA3C-008 (PL.22)
See Detail of Block 40, HA3C-008 (PL. 22)
See Detail "A"
Grout Holes
Drain Holes
Gutter
MAXIMUM SPACING GROUT HOLES (A HOLES) - TYPICAL
SCALE: 1" = 10'
48' Block
68' Block
Drilling EX (1½") Grout Holes - Type A From Gallery - First Zone 28
Drilling EX(1½") Grout Holes - Type A From Gallery - Second Zone 28
Drilling EX(1½") Grout Holes - Type A From Gallery - Third Zone 28
1st Zone - 25'
2nd Zone - 50'
3rd Zone - 75'
NOTE: Grouting may require any number of stages per zone. Grout curtain (A) holes shall be inclined upstream as shown in typical sections. Lateral deviation, if any, from approximate normality with axis of dam shall be determined in the field to meet geological conditions of the site. Grout holes shall be 1½" in diameter at the point of maximum penetration. Spacing of the holes shown in typical profile begins in Block 3.
See permanent Record Drawing file No. HF-92 for data on grout holes.
Need for second and third zone grouting to be determined by the contracting officer according to the field conditions encountered.
TYPICAL PROFILE - DRAIN HOLES
SCALE: 1" = 30'
48' Blocks
68' Blocks
Drilling NX(3") foundation drain holes under inspection gallery 36
NOTE: Foundation drain holes shall be inclined downstream as shown in typical sections. Lateral deviation, if any, from approximate normality with axis of dam shall be determined in the field to meet geological conditions of the site.
Drill drain holes to depth of approximately 30' in sound rock, 2⅞" min. dia. at point of maximum penetration.
DETAIL "A"
BLOCK 13 SHOWN, BLOCK 17 OPPOSITE HAND
SCALE: 1" = 10'
℄ Grout Holes
NOTES:
1. Items shown ▭ are payment items.
2. Place all curtain grout under the dam from the inspection gallery in such a manner that uplift of the rock shall not occur.
3. Spacing, angle, direction and depth of grout holes, order of drilling and grouting and grouting pressure will be determined in the field as the grouting program progresses and will be as directed by the Contracting Officer.
4. Typical grout curtain shown represents approx. spacing of holes. Additional holes will be provided by using the split spacing method, when necessary, as directed by results obtained during grouting program as called for above. Spacing of the holes may be changed, and a portion of the holes may be omitted, if, in the opinion of the Contracting Officer, they are not considered required.
(Notes continued on sheet 2)
COMPANION DRAWING
PL.22 - HA3C-008
NOTES:
All fittings, except plugs, should be made up tight.
Plug all pipes during construction, plugs to be greased with waterproof grease.
During concrete placing great care should be taken to prevent deflecting of embedded pipes.
5'x8' Inspection Gallery
Sound Rock
NON-OVERFLOW SECTION
TYPICAL DETAIL
FOR GROUT CURTAIN AND FOUNDATION DRAIN
SCALE: 1" = 10'
INTAKE SECTION
TYPICAL DETAIL
FOR GROUT CURTAIN AND FOUNDATION DRAIN
SCALE: 1" = 10'
VOID
5'x8' Gallery
Connection to the grout supply line by means of a 2½"x18" wrapped or greased pipe with cup, cemented into hole, to a depth of 12 inches after drilling is completed.
3½"x3½"x2½" Malleable Iron Tee with ... 52
Varies
℄ 3" Drain Hole
℄ 1½" Grout Hole
TYPICAL DETAIL - (ALTERNATE)
FOR GROUT CURTAIN AND FOUNDATION DRAIN PIPE
SCALE: 1" = 2'
3½"x3½"x3½" Malleable Iron Tee with malleable iron face bushing & countersunk plug 52
12" Nipple with cap and 2½" Coupling, wrap nipple with paper. 52
2½" I.D. Black Steel Pipe 52
3½" I.D. Black Steel Pipe 52
℄ Drainage Pipe. Pipe to be carefully aligned into rock as shown.
℄ Grout Pipe
TYPICAL DETAIL
FOR GROUT CURTAIN AND FOUNDATION DRAIN PIPE
SCALE: 1" = 2'
RECORD DRAWING AS CONSTRUCTED UNDER CONTRACT DA-09-133-CIVENG-58-5
RESIDENT ENGINEER
10 AUGUST 1960
10 AUG 1960 | 2 | Revised as constructed.
18 JUL 1958 | 1 | Plan of Inspection Gallery revised. Deleted Block 2.
DATE | NO. | DESCRIPTION | MADE | CHKD | RCMD. | APVC.
REVISIONS
SAVANNAH RIVER BASIN, SAVANNAH RIVER, GEORGIA AND SOUTH CAROLINA
HARTWELL PROJECT
CONCRETE DAM - EARTH EMBANKMENT
FOUNDATION TREATMENT - SHEET 1 OF 2
SCALE: AS SHOWN
CORPS OF ENGINEERS, U. S. ARMY
SAVANNAH DISTRICT
SAVANNAH, GA. 15 OCTOBER 1956
SUBMITTED:
CHIEF, GEOLOGY SECTION
APPROVAL RECOMMENDED:
CHIEF, FOUND. & MAT. BRANCH
APPROVED:
CHIEF, ENGINEERING DIVISION
APPROVED:
COL. CORPS OF ENGINEERS DISTRICT ENGINEER
TO ACCOMPANY SPECIFICATIONS ISSUED UNDER SERIAL NO. CIVENG 09-133-57-105
FILE NO. HA3C-007.2









NOTES: (Continued from sheet 1)

5. Special treatment of the foundation in deeply weathered or questionable areas will be determined by the Contracting Officer after the areas have been excavated and explored.
6. Drill foundation drain holes after foundation grouting in the affected area has been completed. Spacing, angle, and direction of holes will be determined in the field and as directed by the Contracting Officer.
7. The Government reserves the right to have pipe for drilling and grouting placed in certain areas before placing concrete, if in the opinion of the Contracting Officer it is deemed desirable or necessary, even though the Contractor has elected to drill through concrete in lieu of the embedded pipe, as outlined in the specifications.

NOTES:

1. Items shown ☐ are contract payment items.
2. Spacing, direction, angle, and length of grout holes may vary to suit geological conditions at the site.
3. Grout holes will normally be 1½" diameter unless some factor such as extensive washing operations or the use of step grouting method necessitates a larger diameter holes.
4. Use black steel pipe throughout.
5. All pipe to be capped except during drilling and grouting operations.

See permanent Record Drawing HF-92 for extra grout holes shown on this plate.

REFERENCE DRAWINGS:
PL. 44 HA4C-031 Georgia Embankment-Plan and Details.
PL. 45 HA4C-032 South Carolina Embankment-Plan and Details.

COMPANION DRAWING:
PL. 21-HA3C-007

RECORD DRAWING AS CONSTRUCTED UNDER CONTRACT DA-09-133-CIVENG-58-5
10 AUGUST 1960 — RESIDENT ENGINEER

DATE	NO.	DESCRIPTION	MADE	CHKD	RCMD.	APVD.
10 AUG 1960	4	Revised as constructed.				
23 JAN 1959	3	Block 40-Inspection gallery El lowered 5 feet.	B.J.F.			
11 SEPT 1958	2	Inspection gallery El corrected in Block 1.	J.A.M.			
19 JUL 1956	1	Elevations and Inspection Gallery revised. Block 2 deleted.	H.S.D.			

REVISIONS

SAVANNAH RIVER BASIN, SAVANNAH RIVER, GEORGIA AND SOUTH CAROLINA

HARTWELL PROJECT

CONCRETE: DAM - EARTH EMBANKMENT

FOUNDATION TREATMENT - SHEET 2 OF 2

SCALE: AS SHOWN

CORPS OF ENGINEERS, U. S. ARMY
SAVANNAH DISTRICT
SAVANNAH, GA. 15 OCTOBER 1956

SUBMITTED: CHIEF, GEOLOGY SECTION
APPROVAL RECOMMENDED: CHIEF, FOUND. & MAT. BRANCH
APPROVED: CHIEF, ENGINEERING DIVISION
APPROVED: CORPS OF ENGINEERS DISTRICT ENGINEER

TO ACCOMPANY SPECIFICATIONS ISSUED UNDER SERIAL NO. CIVENG 09-133-57-105

FILE NO. HA. 3C-008.4

PROJECT E: OOLOGAH DAM

(This case history was developed with the assistance of Arthur Burkart and Eugene Gilbert, Tulsa District)

Location and Description of Project

E1. Oologah Dam is located on the Verdigris River 2 miles southeast of Oologah, Okla. It is a multipurpose project including flood control and water supply. The project was constructed under a two-stage plan of development. The first stage, completed in 1964, provided for flood control and a minimum amount of conservation storage. It consists of a 4000-ft earth embankment about 140 ft high, and a concrete gate tower controlling flows through two 19-ft conduits. A saddle dike and remote gated spillway completed the second stage in 1969 and provided for water supply storage and navigation storage for the Arkansas River. The spillway is a concrete ogee section controlled by seven tainter gates. The embankment and outlet works were constructed under two contracts. Construction began on the right embankment in March 1956 and was completed in December 1957 (USACE 1957). Construction of the outlet works and left embankment were started in March 1958 and completed in December 1964 (USACE 1964). A positive cutoff trench was provided for the embankment. The abutments were grouted, but it was not necessary to grout across the valley. The project was designed and constructed by the Tulsa District.

Geology

E2. The project is located in the Cherokee Plains subdivision of the Prairie Plains physiographic province. The region is characterized by gently rolling prairies between low, north-south trending, eastward-facing cuestas. The bedrock formations are essentially flat-lying limestone and shales of middle Pennsylvanian age and consist of the Oologah limestone capping the abutments and the underlying Labette shale forming the valley floor. The Fort Scott limestone underlies the Labette shale. The Oologah limestone is hard, crystalline, fossiliferous, jointed, contains solution cavities and is about 60 ft thick.

E3. During excavation of the right abutment trench, large clay-filled solution channels were encountered that extended down to the limestone shale contact. The cutoff trench in the steep sloped left abutment was stair-stepped and varied in depth from 15 to 30 ft, with a 25-ft bottom width. Premixed pneumatic concrete was applied to the downstream wall of the left and right abutment trenches and also along the rock faces upstream of the left abutment cutoff trench. Solution channels encountered in the wall section during excavation were cleaned and backfilled with concrete. Open joints were filled with mortar or concrete. Both abutments were grouted from the bottom of the cutoff trench.

E4. The outlet works and the positive cutoff trench across the valley beneath the embankment were founded in the Labette shale. The shale is hard, fossiliferous, contains some vertical fractures and is about 100 ft thick. A grout curtain in the valley section was not necessary.

Foundation Investigations

E5. Foundation exploration data for the project are meager but include the following: Initial exploration for the entire structure was conducted by various District offices having jurisdiction over the project over a period of more than 20 years. Approximately 16 core holes, two drive type sample holes, and two auger sample holes were taken along or near the proposed embankment axis. In addition to the above, numerous core, auger and drive sample holes were taken over the entire area for the proposed project. During construction, additional explorations were performed as directed by change order. Additional core hole exploration into and through the Oologah limestone was performed on 20-ft centers between stations 3+00 and 9+40A. The holes served a dual purpose in that they were used as grout holes in addition to providing more information on the character of the Oologah limestone. (See Plate I-E1 for Foundation Exploration Plan and Plate I-E2 for a Geological Profile.)

Grouting

Summary of right abutment

E6. Only meager information was available to the investigators concerning the drilling and grouting for the first stage embankment and outlet works excavation contract. No estimated quantities or costs were available. An account of the drilling and grouting requirements, procedures, and equipment, taken from the foundation report follows (USACE 1962).

Drilling and grouting foundation

E7. The drilling and grouting program was originally intended for the foundation from approximate Station 5+00 to 23+00 along the centerline of the dam (Plate I-E3). The program was started after stripping and excavating to the top of rock, approximately 4 to 6 ft below natural ground, from Station 5+00 to 23+50. Initial drilling was started on 6 June 1956. Primary holes, spaced 20 ft, center to center, inclined S30°E, and 30° from vertical, were drilled from Station 12+80A to 21+20A. The majority of those holes had water losses at about 6 ft, and grout takes were excessive at gravity pressure. This condition was brought to the attention of the District office, and after conferences and discussions, the drilling and grouting was discontinued on 18 June 1956. A total of 478 lin ft had been drilled and 914 bags of cement injected in the shallow holes. Only one hole was drilled to the required depth and grouted satisfactorily.

E8. Due to the condition of the limestone foundation, which contained many clay seams, open joints, bedding planes and cavities, change orders were issued to remove the rock down to the Labette shale. A core trench approximately 60 ft deep was excavated in the foundation from Station 9+60 to the abutment. During the excavation of the core trench a series of exploratory core holes were drilled from Station 5+40 to 9+40, to determine the condition of the foundation in this area. A cavity was found in the hole drilled at 9+40 and the excavation limits were moved landward to Station 9+40 to include the excavation of the cavity. The area from Station 5+40 to 9+40 could apparently be successfully grouted. NX exploratory core holes were drilled S30°E, 30 deg from vertical. The holes were drilled on 20-ft centers and the holes plugged at the top for future grouting. The exploratory drilling was started on 15 December 1956 and completed 1 February 1957. All holes were drilled into the Labette shale. Plate I-E1 shows location of exploratory core holes.

E9. After the rock was excavated from the cutoff trench, a series of holes were drilled on 20-ft centers from Station 21+50A to Station 22+80A into the Labette shale. These holes were drilled S30°E, 30 deg from vertical to a depth of 35 ft. Pressure testing proved that water could not be injected into the formation at maximum allowable grouting pressure. These holes were backfilled with a heavy grout mixture.

E10. For record purposes, a series of wagon drill holes were drilled every 100 ft from Station 11+00 to 21+00 to a depth of 10 ft into the Labette shale.

E11. On 21 February 1957 the grouting program was resumed starting with the NX exploratory holes. A series of holes were pressure tested and generally were open and took water. The holes taking the most water were grouted first. Four of the exploratory holes had approximately 2800 bags of cement injected in them. This grouting sealed the foundation sufficiently so that the remaining holes took only a small amount of grout. Tightening up of holes known to be open from pressure testing showed grout had traveled for as much as 120 ft along the axis of the dam. The exploratory holes were grouted from Station 5+40 to 8+00 initially. Secondary holes, on 10-ft centers were then drilled and grouted. The secondary holes were reasonably watertight. Five-foot center holes were drilled and grouted in areas deemed necessary. Only two holes were drilled on 2-1/2-ft centers, both being tight on pressure testing.

E12. After the cutoff trench had been backfilled to approximate elevation 643, the grouting was done from Station 8+00 to 9+40. Grout take in these holes was not excessive. A series of holes were drilled perpendicular to the axis at Station 9+25, from centerline to approximately 15 ft upstream and 12 ft downstream, using the split spacing method as necessary. Four holes were drilled and grouted upstream and two holes drilled and grouted downstream from centerline. Grouting was completed on 2 August 1957.

Methods and procedures for grouting

E13. The stop grouting method was used in all grouting operations. For the first stop, packers were set at about 40 ft and raised 10 to 15 ft on successive stops until the hole had been grouted to the top. The grout was injected into the hole through 2-in. rubber hoses. A by-pass line from the hole to the agitating tank was used with a valve installed at the hole for pressure control. Generally, a series of holes were pressure tested and grouting started on the holes taking the most water. Mixtures varied from 4:1 to 0.75:1. The policy was to start with thin grout and rapidly thicken the grout on extremely open holes. On holes that were reasonably watertight and pressure could be obtained easily, the grout mixture was kept thin. Maximum pressures used were one psi per foot of packer depth. All holes were pressure tested before being grouted. Pressures for pressure testing ranged from approximately 2/3 to the maximum permissible grouting pressure. Holes, or sections of holes, that were watertight on pressure tests at maximum grouting pressures were not grouted.

Drilling grout holes

E14. Drilling was done with a Joy No. 12 rotary core drilling machine, skid mounted. Drilling of exploratory core holes was done with diamond core bits, size NX. Grout holes were drilled with diamond core bits and plug-type diamond bits, size AX. Drilling averaged approximately 40 lin ft per 9-hour shifts per day, 6 days per week. Nipples were set at the surface in all grout holes. The nipples were 2-1/2 in. in diam, 18 in. long steel pipe and were grouted into the foundation to a depth of 12 to 15 in. The tops of the nipples were threaded, and pipe caps were put on when drilling was completed on each hole. The holes averaged 75 ft in depth.

Equipment used in grouting

E15. A Damco Grout plant was used. The Damco plant was manufactured at Dallas, Tex., by the Drilling Accessory Manufacturing Company. The pump and mixing tank were mounted on a trailer. The air driven pump was a size 6 by 3-1/2 by 6, Gardner-Denver. The mixing tank had a capacity of approximately 30 cu ft and was operated by an air driven motor. The air driven agitating tank had a 17-cu-ft capacity and rested on the ground beneath the mixing tank. A watermeter was installed on the unit, reading to 0.1 cu ft. Water was supplied for the drilling and grouting from the river and a stock pond nearby. A bean-piston type pump supplied the water through 2-in. water lines.

E16. Packers were the pneumatic, expansion type, with 3/8-in. opening on AX size packers and 3/4-in. opening on NX size. Air was supplied by an Ingersoll Rand Compressor, size 600 cu ft/min.

E17. Dewey Portland cement, Type 1, from Dewey, Okla., was used for grouting. Miscellaneous hose, gages, pipes, and hand tools were used as needed. All holes were backfilled with a heavy grout mixture upon completion of grouting operations. The nipples were removed prior to placing fill material in the trench. Plate I-E3 shows the plan and elevation for the right abutment grouting.

Change order affecting grouting

E18. Several change orders were issued affecting the foundation, however, only one affected the grouting program. Change Order No. 6, dated 30 August 1956, was issued to provide additional excavation of weathered

Oologah limestone rock from the cutoff trench between Station 9+40A and Station 23+00A, and to delete requirements for drilling and grouting the right abutment foundation section.

Grout takes

E19. Total drilling for the right abutment was 4354 ft, and 3048 cu ft of cement were placed for a ratio of 0.70 cu ft/lin ft.

Technical Considerations, Left Abutment

E20. The plans and specifications described the work to be performed and the equipment to be used for the grout program which included the grout curtain designed to reduce foundation leakage and protect the embankment. The right abutment had been grouted previously thereby providing prior experience in grouting under similar conditions and foundations. There were six pay items for the drilling and grouting program including mobilization and demobilization of drilling and grouting equipment, drilling grout holes, drilling exploratory holes, washing and pressure testing grout holes, placing grout, and connections to grout holes.

Contractual Considerations, Left Abutment

E21. The contract for the outlet works and completion of the embankment was a firm fixed-price contract awarded to the lowest bidder, the J. A. Jones Construction Company. Geo Prospectors, a geophysical contracting company of Tulsa, Okla., was the subcontractor for the drilling and grouting. Mr. John Soderberg was resident engineer, Mr. Frank Johnson was the foundation engineer, and Mr. Tom Washburn was the grouting supervisor. Mr. Allan Stone was the Chief of Geology Section in Tulsa District and the designer of the grout curtain. Nothing in the available records indicates any major conflicts between the prime contractor, subcontractor, or Corps personnel. The specifications contained the following statements:

"b. Program. The work contemplated consists of constructing a grout curtain beneath the dam the approximate locations, limits and details of which are indicated on the contract drawings. The program shown on the drawings and described herein is tentative and is presented for the purpose of canvassing bids. The amount of drilling and grouting which actually will be required is unknown, and will be governed by conditions encountered as the work progresses. The Government reserved the right to increase by as much as 100 percent or to eliminate any part of the entire drilling and grouting program should conditions indicate this as being desirable, and the contractor will not be allowed any increase in the unit prices bid in the schedule for drilling and grouting by reason of any changes in the amount of work or materials actually involved.

c. Procedures. Grouting mixes, pressures, the pumping rate and the sequence in which the holes are drilled and grouted will be determined in the field and shall be as directed by the contracting officer" (USACE 1956, 1957).

E22. The specifications also included a differing site condition clause. There were no claims related to the drilling and grouting operations.

Drilling and Grouting Methods, Left Abutment

E23. All drilling and grouting were done from the bottom of the cutoff trench. Left abutment grouting profiles are shown in Plates I-E4 and I-E5. Grouting started at an excavation step until it was grouted for its length. Then the grouting operations were moved landward from a transverse stepped excavation face about 100 ft. Grouting then continued to the end of the trench. After fill had been placed on the first grouted step to the top of the next face, the 100-ft gap was grouted. This procedure was used to avoid the possibility of the grout breakouts in the cutoff trench and the possibility of damaging the pneumatic mortar that was applied on the transverse limestone face.

Drilling

E24. The specifications called for grout holes to be drilled with standard rotary drilling equipment. Payment was by the linear foot of hole. No recovery was required and the type bit was optional. Minimum diameter of hole was specified to be 1-27/32 in. in diameter. Gardner-Denver Air Trac drills, percussion type, equipped with rotary head and using water for drilling fluid, were used atop the abutment. The drills were capable of drilling from 80 to 120 ft per shift.

Washing and pressure testing

E25. Pressure testing was paid for by the hour. The hole was required to be washed under pressure immediately prior to grouting. Clay or other washable material in crevices, etc., should be washed with water and air under pressure. The pressures were not to exceed the grouting pressures. Pressure used ranged from zero to maximum grouting pressure. Holes that could not build up pressure were washed for 10 min.

Grouting mixtures

E26. All grouting was done with a mixture of water and cement as required by the specifications. No separate payments were made for the cement used in the grout. Dewey Portland Cement, Type 1, from Dewey's plant in Tulsa was used. Grout mixtures ranged from 4:1 to 0.75:1. The greater part was placed at about 1:1.

Pressure

E27. Specifications stated that expected pressures up to 75 lb would be required for the deeper sections of the hole, while lower pressures would be used in the upper zones. The speed of pump operation and pressure would be as directed by the contracting officer. The grouting was performed by the stop grouting method. Pressures applied were 1 psi/ft of hole to the packer depth.

Refusal rate

E28. Specifications required that grouting should be continued until the hole takes the grout at a rate of less than 1 cu ft in 10 min under the required grouting pressure and the grouting of any hole shall be discontinued when so directed.

Connections to grout holes

E29. Payment for connections to grout holes were set at $5 for each connection, regardless of the amount placed. Measurement was not to include consecutive connections on the same hole for adjusting packer height, but only when line was moved from one hole to another.

Field procedures

E30. Holes were drilled on about 20-ft centers, grouted; then intermediates, or 10-ft center holes, were drilled and grouted. The split spacing method was used until the foundation was considered tight. The split spacing continued until some holes were on 2-1/2-ft centers. These field procedures followed the requirements of the specification. Specifications limited the angle of the holes to be no greater than 30 deg from the vertical and anticipated depths between 40 and 80 ft, with a maximum of 120 ft. The average depth of hole was 45 ft. If water was lost or artesian flow was encountered, the hole was stopped and grouted prior to deepening the hole. Grouting was performed by the stop grouting method by use of packers starting at the lower part of the hole and successively raising to higher levels. The grout mixtures and determination when to change was left to the judgment of the Government grout supervisor.

Equipment

E31. Specifications required plant capable of supplying, mixing, stirring, and pumping the grout to the satisfaction of the contracting officer. It required a capacity of 30 gal/min of grout injected at a pressure not greater than 100 psi. Minimum equipment specified included a pump, mechanical mixer and sump, water tank, water meter, and other such valves, packers, hoses, etc., necessary to meet the requirements. The capacity of mixer and sump was specified to be not less than 9.0 cu ft.

Records

E32. The specifications stated that the contracting officer would keep records of all the grouting operations, such as log of the grout holes, results of washing and pressure testing operations, time of each change of grouting operation, pressure, rate of pumping, amount of cement for each change in water-cement ratio, and other data as deemed necessary. The contractor was to furnish necessary assistance and cooperation.

Grout Takes

E33. Total drilling for the left abutment was 6616 ft with 2936 cu ft of cement placed for a ratio of 0.44 cu ft/lin ft.

Unexpected Geological Conditions Encountered During Construction

E34. The severity of the solutioning of the right abutment (first contract) was a surprise and caused much more excavation than anticipated. It also required corrective measures such as pneumatic concrete on the trench faces, dental concrete, etc. Conditions encountered here were taken into consideration for the second contract which included the left abutment. Since the problems could be anticipated, provisions were made for proper treatment in the specifications. While these considerations were not directly related to the drilling and grouting, their proper treatment does impact the potential for leakage.

Evaluation of Grouting

E35. The grouting program resulted in a tight foundation and was judged to be adequate at the time of completion. The extra excavation, application of pneumatic concrete to the trench faces, the dental treatment, and other remedial measures, combined with the grout curtain, in direct response to the unfavorable geologic conditions encountered during construction resulted in controlling through or under seepage.

Costs and Quantities

E36. Total drilling costs were $13,659, and total grout placement costs were $8,514. Total costs of all drilling and grouting related items were $26,005.15 (USACE 1964). Government estimated unit prices are not available. The total bid cost (Government quantities x contractor bid) was $24,075 or $1,930.15 less than total actual cost which represents 7 percent more than the bid cost. The actual drilling quantities were 1,163 lin ft above estimated quantities, no exploration drilling was done, pressure testing was 31.3 hr above the estimated, placing grout was 64 lin ft below the estimated, and 31 more connections were used than estimated. The following is a summary of the grouting statistics:

Item	Description	Government Quantities	Estimate Unit Cost	(Bid Price) Unit Cost	Actual Quantities	Cost
11	Mobilization and Demobilization	Sum-Job		(2,300.00)	Sum-Job	2,300.00
12	Drilling Grout Holes	5,500 lin ft		(11,275.00) 2.05	6,663 lin ft	13,659.15
13	Drilling Exploratory Holes	150 lin ft		(1,050.00) 7.00	0	0
14	Washing and Pressure Testing Grout Holes	25 hr		(500.00) 20.00	56-1/3 hr	1,126.60

Item	Description	Government Quantities	Estimate Unit Cost	(Bid Price) Unit Cost	Actual Quantities	Cost
15	Placing Grout	3,000 cu ft		(8,700.00) 2.90	2,936 cu ft	8,514.40
16	Connections to Grout Holes	50 ea	5.00	(250.00) 5.00	81 ea	405.00
				(24,075.00)		26,005.15

E37. The following is a summary of the drilling and grouting totals for the complete embankment.

	Drill Footage	Sacks Placed	Ratio sacks/lin ft
Right Abutment	4,354	3,048	0.70
Left Abutment	6,616	2,936	0.44
Total	10,970	5,984	0.55

Performance

E38. The performance of the grout curtain and other foundation treatment has been evaluated by continued monitoring under operational conditions and has proven to be adequate. Scheduled project monitoring under different pool conditions and the Periodic Inspections (USACE 1968, 1978) performed at the site have revealed no leakage. There has been no need for remedial grouting.

References

US Army Corps of Engineers. 1956. Specifications for Construction of First Stage Embankment and Outlet Works Excavation, Oologah Dam, Verdigris River, Oklahoma, Tulsa District, Tulsa, Okla.

____________. 1957. Oologah Dam, Foundation Report No. 1, First Stage Embankment and Outlet Works. Excavation, Tulsa District, Tulsa, Okla.

____________. 1957. Specifications for Construction of Outlet Works and Spillway and Completion of Embankment, Tulsa District, Tulsa, Okla.

____________. 1962. Foundation Report Number 3, Completion of Embankment and Outlet Works Excavation and Construction, Oologah Dam, Verdigris River, Oklahoma, Tulsa District, Tulsa, Okla.

US Army Corps of Engineers. 1964. Payment Estimate, Construction of Outlet Works and Completion of Embankment, Oologah Dam, Tulsa District, Tulsa, Okla.

___________. 1968. Periodic Inspection and Continuing Evaluation of Completed Civil Works Structures, Oologah Dam, Verdigris River, Oklahoma, Tulsa District, Tulsa, Okla.

___________. 1978. Periodic Inspection and Continuing Evaluation of Completed Civil Works Structures, Oologah Dam, Verdigris River, Oklahoma, Tulsa District, Tulsa, Okla.

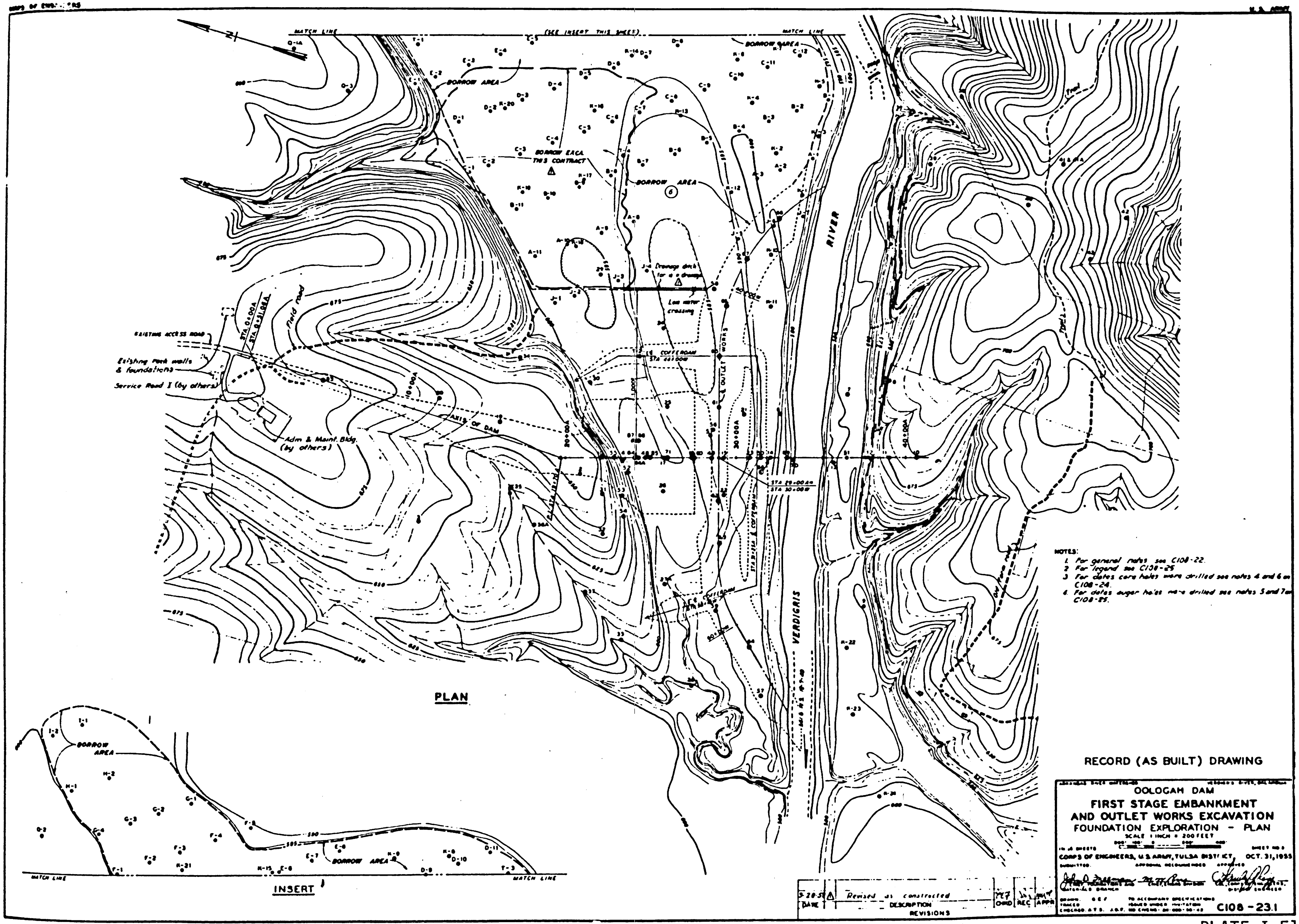
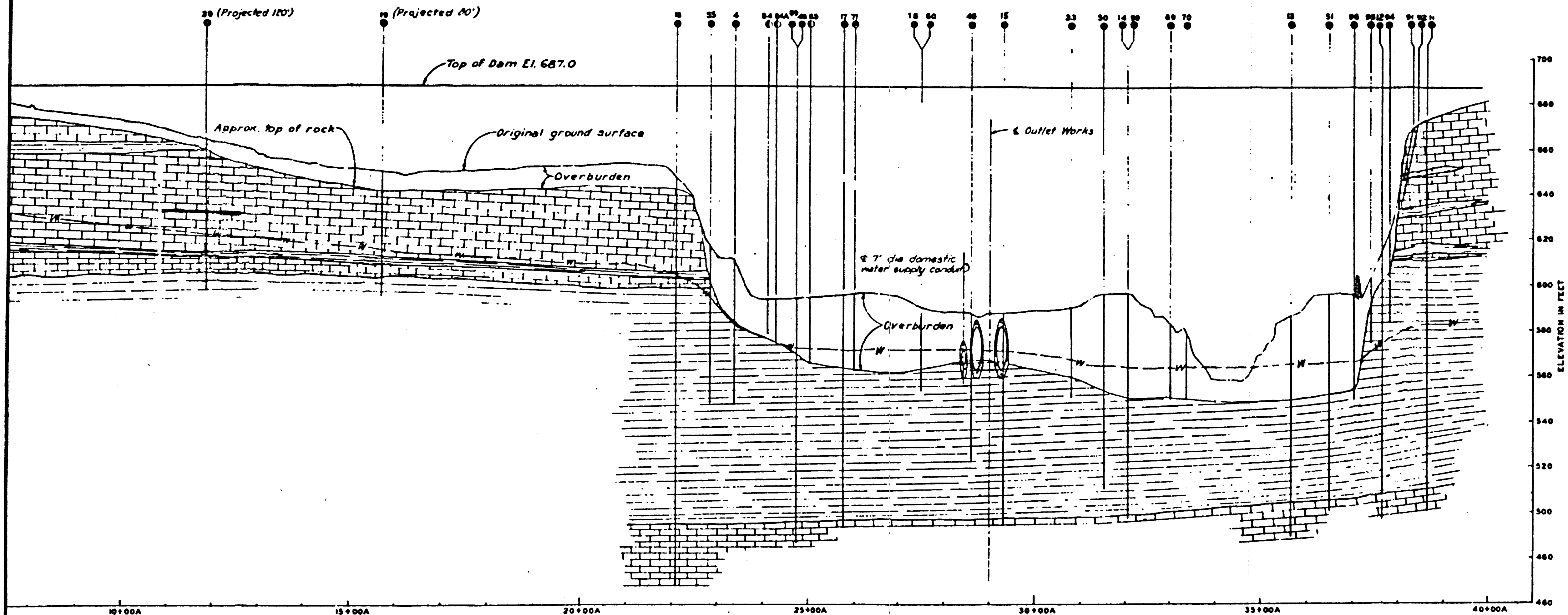

PLAN
INSERT
MATCH LINE
(SEE INSERT THIS SHEET)
BORROW AREA
BORROW EXCA. THIS CONTRACT
Field road
EXISTING ACCESS ROAD
Existing rock walls & foundations
Service Road I (by others)
Adm. & Maint. Bldg. (by others)
AXIS OF DAM
Low water crossing
COFFERDAM
OUTLET WORKS
VERDIGRIS
RIVER
NOTES:
1. For general notes see C108-22.
2. For legend see C108-25
3. For dates core holes were drilled see notes 4 and 6 on C108-24.
4. For dates auger holes were drilled see notes 5 and 7 on C108-25.
RECORD (AS BUILT) DRAWING
OOLOGAH DAM
FIRST STAGE EMBANKMENT
AND OUTLET WORKS EXCAVATION
FOUNDATION EXPLORATION - PLAN
SCALE 1 INCH = 200 FEET
CORPS OF ENGINEERS, U.S. ARMY, TULSA DISTRICT
OCT. 31, 1955
C108 - 23.1
Revised as constructed
DATE
DESCRIPTION
REVISIONS
CHKD
REC
APPR

PLATE I-E1



PROFILE ALONG AXIS OF DAM

(LOOKING UPSTREAM)

ARKANSAS RIVER WATERSHED — VERDIGRIS RIVER, OKLAHOMA

OOLOGAH RESERVOIR

FOUNDATION PROFILE ALONG CENTERLINE OF DAM LOOKING UPSTREAM

IN 1 SHEET — SCALE AS SHOWN — SHEET NO. 1

CORPS OF ENGINEERS, U.S. ARMY, TULSA DISTRICT, SEPT., 1956

DRAWN: E.L.F.
TRACED:
CHECKED: A.T.S., J.D.F.

TO ACCOMPANY GENERAL DESIGN MEMORANDUM NO. 11 DATED NOVEMBER 1956

V-18/6

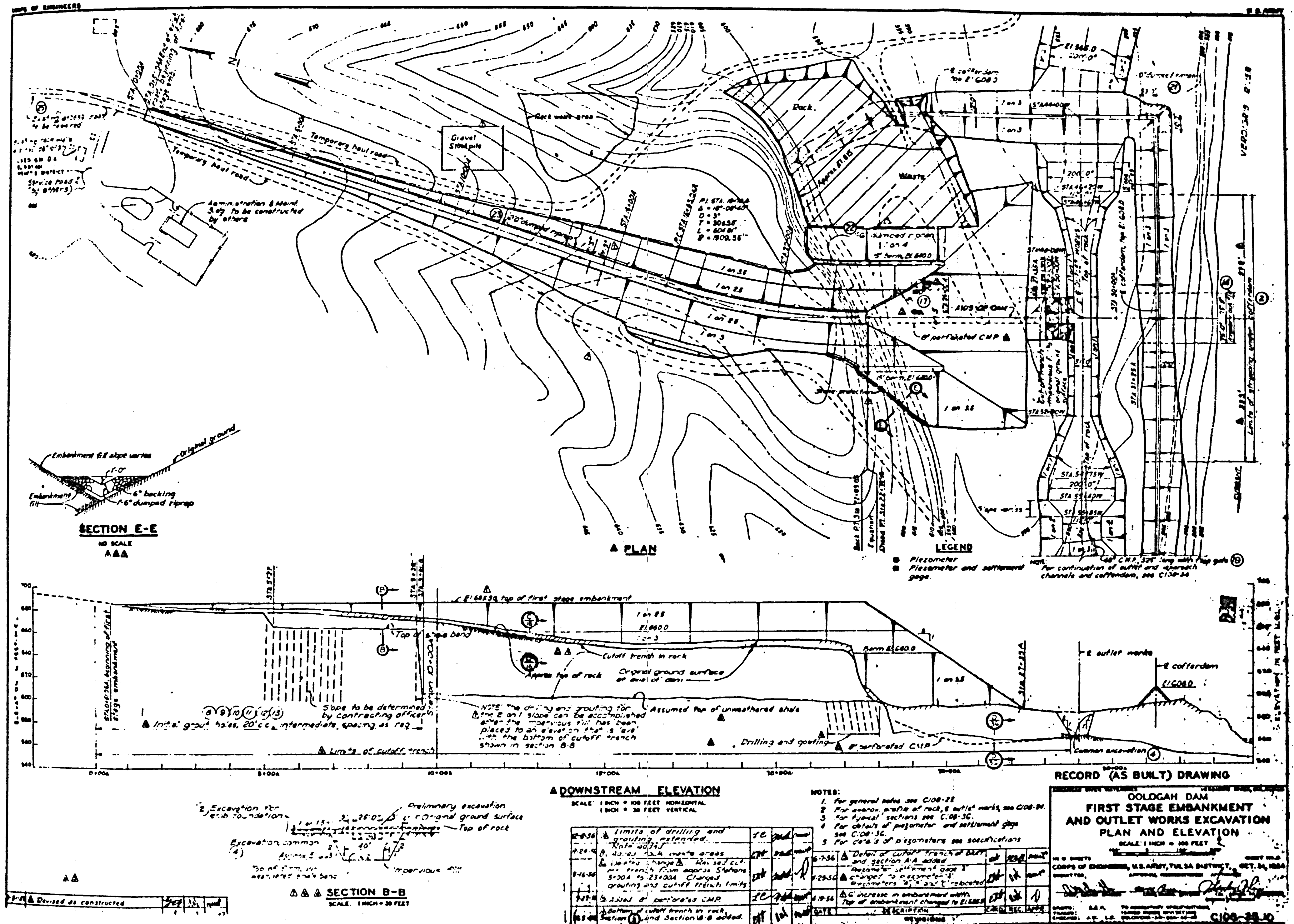
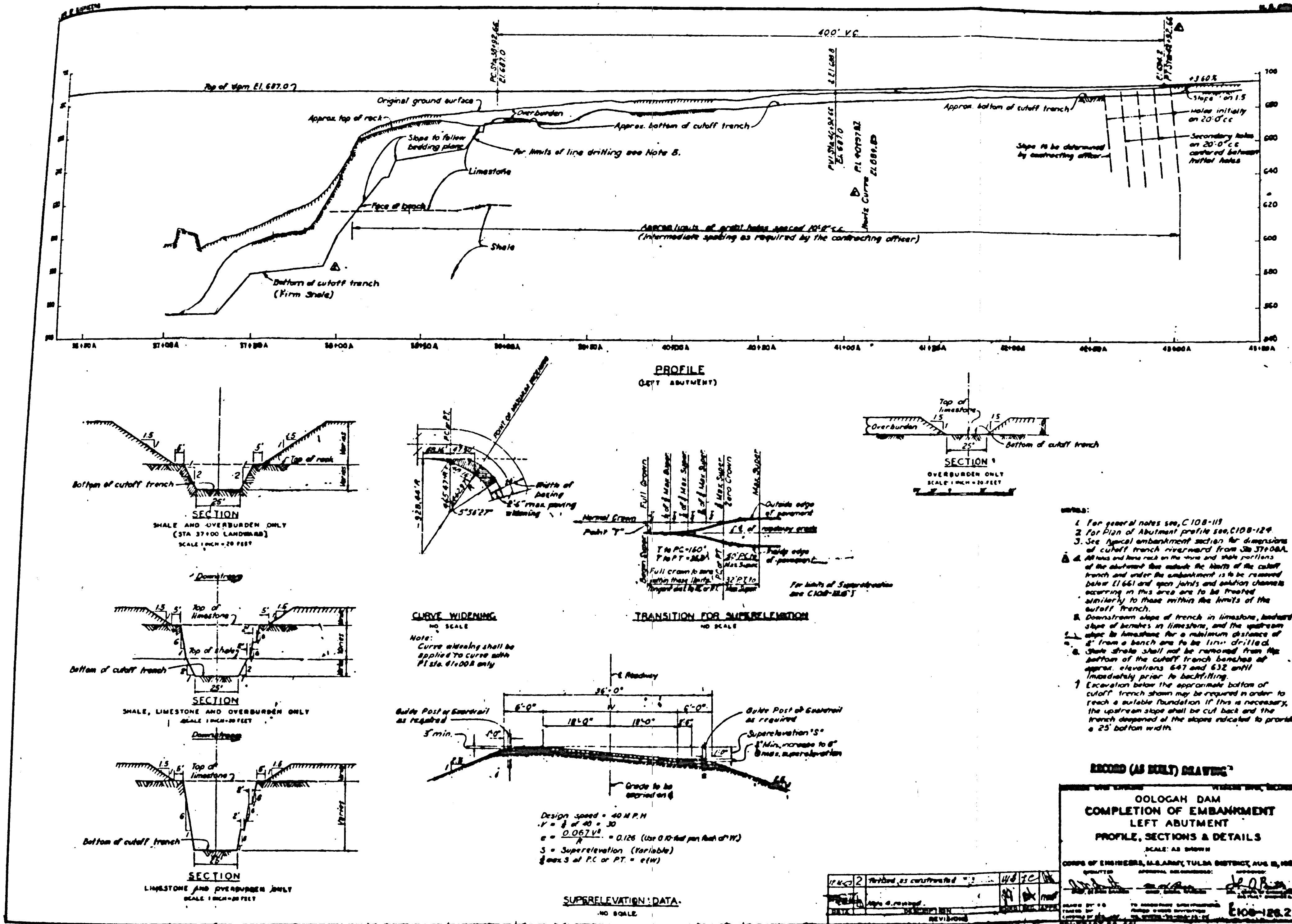

PLAN
LEGEND
Piezometer
Piezometer and settlement gage
SECTION E-E
NO SCALE
Embankment fill slope varies
Original ground
6" backing
1'-6" dumped riprap
Embankment fill
Temporary haul road
Gravel Stockpile
Rock waste area
Rock
Waste
Administration & Maint. Bldg. to be constructed by others
DOWNSTREAM ELEVATION
SCALE: 1 INCH = 100 FEET HORIZONTAL
1 INCH = 30 FEET VERTICAL
Cutoff trench in rock
Original ground surface at axis of dam
Approx. top of rock
Assumed top of unweathered shale
Drilling and grouting
8" perforated CMP
Common excavation
Initial grout holes, 20' c.c., intermediate spacing as req.
Slope to be determined by contracting officer
Limits of cutoff trench
Top of slope band
Berm El. 640.0
℄ outlet works
℄ cofferdam
SECTION B-B
SCALE: 1 INCH = 30 FEET
Preliminary excavation
Original ground surface
Top of rock
Excavation common
Impervious fill
NOTES:
1. For general notes see C108-28
2. For approx. profile of rock, & outlet works, see C108-34.
3. For typical sections see C108-36.
4. For details of piezometer and settlement gage see C108-36.
5. For data's of piezometers see specifications
Limits of drilling and grouting extended.
Added rock waste areas
Added perforated CMP.
Bottom of cutoff trench in rock, Section A and Section B-B added.
Detail of cutoff trench at ... and section A-A added
6' increase in embankment width. Top of embankment changed to El. 685
Revised as constructed
DATE
DESCRIPTION
REVISIONS
RECORD (AS BUILT) DRAWING
OOLOGAH DAM
FIRST STAGE EMBANKMENT
AND OUTLET WORKS EXCAVATION
PLAN AND ELEVATION
SCALE: 1 INCH = 100 FEET
CORPS OF ENGINEERS, U.S. ARMY, TULSA DISTRICT
C108-35.10

PLATE I-E3



PROFILE
(LEFT ABUTMENT)
SECTION
SHALE AND OVERBURDEN ONLY
SECTION
SHALE, LIMESTONE AND OVERBURDEN ONLY
SECTION
LIMESTONE AND OVERBURDEN ONLY
CURVE WIDENING
TRANSITION FOR SUPERELEVATION
SECTION
OVERBURDEN ONLY
SUPERELEVATION DATA
RECORD (AS BUILT) DRAWING
OOLOGAH DAM
COMPLETION OF EMBANKMENT
LEFT ABUTMENT
PROFILE, SECTIONS & DETAILS
C108-126.2
CONTRACT 58-441

PLATE I-E4

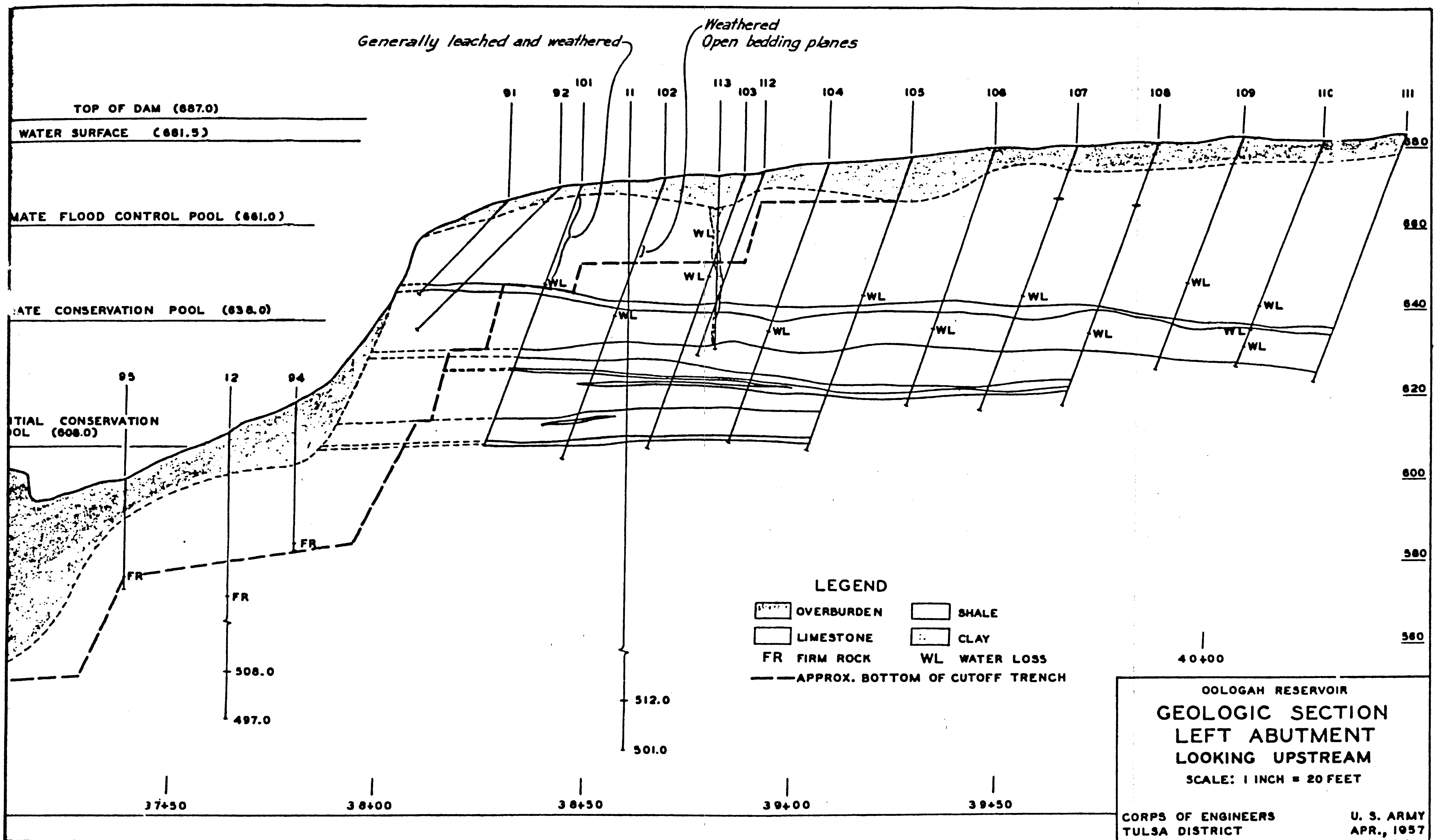

Generally leached and weathered
Weathered
Open bedding planes
TOP OF DAM (687.0)
WATER SURFACE (681.5)
MATE FLOOD CONTROL POOL (661.0)
ATE CONSERVATION POOL (638.0)
ITIAL CONSERVATION
OL (608.0)
91 92 101 11 102 113 103 112 104 105 106 107 108 109 110 111
95 12 94
WL
FR
508.0
497.0
512.0
501.0
680
660
640
620
600
580
560
37+50
38+00
38+50
39+00
39+50
40+00
LEGEND
OVERBURDEN
SHALE
LIMESTONE
CLAY
FR FIRM ROCK
WL WATER LOSS
APPROX. BOTTOM OF CUTOFF TRENCH
OOLOGAH RESERVOIR
GEOLOGIC SECTION
LEFT ABUTMENT
LOOKING UPSTREAM
SCALE: 1 INCH = 20 FEET
CORPS OF ENGINEERS
TULSA DISTRICT
U. S. ARMY
APR., 1957

PLATE I-E5

PROJECT F: ALVIN BUSH DAM

(This case history was developed with the assistance of Richard Royer, Baltimore District)

Location and Description of Project

F1. The Alvin R. Bush Dam is located on Kettle Creek, a left bank tributary of the West Branch of the Susquehanna River, approximately 10 miles west of the town Renova in Clinton County, Penn. The dam is a straight embankment dam approximately 160 ft high (crest elevation: 967.7) and 1500 ft long. The spillway is a 150-ft wide chute spillway in the right abutment with weir crest at elevation 937. The outlet works consisting of an intake structure, tunnel and stilling basin are also located in the right abutment. The Dam was designed by the Baltimore District and constructed between 1958 and 1962. Foundation grouting was accomplished during three separate periods, as follows:

a. 1958-1962 - Dam construction and grouting of the center and left abutment (Plate I-F1).

b. 1964 - Remedial grouting of the right abutment and portion of left abutment. See Plate I-F2 for limits of 1964 grouting program.

c. 1973-1974 - Regrouting of portions of the left abutment (Plate I-F3).

Geology

F2. The damsite and reservoir are situated in the Appalachian Plateau Physiographic Province. This broad flat plateau was dissected by streams, now ranging from youth to maturity, resulting in steep walled valleys and pronounced topography with relief ranging up to 1700 ft. The Alvin Bush Dam is underlain by the Devonian Catskill formation which consists of Marine shales, siltstones, and sandstones interbedded with red beds of a semiarid terrestrial origin. The site is situated on the southeast limb of the Wellsboro Anticline. Dips range between 5 deg and 7-1/2 deg SE in the vicinity of the dam.

F3. Two or more joint patterns exist at the site with joints varying from open to clay filled. Beneath the dam, although difficult to define, the top of rock runs from elevation 775 to 900 ft msl. "Along what has been interpreted as top of rock has been a preponderance of badly weathered rock fragments; of sandstone and siltstone, angular to subangular, with isolated rounded gravels, badly weathered, moderately hard to soft, in a red-brown plastic matrix. Overlying shale and siltstone decomposing to clay has migrated into the fractures and joints of the underyling rock; inducing weathering, and rock movement. Overlying stream flow of earlier geologic time has also helped in creating open joints providing for deeper avenues of water, weathering, and clay deposition. Possible valley glaciation of the Pleistocene Epoch could have induced ice wedging, undercutting of bedding, and tension relief after rapid downcutting" (USACE 1965).

Subsurface Investigations

F4. Preconstruction investigations consisted of borings and pressure testing. Information as to the number, locations, and angles of the borings was not available to this study. The investigations were adequate to define general geological and foundation conditions but would probably be considered inadequate for detailed grout curtain design using today's standards. There was a large apparent discrepancy between water pressure tests in the right abutment and performance at the first major filling of the reservoir. Preconstruction pressure testing was done in subzero weather and the possibility of frozen water in lines or pipes could have affected results. It was also documented that no full-time, onsite Government inspector was present during the pressure testing which was done by contract. After the dam was constructed, investigations were continued by monitoring seepage conditions, installation of piezometers, and additional borings. Monitoring and evaluation of postconstruction performance led to additional grouting in 1964 and 1973.

Grouting Design

Original curtain

F5. The original grout curtain consisted of a single line in the left abutment and about half way across the floodplain where a cutoff trench was excavated to rock (Plate I-F1). Tunnel grouting was also included in the work but will not be discussed in this report. The underseepage report (USACE

1965) indicates the Division Geologist and District Geologist were both overruled after they recommended more than one line of grout holes in the left abutment. The plans and specifications (USACE 1959) outlined a tentative program of tunnel grouting and curtain grouting beneath the dam but reserved the right to increase as much as 100 percent or to eliminate any part of the entire drilling and grouting program without any increase of unit prices. The limit of the cutoff trench and grout curtain were determined in the field by the contracting officer. A reach of approximately 650 ft of the dam foundation in the right abutment was not grouted. Even so, excluding spillway grouting, the quantity of grout injected (about 21,000 cu ft) was five times the estimated quantity (4,300 cu ft) and drilling footage (4,527 lin ft) was slightly more than the estimated quantity (4,040 lin ft). The original curtain as constructed consisted of a single line beneath the spillway weir and beneath the dam from station 11+93 to station 19+16. The valley curtain was 50 ft in depth while the depth was increased to 80 ft in the left abutment.

Remedial grouting, 1964

F6. Seepage at the toe of the dam was measured to be 20 cu ft/min in 1963 with the reservoir pool at elevation 840. This was more than anticipated. In March 1964 high reservoir stages (888 ft msl and 883 ft msl) were experienced. Seepage was observed from the east face of exposed rock at the outlet works and at the toe of the dam at station 11+00. Two boils developed 70 ft and 90 ft downstream from the dam toe. In June 1964 a contract was awarded to construct a grout curtain in the right abutment from station 5+40 to station 12+60 (the reach not grouted originally), to regrout a portion of the left abutment from station 16+60 to station 18+30 and to provide a toe drain between station 11+00 and 15+85. Estimated and actual drilling and grouting quantities for this work were as follows:

	Estimated	Actual
Drilling grout holes in overburden, lin ft	14,000	?
Drilling grout holes in rock, lin ft	4,500	8,740.5
Placing grout, cu ft	11,000	17,774

F7. The right abutment curtain extended to a depth of 50 ft into rock with every other primary hole going to 75 ft. Remedial grouting in the left abutment extended 25 ft into rock.

Regrouting of left abutment, 1973-74

F8. Based on continued monitoring and evaluation and the District's final report on underseepage treatment (revised June 1972), the District decided to regrout the left abutment between stations 16+50 and 18+10 and from 15 ft upstream to 17.5 ft downstream of the dam axis (Plate I-F3). Four complete lines and two partial lines were constructed with all grout holes being drilled a minimum of 40 ft into rock. Estimated quantities for this work are not known, however, the actual quantities were:

Embankment drilling	11,860 lin ft
Rock drilling	6,120 lin ft
Grout placed	17,450 cu ft

After the grouting, seepage was reported to be approximately 0.0 cu ft/min at reservoir elevation 840-842, and not significant with the pool at higher elevations (USACE 1976).

Contractual Considerations

Contracts

F9. Each of the three curtain grouting programs at the Alvin Bush project utilized different contractual procedures. During construction of the dam, the initial grouting was performed by a grouting subcontractor, Roval Contracting Company. In 1964 grouting was performed by the prime contractor, Layne New York Drilling Company, and construction of the toe drain was by the subcontractor, Gearhart Excavating Company. Finally, in the 1973-74 program, grouting was performed by the Mobile District utilizing Government furnished equipment and materials, and hired labor. The 1958 and 1964 contracts contained identical "General Conditions" paragraphs (USACE 1959, 1964). Neither contract contained "Changed Conditions" or "Differing Site Conditions" paragraphs which later became standard in Corps contracts, and both contracts had exculpatory language in both the "General Conditions" and "Special Conditions" paragraphs referring to "Site Investigations" and "Physical Data." No claims or legal disputes relating to grouting contract documents were revealed in this investigation; however, it should be noted that both contracts had quantity overruns for drilling grout holes and placing grout. Also, the circumstances for not grouting the right abutment are not known, but had the prime contractor been delayed in order for this work to have been accomplished in the original contract, it might have resulted in a costly contract modification or increase in cost due to longer construction time.

Specification drilling and grouting requirement

F10. Original contract. The specifications technical provisions presented the grouting program as tentative and reserved the right to increase curtain grouting by as much as 100 percent or eliminate any part of the drilling and grouting program. Pay items and estimated quantities were as follows:

Item No. 15		Curtain Grouting	
	a.	Mobilization and demobilization, Job	
	b.	Drilling 1-1/2-in. (ex. grout holes)	4,040 lin ft
	c.	Drilling 3-in. drain holes in concrete and rock	2,100 lin ft
	d.	Drilling 3-in. exploratory holes (NX)	500 lin ft
	e.	Pipe for grout holes	1,000 lb
	f.	Portland cement in grout	4,000 cu ft
	g.	Mineral filler in grout	100 cu ft
	h.	Sand in grout	200 cu ft
	i.	Placing grout	4,300 cu ft
	j.	Connections to grout holes	350 each

Paragraph SC-7 of the contract exempted subitems No. 15b-15j from variations in estimated quantities price adjustments based on underruns or overruns.

F11. Rotary drilling equipment was required for grout holes, drainage holes, and exploratory holes. Core was only required for the exploratory holes. As for grouting equipment, the requirements were very general but subject to approval of the contracting officer. The specifications required that grouting procedures, pressures, mixtures, and the detailed program be determined in the field and as directed by the contracting officer. Stage grouting, split spacing methods were required. Each hole was pressure washed and pressure tested just prior to grouting. The range of water-cement ratios was specified as 3.0 to 0.6. Grouting was through steel nipples grouted into rock. A circulating header was required. Only factual subsurface data were presented in the contract and the specification had a disclaimer clause for any interpretation or conclusion drawn therefrom.

F12. 1964 contract. The technical provisions of the 1964 contract also described the grouting program as tentative but did not place a limit on the amount the work might be increased (such as 100 percent in earlier contract) or decreased. Grouting specifications were similar to the previous contract but more detailed since this program required drilling and grouting from the crest of the embankment, as well as considerably more exploration, piezometer installation, and technical evaluation. Pay items and estimated quantities are shown in Table F1. Grout holes through overburden were specified to be 6-3/4 in. diam. Noncoring bits were required, as well as utilization of drilling mud. On reaching rock, 4-in. casing was required to be installed and firmly seated into rock. Drilling mud was required to be removed from the casing by flushing but maintained near the top of dam elevation in the annular space between the casing and hole walls. Grout holes in rock were specified as 3 in. in diam and required to be drilled with rotary equipment. No core was required; however, every second primary grout hole was also designated as an exploratory hole in rock to be cored. In addition, every fourth primary hole was designated as an exploratory hole in overburden with sampling of overburden materials required. Exploratory holes in rock were to be pressure tested in 5-ft lifts utilizing straddle packers. Split spacing stage grouting methods were required in a single line sequence to a maximum depth in rock of 75 ft. Pressure washing was required just prior to grouting. Grouting mixtures, pressures, procedures, sequence, and the detailed program were to be determined or adjusted in the field as directed by the contracting officer. The range of water-cement ratios specified was 3.0 to 0.6. A circulating header was required. The specifications for pressure grouting required a packer at or slightly below the top of rock. The pressure range for pressure grouting was specified as 10 to 50 psi; however, the specifications stated that most grouting would be done with gravity pressures. Gravity grouting was specified using the tremie method to inject grout at the bottom of the hole through NW drill rods. On completion of grouting, holes were backfilled using the tremie method and the casing withdrawn.

Contract management

F13. Original contract. It is not possible to evaluate overall contract management for the original Alvin Bush Dam construction contract;

however, evidence of a few management decisions and problems which affected grouting quality were revealed during the study. Briefly, these decisions were as follows:

a. During the 1959 grouting, the Corps' field control and supervision was by a construction inspector with little or no grouting experience. Assistance and advice were provided by the District Geologist during visits to the site, but no grouting expert was continuously present to make necessary field decisions. The foundation was lifted by grouting pressures on at least two occasions.

b. During the 1960 grouting, it became necessary to expedite grouting operations in order to complete the required embankment section before the close down of the construction season. At the same time, it became evident that the estimated grouting quantities would be exceeded in the left abutment and the scope of work was more difficult than anticipated. Because of the rushed schedule, the prime contractor tended to "push" the grouting subcontractor by placing fill adjacent to the grouting area. In addition, the District turned down recommendations by the District and Division Geologists to use three rows of grout holes in the left abutment.

c. The inspector's report for the 1960 work indicated the contractor's grouting supervision at the beginning of the work lacked "experience and know how." At times when given instruction, he reacted in an overly aggressive and, in my opinion, highly irregular and inefficient manner (USACE 1965).

d. No project geologist was assigned to the job.

F14. 1964 grouting contract. The right abutment grouting and regrouting a portion of the left abutment was done by contract with Layne, N. Y. Since grouting was done by the prime contractor, contract management was simplified. Included in the contract was an exploratory boring program. Additional core borings were drilled by Mobile District to check the grouting after completion and install piezometers. Because of the seepage measurements since reservoir impoundment, much more attention was apparently given to geotechnical concerns in management of the contract, and more experienced people were available for making field decisions.

F15. Mobile District grouting (1973-74). This was noncontract work.

Drilling

F16. Grout holes were 1-1/2 in. in diam and drilled vertical in the cutoff trench and normal to the slope of the left abutment. Noncoring rotary drills were required. In the 1959 season (29 July to 28 August) drilling and grouting were conducted from station 11+93 to station 15+16.5. The remainder of the original contract grouting from station 15+26 to station 19+16 took place in the 1960 season. Primary holes were on 20-ft spacing and drilled to 50-ft depth in the valley and 80-ft depth in the left abutment. Secondary holes were split spaced and drilled to an average depth of 25 ft. Tertiaries and a few additional splits only went to 10-ft depth. After the work was expedited in 1960, the contractor was allowed to drill primary and secondary holes in a continuous sequence in the left abutment (10-ft spacing). High early-strength cement was allowed and drilling was permitted within 12 hr after grouting instead of the specified 24 hr.

Washing and pressure testing

F17. Pressure washing and testing were required just prior to grouting. Starting grout mixtures (water-cement ratios) were based on the pressure test results.

Grouting mixtures

F18. Neat cement grout was used for the entire job with water cement ratios ranging from 3.0 to 0.6. During the first season, pressure test results were used to determine starting grout mixtures; however, during the second (1960) season grouting of the left abutment, it was a general procedure to start all holes with thinner mixtures regardless of pressure test results.

Pressure

F19. Specified grouting pressures were to be as directed and generally within the range of 5 to 50 psi. The inspection report for the 1959 season indicated that the maximum pressure to be used was 1 psi per foot of hole depth; however, the weight of the grout column was not considered. Pressures used were generally below the maximum but for brief periods, instances occurred where they were higher. Several instances of lifting occurred, and the inspection report indicated that some cases of uplift were noticed when using gage pressures of only 2 psi.

Field procedures

F20. Split spacing, stage grouting procedures were specified with primary grout holes on 20-ft spacing. Grouting pressures, mixtures, and procedures were as directed by the Contracting Officer's Representative. In the left abutment grouting, primary and secondary holes were grouted in sequence and, to expedite the job, high early-strength cement was used and drilling was permitted 12 hr after grouting. In the valley section, because of the low angle bedding plane joints, the rock was uplifted by grouting pressures in a few cases. Slight artesian pressures were occasionally noted. Numerous surface leaks occurred, and some of them reopened when grouting deeper zones. In the left abutment, numerous problems occurred during grouting. Open joints existed transverse to the dam axis extending for considerable distances. According to the Report on Underseepage Treatment, the left abutment was not prepared to the standard presently required by the District and the Corps. The width of the area on the abutment that received special attention for good contact with the embankment was 30 ft, and the treatment given this area was less than presently required (USACE 1965). At the time of construction, additional rock excavation was not considered feasible because of construction difficulty due to the steepness and height of the abutment. The joints were to be filled by grouting. During grouting, numerous surface leaks developed and grout was known to travel as far as 350 ft. To reduce the danger of rock movement due to grouting pressures and because of the many leaks, it was decided to grout the abutment in sequence on 10-ft centers.

Grout take

F21. Grout takes were generally moderate to high. They are summarized as follows:

Reach	Lin ft	Cement, cu ft	cu ft/lin ft
Sta 11+93 to Sta 15+16.5			
Primary Holes	850	1050	1.24
Secondary Holes	250	425	1.70
Tertiary Holes	180	69	0.38
TOTAL	1280	1544	1.11 AVG

Reach	Lin ft	Cement, cu ft	cu ft/lin ft
Sta 15+26 to Sta 17+06			
Primary Holes	450	654	1.45
Secondary Holes	320	548	1.71
Tertiary Holes	220	74	0.33
TOTAL	990	1276	1.16 AVG
Sta 17+11 to Sta 19+16			
Primary Holes	820	9643	11.78
Secondary Holes	455	4894	10.75
Tertiary Holes	630	3009	4.77
Quaternary Holes	352	312	0.90
TOTAL	2257	17858	7.05 AVG
GRAND TOTALS	4527	20678	4.57

F22. Sufficient data were not available during this study to compare pressure test results with grout take; however, if pressure test take was less than 0.1 cu ft/min, the stage was not grouted. Also, the inspector indicated that some holes which took only a small amount of water during pressure testing would take considerable grout. The reverse was also noted; i.e., holes with large water takes would only take a small amount of grout. Rock movement or lifting could explain the first case while fine fractures and grout too thick to penetrate them could explain the second case.

Refusal criteria

F23. Refusal criteria was established in the field as no take in 15 min, or if taking thin grout (2:1 or 3:1), less than 1/4 to 1/2 cu ft in 30 min. The specifications defined refusal as refusing to take any grout whatsoever at three fourths the maximum pressure required for that stage; however, no time was specified.

Records

F24. The contracting officer was required by the specifications to keep records of grouting operations, logs of grout holes, and washing and pressure testing operations. The contractor was required to furnish necessary assistance and cooperation. Since there was no geologist in residence at the project, it is doubtful that grouting data were plotted and related to geological data on a continuous basis.

Drilling and Grouting Methods, 1964 Program

Drilling

F25. Grout hole drilling included drilling and setting casing through embankment and natural overburden materials into bedrock. The 3-in. grout holes were then drilled with rotary equipment full depth without staging if possible. Stage grouting was required, however, in the event circulation was lost and could not be regained after drilling 2 ft in the blind.

Grouting equipment

F26. The grouting plant consisted of two 18-cu ft mixing tanks with "hammermill type" agitators and a "Moyno" progressing cavity pump. A circulating header was used.

Grouting procedures

F27. Although the specifications allowed pressure grouting through a packer seated in rock, all of the holes were gravity grouted. Grout mixtures varied from a water-cement ratio of 3.0 to a ratio of 0.6. Initial mixture ratios were determined by the drilling history of the holes; those deemed "tight" were grouted with a thin mixture. The general procedure was to let the grout in the primary sequence penetrate the rock fractures for longer distances by holding thinner mixtures for longer intervals of time. On the secondary, tertiary, and quaternary series, the general procedure was to contain the grout within close proximity of the grout curtain by escalating mixtures to a stiffer consistency more rapidly.

F28. Open holes were started with grout having a water-cement ratio of 1.0 and the mixture was thickened as appropriate. In one instance (Drill Hole 10) a sanded mixture was required after 140 cu ft of 0.6 grout had been pumped into the hole. The mixture used was a mixture of 1-1-1 (cement, sand, and water).

F29. When the grout column had risen to the top of the casing in the hole, pumping was continued until the column remained static. Then pumping was discontinued and the hole was considered grouted.

F30. Backfilling was accomplished by raising the casing 2 ft off the bottom of the hole and pumping in grout until it reached the top of the hole. The casing was then raised until one joint could be removed and the hole again filled to the top with grout. This procedure was followed until the casing was all removed from the hole and the hole backfilled level with the top of the dam. Because of the previously noted drilling into rock by the air rig, many of the primary holes required considerable quantities of grout to backfill them. The backfill was actually grouting the upper portions of the badly weathered and fractured rock. Where possible, backfilling was accomplished with grout having a water-cement ratio of 1.0. Where larger quantities of grout were needed, 0.8- and 0.6-neat mixtures were used as well as sanded mixtures. Sand and flyash were used separately to thicken mixtures. Both sand and flyash were used in 1-1-1 ratio. A common practice in reducing grout waste at the end of a shift was to inject additional grout into the grout columns which had settled in backfilled holes.

Grout takes

F31. Tables F-2 and F-3 show the grout take in rock for each grouting series (USACE 1965). Comparison of grout takes for each series shows a reduced grout take per foot of hole indicating a general tightening up of the foundation.

Refusal criteria

F32. Grouting continued until the grout column was static at the top of dam in the 4-in. casing.

Records

F33. Detailed geological, drilling and grouting records were required for continuous evaluation during this program. The contracting officer was responsible for these records. To this end, the specifications required the contractor to furnish all necessary assistance and cooperation. In addition, the contractor was required to furnish an accurate Driller's Log of all exploratory holes, including pressure testing records.

Drilling and Grouting Methods, 1973-74 Program

General

F34. In the 1973-74 regrouting program for the left abutment of the dam, deep area grouting was required utilizing split spacing stop grouting methods in a multiline sequence. The job was done in two phases, each approximately 3 months in duration. Phase I consisted of doing three lines and a short stretch of a fourth line (Lines "A," "B," "C," and partial "E") (Plate I-F3). One complete and two partial lines, along with additional split spacing on Phase I lines, were done in Phase II (line "D" and partials "E" and

"F") (Plate I-F3). Grout holes were drilled a minimum of 40 ft below top of rock. The main objective was to cut off seepage in the foundation rock, especially in the zone right below the embankment and to reduce uplift pressures on the embankment downstream of the dam centerline.

Drilling grout holes

F35. General. Grout hole drilling, while done in two phases, followed the same procedures throughout the job. Primary holes were spaced 10 ft on centers, and the lines were so staggered that primary holes on adjacent lines were offset up to 5 ft. Split spaced, secondary, tertiary and testing holes were drilled on a line once the primaries were completed. All holes except the ones on "B" line were vertical. "B" line holes were inclined at 15 deg from the vertical, into the left abutment. The "A" line was the farthest downstream, and the first drilled, with "B" line, the upstream most line, second drilled. The other lines were drilled between these lines.

F36. Method of drilling. Air was used as the drilling media. While drilling through the embankment, a squeezing condition was encountered in several holes in the saturated impervious zone, and this required the use of drilling mud to keep the hole open until casing could be set. Grout holes in rock were drilled using a 2-1/2-in. down-hole air hammer with a 2-15/16-in. X-bit. In Phase II, a 3-in. mega-drill with a 3-1/2-in. button bit was also used. The latter drill and bit type cut drill time per hole in half and gave superior cutting returns, both in size and quantity of chips. With this larger bit, 4-in. casing was required through the embankment. In four of the holes on the "A" line, a 2-1/2-in. drive sampler was used to advance the hole from approximately 20 ft above the top of rock to top of rock, using a 3-in. rock bit to ream the hole after each drive. In these holes a minimum 5-ft core run was made to verify top of rock.

F37. Drilling equipment. Two truck-mounted Failing "315" rotary-drill rigs were used for the complete operation. The air for drilling was provided by a Joy 1200 cu ft/min-100 psi towed compressor, and a 350 cu ft/min-250 psi Leroy skid-mounted compressor.

F38. Rate of drilling. In drilling the grout holes the rate of penetration (min/ft) helped in the identification of the materials being cut, particularly in holes where either the air was lost or the water encountered prevented the cuttings and dust from being blown clear. With the 2-1/2-in. down-hole air hammer and X-bit, sandstone cut at 5 to 6 min/ft, siltstone at

2.5 to 3.0 min/ft and shale at 1.0 to 1.5 min/ft. When the 3-in. mega-drill and button bit were used, all the above times were cut approximately in half.

F39. Loss of drilling media. Drilling air was lost to some extent in the rock in all holes that took grout. Of the six lines of grout holes, the "A" line had the most holes which had a partial or complete air loss, while the holes on the "B" line had virtually no air losses. While drilling hole D-12, air return was lost at a depth of 35.0 ft, and it came out through holes D-13, D-14, and D-15 (about 30 ft away). The air loss was probably along the contact between two lifts of placed material. In backfilling the hole, a close watch was maintained on the quantity of grout to see if penetration of the weak zone would occur, but the volume of grout used was very close to the estimated volume.

F40. Pressure testing. Pressure testing of grout holes was done using the same setup of pumping equipment and header as described in paragraph 41. A maximum water pressure of 1 lb/ft of depth to the bottom of the packer was used.

Grouting of foundation

F41. Equipment. The grouting plant consisted of a mixer and an agitator tank which had a capacity of 16 cu ft. A sump well on the side of the agitator tank held the suction end of a 3-in. line to the grout pump. Grout, discharged by the pump, traveled through the 2-in. supply line, grout header, and 2-in. return line to the agitator tank. The grout pump was a "Moyno" progressing cavity type powered by a Ford industrial motor. The grout header was set up for either pressure grouting or gravity grouting. Water used in grout and in pressure testing came directly from the reservoir. The cement was Type II Portland cement supplied in 94-lb bags. Sand used in certain mixtures was a fine-grained washed-mortar sand. A plywood, tin, and tarp structure enclosed the complete grout plant and cement storage area for protection against inclement weather.

F42. Grout mixtures. Neat cement grout mixtures varied from 3 to 1 water/cement ratio to a 0.6 to 1 ratio. Sanded grout mixtures were either 0.75 to 1 or 0.6 to 1 water/cement ratio. Grout mixtures were designed in the field to meet the different conditions encountered.

F43. Grout delivery. The arrangement of the equipment was such as to provide a continuous circulation of grout throughout the system and to permit accurate pressure control. When grouting on days when temperatures were in the subteens and the wind blowing, heat had to be applied to the grout lines, metal connections, and the header to prevent freezing. Failure to counter freezing at any point would result in the entire system becoming frozen solid. Heat was supplied using a brush burner and a small bottle of butane gas.

F44. Grout placement. In pressure grouting, mixtures as thin as 3.0 (water/cement ratio) were used in starting holes, while mixtures of 2.0 were used to start gravity grout zones.

F45. Pressure grouting. In the pressure grouting operation the grout header was connected to the hole by means of a pipe to the expanding packer. Grouting pressures were held to 1 lb/ft of depth for the total allowable pressure. During pressure grouting, the full permissible grout pressure of 1 lb/ft of depth was applied as soon as possible and maintained throughout the operation. After having reached the maximum pumpable mixture, pumping was continued at this consistency at the maximum permissible pressure until a declining rate of consumption indicated the hole was reaching refusal. Refusal for a pressure grouted zone was when the zone took less than 0.5 cu ft of mixture in a 5-min period.

F46. Gravity grouting. In the gravity system the header was attached to the grout pipe and the complete unit was hung in the open hole. The only pressure in this type of grouting was from static head, which was the weight of the grout in the column from the top of hole to the point or depth of measurement, and ranged from 0.55 to 0.78 lb/lin ft of depth. Gravity grouting was done originally with the bottom end of the grout pipe (BX casing), 13 ft below the top of rock. After nearly grouting in the grout pipe in a couple of holes (because the "take" zone was above the bottom of the pipe), all but 5 ft of pipe were removed, and the grout was allowed to free fall through the NX casing which was firmly set in rock. The mixtures were progressively thickened until the maximum pumpable mixture was reached, then pumping was continued until refusal was reached. Refusal for gravity grouting was achieved when grout reached the top of the NX casing and remained there.

E47. Backfilling holes. Backfilling of the holes was accomplished using a mixture of 1.0 or thicker. The casing was first pulled back several feet and then grout pumped in until it reached the top of casing and stabilized. Ten feet of casing was then removed and again the hole was filled to the top of the casing with grout, and the process was repeated until all casing was removed from the hole. In most cases, by the time two casing lengths had been removed, the grout returned on the outside of the casing before filling the inside. The grout returning up the outside of the casing was preceded by any water in the hole. This water and thin grout was allowed to flow from the hole until a thick, rich mixture showed. Any remaining casing was pulled continuously as long as the grout could be seen in the hole. When all the casing was removed, the grout was again brought to the surface and permitted to set.

F48. Grout leaks. Whenever grout leaks developed downstream of the dam, grout was allowed to flow out of the leak until it sealed itself. All the leaks developed while gravity grouting under a vacuum; the hole was sucking grout faster than it could be mixed and pumped. In all cases, the leaks showed up after the grout had been thickened to the maximum possible mixture.

F49. Special techniques. Chemical dyes were used on the three lines of Phase I grouting to check the grout spread. The dyes were shown on the drill logs of the grout holes and also on the logs for the cored check holes. From the colored grout cored while drilling, it was concluded that most of the grout travel was in a downstream direction and into the hill, or downdip (USACE 1976).

F50. Analysis of grouting. Drilling and grouting data were recorded in field logs at the time the work was performed. These logs tabulated a record of drilling, results of pressure test operations, time of change of each grouting operation, pressure, rate of pumping, the amount of solids, cement and sand for each change in water/solid ratio, and other data pertinent to the grouting operations. Master grout profile charts were prepared and brought up-to-date daily. These charts showed hole elevation, angle of drilling, depth to embankment-rock contact, the two zones of grouting, and coded quantities. Also included was a plan view of the hole layout on top of the dam. The field logs, grout charts, piezometer readings, and other assembled data are part of the history and constitute a ready reference of factual data on which to base judgments regarding the effectiveness of the grouting program. Drilling and grouting quantities exceeded the estimated amounts by 145 and 281 percent, respectively. This is because a large number of split-spaced holes were required due to very high grout takes on the "A" line; also, all full lines were extended up station an additional 30 ft, and lines C and D were extended down station 20 ft. The up station extension was to force the seepage path, if any, farther into the hillside, while the down station extension was to check on possible seepage paths of the blocked water around the right side of the newly grouted area. Tables F4 and F5 illustrate the relationship of the drilling and grouting quantities for the grout lines and zones.

F51. A comparison of the drilling and grouting for the four complete and two partial grout lines (Table F4) shows a tightening trend in the foundation in the grouted area. Line "A" (the farthest downstream line) shows high takes overall. This is primarily due to the fact that this line is 17.5 ft downstream of the previous grout lines in an area of the foundation that did not require a really thorough final cleanup or dental work before placing embankment. From the table it also appears that the secondary holes took more grout per linear foot than the primary holes, but this was because of the extremely high takes of two of the eleven holes, and these were high on the left abutment. Nine of the secondary or split-spaced holes show a very definite decrease in grout take when compared to the primary holes on either side. Tertiary holes which were drilled on either side of the biggest secondary takes were both tight. The "B" line (upstream most line) had a very low grout take, probably because it was located between the original grout line and the 1964 grout line. Lines C, D, E, and F show a progressive decrease in the amount of grout placed which reflects a tightening of the area. Besides the "A" line, only the "C" line required any split-spaced secondary holes, and only two of the eight holes took grout.

F52. From Table F5 it can be seen that Zone I, the zone generally from top of rock to 15 ft below top of rock, was the zone where almost all the grout was placed, both in primary and secondary holes. Zone II, the pressure grout zone, took very little grout in the primary holes, and none in the split-spaced secondary holes. The large grout takes in Zone I were due to the fact that this zone contained many open and/or highly weathered bedding and high angle joints which were interconnected both horizontally and vertically over a large area which had not previously been completely grouted. This can be seen by the fact that grout seeped from joints at the toe of the dam and from the left abutment hillside as much as 550 ft downstream of the centerline. A contributing factor to the openness of the rock is the possibility that during the regrouting operation of 1964, the upper 10 to 15 ft of weathered rock, Zone I, had been drilled through by the contractor who believed that he was still in the embankment. The top of rock as encountered in holes on lines B and C, 215 ft on either side of the dam centerline shows the rock to be much higher (USACE 1976).

Unexpected Geological Conditions Encountered During Construction

F53. Significant quantity overruns were experienced during grouting due to the presence of many open and weathered joints. Two programs of remedial grouting were required.

Evaluation of Grouting

F54. After the regrouting of the left abutment in 1974, it was concluded that a satisfactory grout curtain had been completed. This is based on weir measurements, temperature measurements, dye test, piezometer readings, and evaluation of performance. Permanency of the treatment and performance at high pool levels above Elevation 913 is not known. The piezometric profile at the base of the left abutment (Plate I-F4) indicates considerably improved grout curtain performance after regrouting in 1973-74. Monitoring of seepage conditions is necessary to assure detection of any future changes immediately.

F55. The original grouting contract was probably adversely affected by all of the following:

a. There was no resident geologist assigned to the job during the grouting.

b. An expedited grouting program apparently led to using a single line in the left abutment rather than three lines as recommended by both the District and Division geologists, and to other changes in field procedures which may have been detrimental.

c. Additional excavation and foundation preparation probably should have been required on the left abutment rather than relying on grouting to seal the open joints.

d. Pressures were too high for conditions.

Costs

F56. Cost data were not available to the investigators during this study; however, based on estimated unit prices and actual quantities, our estimates of actual costs are as follows:

			Estimated Unit Price	Actual Quantity	Amount
a.	Original Contract Curtain Grouting	Unit			
	(1) Mobilization & Demobilization	ea	2,500	1	2,500
	(2) Drilling 1-1/2-in. Grout Holes	lin ft	4.50	4,527	20,371
	(3) Pipe for Grout Holes	lb	.70	1,000	700
	(4) Portland Cement in Grout	cu ft	3.00	20,678	62,034
	(5) Mineral Filler in Grout	cu ft	3.50	100	350
	(6) Sand in Grout	cu ft	1.50	200	300
	(7) Placing Grout	cu ft	3.50	20,678	72,373
	(8) Connection to Grout Holes	ea	2.00	350	700
				TOTAL	$159,328
b.	1964 Remedial Grouting Contract				
	(1) Mobilization & Demobilization	ea	1,000	1	1,000
	(2) Drilling Grout Holes in Overburden	lin ft	6.00	14,000	84,000
	(3) Drilling Grout Holes in Rock	lin ft	6.00	8,746	52,476
	(4) Portland Cement in Grout	cu ft	1.65	17,774	29,327
	(5) Mineral Filler in Grout	cu ft	0.45	500	225
	(6) Sand in Grout	cu ft	0.25	500	125
	(7) Placing Grout	cu ft	3.75	17,774	66,652
	(8) Connections to Grout Holes	ea	3.00	800	2,400
				TOTAL	$236,205

c. 1973 Remedial Grouting (Mobile District)

2 crews x 26 weeks = 52 rig weeks @ $5,000 =		$260,000
cement	17,450 cu ft @ 3.50	61,075
	TOTAL	$321,075

Assumed unit prices are as follows: Drilling - $8.64/lin ft
Placing Grout - $6.00/cu ft
Cement - $3.50/cu ft

Performance

F57. Seepage problems and evaluation of conditions led to two additional grouting programs after construction of the dam. The present grout curtain performance is apparently satisfactory.

References

US Army Corps of Engineers. 1959. Specifications for Kettle Creek Dam, Baltimore District, Invitation No. CIVENG-18-020-59-8.

___________. 1964. Specifications for Grouting and Toe Drain, Alvin R. Bush Dam, Baltimore District, Invitation No. CIVENG-18-020-64-76.

___________. 1965. Alvin R. Bush Dam, Report on Underseepage Treatment, Baltimore District, 52 pp.

___________. 1976. Alvin R. Bush Dam, Report on Regrouting of Left Abutment, Baltimore District, Vol 1, 15 pp.

___________. 1976. Alvin R. Bush Dam, Report on Regrouting of Left Abutment, Baltimore District, Vol 2, Appendices.

Table F1

Pay Items and Estimated Quantities for Grouting

Alvin R. Bush Dam, 1964 Contract

Item No.	Description	Estimated Quantity	Unit
1	Mobilization and demobilization	---	job
2	Excavation	12,400	cu yd
3	Backfill		
	a. Filter material	1,900	cu yd
	b. Drainage fill	3,000	cu yd
	c. Granular backfill	3,800	cu yd
3A	Riprap	50	sq yd
4	Drilling piezometer holes		
	a. In overburden	670	lin ft
	b. In rock	115	lin ft
5	Casing left in holes	670	lin ft
6	Standby time	60	hour
7	Drilling grout holes - overburden		
	a. First 8,000 ft	8,000	lin ft
	b. Over 8,000 ft	6,000	lin ft
8	Drilling grout holes - rock		
	a. First 2,500 ft	2,500	lin ft
	b. Over 2,500 ft	2,000	lin ft
9	Drilling exploratory holes - earth foundation		
	a. First 400 ft	400	lin ft
	b. Over 400 ft	300	lin ft
10	Drilling exploratory holes - rock		
	a. First 800 ft	800	lin ft
	b. Over 800 ft	600	lin ft
11	Portland cement in grout		
	a. First 6,000 cu ft	6,000	cu ft
	b. Over 6,000 cu ft	4,000	cu ft
12	Mineral filler in grout		
	a. First 300 cu ft	300	cu ft
	b. Over 300 cu ft	200	cu ft

(Continued)

Table F1 (Concluded)

Item No.	Description	Estimated Quantity	Unit
13	Sand in grout		
	a. First 300 cu ft	300	cu ft
	b. Over 300 cu ft	200	cu ft
14	Placing grout		
	a. First 6,000 cu ft	6,000	cu ft
	b. Over 6,000 cu ft	5,000	cu ft
15	Connections to grout holes		
	a. First 500	500	ea
	b. Over 500	300	ea
16	Pressure testing (hydraulic)		
	a. First 100 hr	100	hr
	b. Over 100 hr	100	hr

Table F2

Remedial Curtain Grouting - Right Abutment
Foundation Grouting, Alvin R. Bush Dam

Primary Holes		
Number	Total Grout cu ft	Total Footage in Rock
1	205	75
2	6	50
3	346	75
4	177	40
5	592	77
6	64	52
7	314	77
8	1260	50
9	146	77
10	750	85
11	216	77
12	1096	50
13	622	77
14	347	52
15	1135	77
16	714	50
17	1014	77
18	558	52
19	14	77
20	904	58
21	26	76
22	382	52
23	18	77
24	22	50
25	104	77
		51
27	172	77
28	232	50
29	121	76
		50
31	140	75
		50
33	104	77
34	16	52
35	212	78
36	6	50
Sum Total	12,035*	2,323

Grout per foot 5.181 cu ft

PRIMARY HOLES

Secondary Holes		
Number	Total Grout cu ft	Total Footage in rock
1A	8	50
2A	8	50
3A	36	50
4A	92	50
5A	182	50
6A	89	50
7A	6	50
8A	2	50
9A	18	50
10A	36	50
11A	213	50
12A	6	50
13A	8	50
14A	13	50
15A	65	50
16A	158	50
17A	184	50
18A	309	52
19A	273	50
20A	10	50
21A	4	50
22A	4	50
23A	10	50
24A	28	50
25A	4	50
26A	8	50
27A	26	50
28A	22	50
29A	4	50
30A	34	51
31A	4	50
32A	16	50
33A	66	50
34A = T-1	124	57
T-5	204	50
Sum Total	2,274*	1,760

Grout per foot 1.292 cu ft

SECONDARY HOLES

(Continued)

Table F2 (Continued)

Tertiary Holes					
Number	Total Grout cu ft	Total Footage in Rock	Number	Total Grout cu ft	Total Footage in Rock
A-1	0	0	18A-1	102	50
1A-1	3	25	18A-2	299	51
1A-2	2	25	19A-1	26	49.2
2A-1	32	25	19A-2	289	50
2A-2	22	50	20A-1	4	50
3A-1	5	60	20A-2	4	25
3A-2	4	50			25
4A-1	4	50	21A-2	64	25
4A-2	6	60	22A-1	31	59.5
5A-1	6	60	22A-2	7	25
5A-2	5	50	23A-1	2	25
6A-1	6	50	23A-2	5	35
6A-2	13	50	24A-1	5	25
7A-1	5	50	24A-2	4	24.5
7A-2	5	50	25A-1	6	25
8A-1	10	42	25A-2	7	25
8A-2	4	60	26A-1	4	25
9A-1	3	60	26A-2	6	25
9A-2	5	60	27A-1	4	50
10A-1	6	69.8	27A-2	9	50
10A-2	325	69	28A-1	11	50
11A-1	378	60	28A-2	10	50
11A-2	67	27.5	29A-1	4	50
12A-1	4	50	29A-2	4	25
12A-2	4	40	30A-1	5	50
13A-1	348	40	30A-2	12	50
13A-2	6	25	31A-1	9	50
14A-1	4	50	31A-2	8	25
14A-2	8	50	32A-1	8	52
15A-1	7	50	32A-2	4	25
15A-2	287	50	33A-1	7	47.5
16A-1	6	50	33A-2	7	50
16A-2	122	50	34A-1	4	50
17A-1	92	39.2	34A-2	6	50
17A-2	4	50	35A-1	36	70.3
			Sum Total	2821*	3061.5

Grout per foot 0.921 cu ft

TERTIARY HOLES

(Continued)

Table F2 (Concluded)

Number	Total Grout cu ft	Total Footage in Rock	Number	Total Grout cu ft	Total Footage in Rock
8A-1A	4	25	15A-2A	2	50
8A-1B	2	25	15A-2B	4	40
9A-2B	4	60	16A-2A	4	40
10A-1A	4	73	16A-2B	2	40
10A-1B	2	65.5	17A-1A	20	40
10A-2A	3	67	17A-1B	3	40
10A-2B	4	71	18A-1A	28	40
11A-1A	3	71	18A-1B	6	40
11A-1B	3	50	18A-2A	3	25
11A-2A	2	50	18A-2B	3	25
11A-2B	5	50	19A-2A	8	40
13A-1A	8	40	19A-2B	12	40
13A-1B	3	40	19A-2B	6	25
			Sum Total	148*	1172

Grout per foot 0.126 cu ft

QUATERNARY HOLES

	Grout cu ft	Rock Drilling cu ft
PRIMARY	12,035.0	2,323.0
SECONDARY	2,274.0	1,760.0
TERTIARY	2,821.0	3,061.5
QUATERNARY	148.0	1,172.0
TOTAL	17,278.0*	8,316.5

Grout per foot 2.08 cu ft
Average of four series

* Note: Quantities do not include backfill quantities.

Table F3

Remedial Curtain Grouting - Left Abutment
Foundation Grouting, Alvin R. Bush Dam

Primary Holes			Secondary Holes		
Number	Total Grout cu ft	Total Footage in Rock	Number	Total Grout cu ft	Total Footage in Rock
L1	4	25	L2	5	25
L3	4	25	L4	6	25
L5	4	25	L6	20	10
L7	4	25	L8	3	10
L9	4	25	L10	83	25
L11	4	25	L12	4	110
L13	7	25	L14	9	10
L15	4	25	L16	27	10
L17	260	25	L18	3	25
Sum Total	295*	225	Sum Total	160*	150

Grout per foot 1.31 cu ft

PRIMARY HOLES

Grout per foot 1.07 cu ft

SECONDARY HOLES

Tertiary Holes		
Number	Total Grout cu ft	Total Footage in Rock
L5A	4	10
L6A	3	10
L9A	9	10
L10A	22	15
L16A	2	10
Sum Total	41*	55

Grout per foot 0.75 cu ft

TERTIARY HOLES

* Note: Quantities do not include backfill quantities.

Table F4

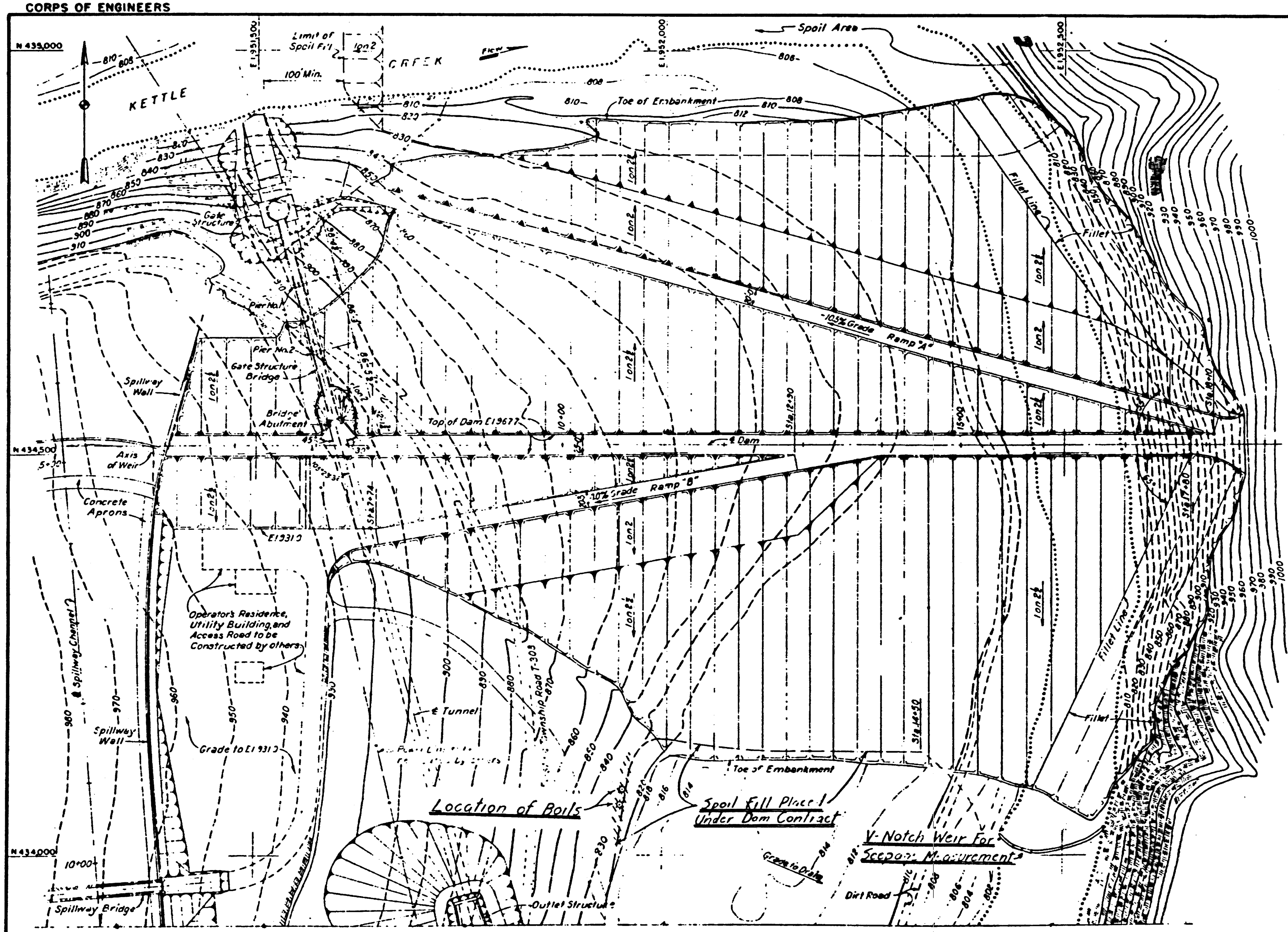
Drilling and Grouting Summation of Lines (Entire Curtain)

	Footing Drilled lin ft		Grout Placed	Grout Distribution cu ft/lin ft of Hole	
	Total	Rock	cu ft Solids	Total	Rock
LINE					
A					
Primary	2,790.0	984.7	8,683.5	3.11	8.11
Secondary	1,801.4	592.8	5,849.6	3.25	9.87
Tertiary	220.0	82.0	0.0	0.0	0.0
Total	4,811.4	1,659.5	14,533.1	3.02	8.75
B					
Primary	2,730.2	968.4	213.5	0.078	0.22
C					
Primary	3,219.0	1,067.9	1,744.0	0.54	1.63
Secondary	1,533.2	377.7	149.2	0.097	0.39
Total	4,752.2	1,445.6	1,893.2	0.398	1.31
D					
Primary	3,392.0	1,181.2	606.7	0.18	0.51
E					
Primary	1,297.0	420.5	93.5	0.07	0.22
F					
Primary	1,191.0	444.4	109.5	0.09	0.25
TOTALS					
Primary	14,425.2	5,067.1	11,450.7	0.79	2.26
Secondary	3,334.6	970.5	5,998.8	1.80	6.18
Tertiary	220.0	82.0	0.0	0.0	0.0
GRAND TOTALS	17,979.8	6,119.6	17,449.5	0.97	2.85

Table F5

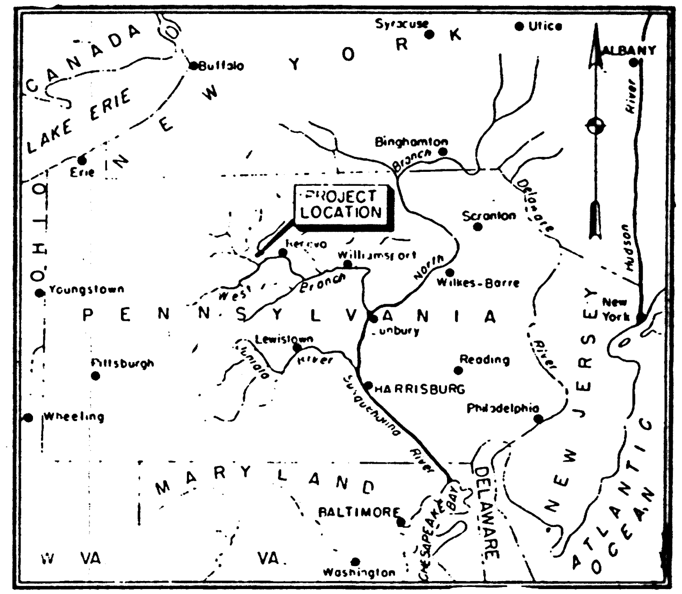
Drilling and Grouting Summation by Zones of Entire Grout Curtain

	Rock Footage Drilled, lin ft	Grout Placed cu ft Solids	Grout Distribution cu ft/lin ft
Zone I (Gravity)	1,444.4	15,642.8	10.83
Zone II (Pressure)	4,675.2	1,806.7	0.386
Zone I (Gravity)			
Primary	1,130.1	9,644.05	8.53
Secondary	284.3	5,998.8	21.10
Tertiary	30.0	0.0	0.0
Zone II (Pressure)			
Primary	3,937.2	1,806.7	0.46
Secondary	686.1	0.0	0.0
Tertiary	52.0	0.0	0.0



PLAN

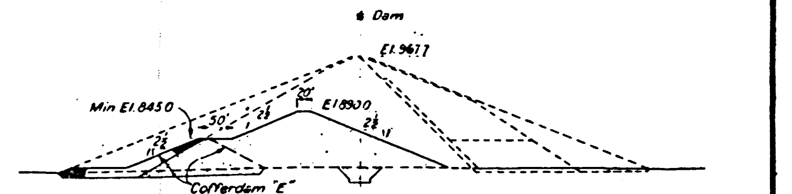
60 0 60 120 FEET



VICINITY MAP

SCALE OF MILES

50 0 50 100

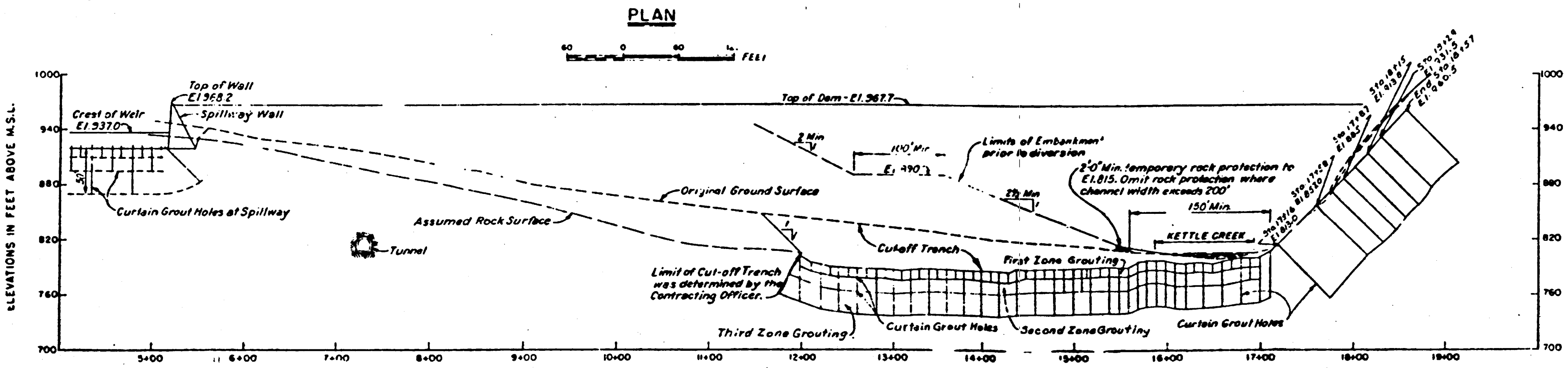


MINIMUM EMBANKMENT SECTION AT END OF CLOSURE YEAR

100 0 100 200 FEET

NOTE:

This figure was made from the as built contract drawing (no. 140 A-36-2) for the Dam which was modified to include Vicinity Map and show locations of Boils, Spoil Fill and Weir.



PROFILE ALONG ℄ DAM

LOOKING UPSTREAM

60 0 60 120 FEET

CORPS OF ENGINEERS, U.S. ARMY
OFFICE OF THE DISTRICT ENGINEER
BALTIMORE DISTRICT
BALTIMORE, MARYLAND

SUSQUEHANNA RIVER BASIN - KETTLE CREEK, PA.

KETTLE CREEK DAM

EMBANKMENT

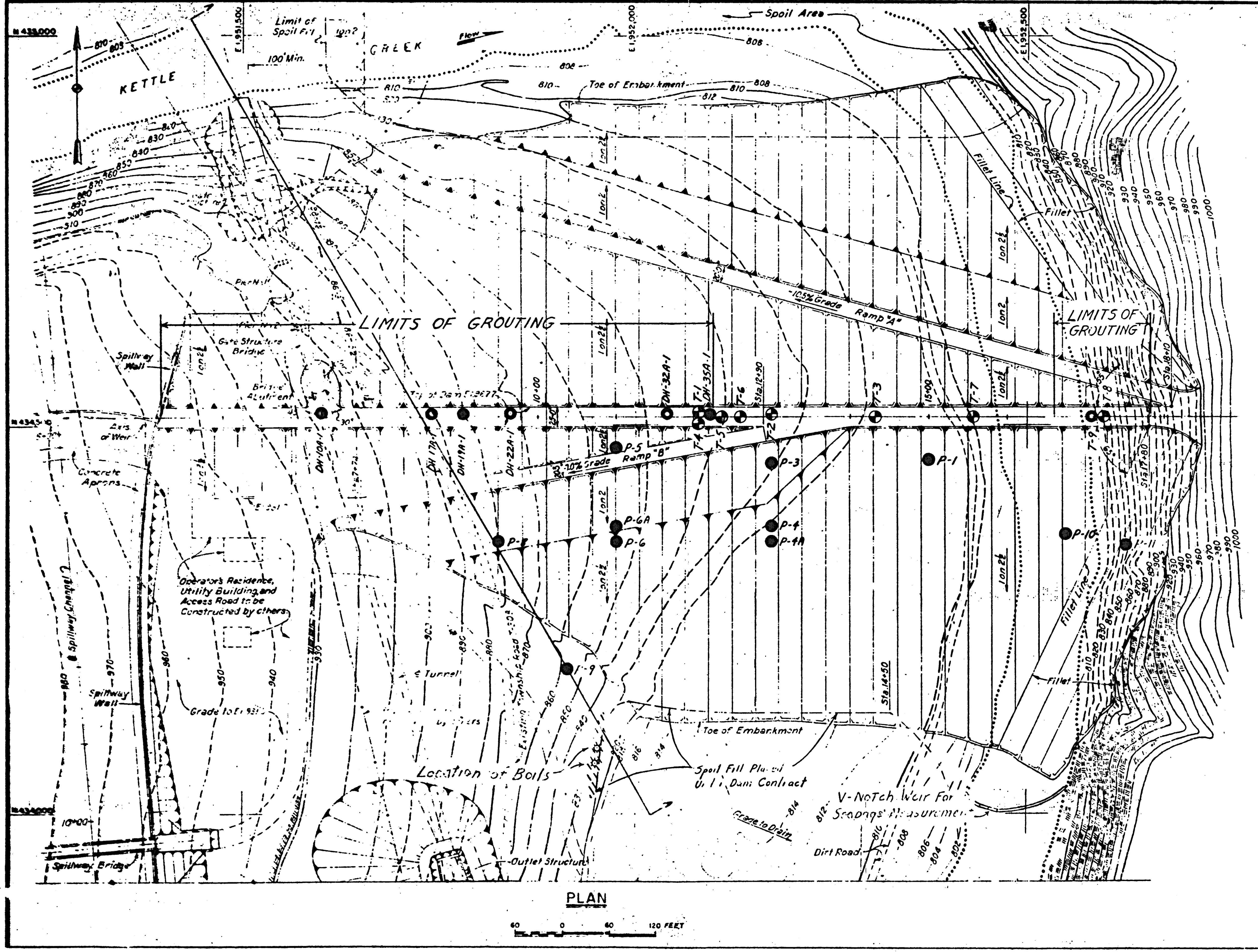
PLAN AND PROFILE

DRAWN BY: TRACED BY: CHECKED BY:

APPROVED FOR: DATE:

SCALE AS SHOWN SPEC NO. DRAWING NUMBER

CORPS OF ENGINEERS



PLAN

Hole No.	Station	Offset
P-1	15+00	55'R
P-3	13+00	60'R
P-4	13+00	140'R
P-4A	13+00	160'R
P-5	11+00	40'R
P-6	11+00	160'R
P-6A	11+00	140'R
P-8	9+50	160'R
P-9	10+35	325'R
P-10	16+75	150'R
P-11	17+50	165'R
T-1	12+08	4'L
T-2	13+00	4'L
T-3	14+32	℄
T-4	12+08	4'R
T-5	12+30	℄
T-6	12+60	℄
T-7	15+57	℄
T-8	17+20	℄
T-9	17+10	℄
DH-10A-1	7+25	4'L
DH-17A-1	8+65	4'L
DH-19A-1	9+05	4'L
DH-22A-1	9+65	4'L
DH-32A-1	11+65	4'L
DH-35A-1	12+25	4'L

LEGEND

- ● Piezometer Well.
- ◐ 3" I.D. Drill Hole (Disturbed Sampling, Water Loss Test.)
- ○ 6" I.D. Drill Hole (Undisturbed Sampling, Water Loss Test in T-9 only.)

Note: For section A-A see Fig 24

ALVIN R. BUSH DAM

Location Plan

Piezometer Wells & Exploratory Borings

February, 1965 RLW

PLAN VIEW

SCALE

10 0 10 20 30 40 50 FT.

LEGEND

- ○ – PHASE I GROUT HOLES A & C LINES
- △ – PHASE I GROUT HOLES B LINE, 15° ANGLE
- ⬡ – SPLIT SPACED (SECONDARY) GROUT HOLES-PHASE
- □ – PHASE II GROUT HOLES DONE IN PHASE I
- ◇ – GROUT CHECK HOLES
- ◩ – PHASE II GROUT HOLES D, E & F LINES
- ⬢ – SPLIT SPACED (SECONDARY) GROUT HOLES-PHASE
- ● – TERTIARY GROUT HOLES
- ◐ – ADDITIONAL HOLE TO PHASE I LINE DONE IN PHASE II
- ◆ – GROUT CHECK HOLES - PHASE II

NOTES:

1. PHASE I COVERED FROM 4 SEPT 73 TO 13 DEC 73.
2. PHASE II COVERED FROM 15 MARCH 74 TO 2 JUNE 74.

ALVIN R. BUSH DAM

LEFT ABUTMENT REGROUT

GROUT HOLE LOCATIONS

WBT	2 APRIL 1975	PLATE 2

PLATE I-F3

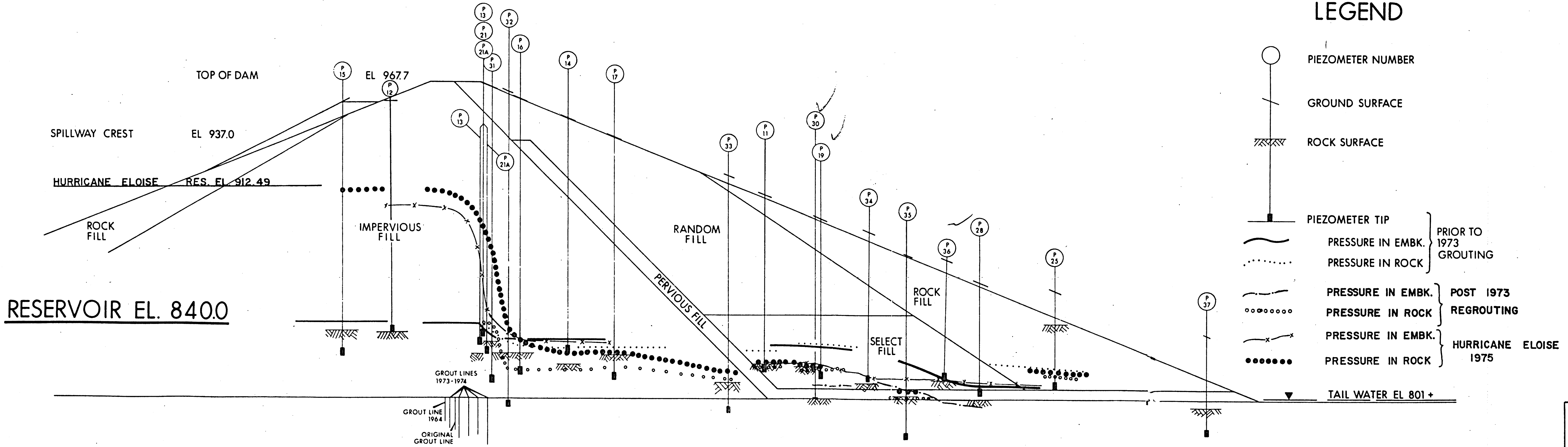
PLAN VIEW

SCALE

10 0 10 20 30 40 50 FT.

NOTES:

ALVIN R. BUSH DAM
PIEZOMETRIC PROFILE
BASE OF LEFT ABUTMENT



LEFT ABUTMENT SECTION A-A

ALVIN R BUSH DAM LEFT ABUTMENT REGROUT PIEZOMETRIC PROFILE		
WBT	OCT 1975	PLATE 14

PROJECT G: ABIQUIU DAM

(This case history was developed with the assistance of Victor Huesinger and Jim McAdoo, Albuquerque District)

Location and Description of Project

G1. Abiquiu Dam is located on the Rio Chama, a tributary of the Rio Grande, about 35 miles northwest of Espanola, New Mex. The project was authorized for the purpose of flood control and sediment detention. It consists of a rolled earthfill dam, a controlled outlet works, and a spillway. The dam has a crest length of 1,540 ft, a crest width of 30 ft, and is about 325 ft above streambed. The outlet works consists of a 12-ft-diam tunnel, 2,260 ft long in the left abutment, intake structure, gate chamber, and flip bucket. The 40-ft wide, unlined, uncontrolled spillway was excavated in a saddle about 4,000 ft landward from the left abutment. It has a total length of 2,600 ft and is excavated in a sandstone with interbedded shale layers. A positive cutoff trench was provided under the dam and a single line grout curtain was installed from the base of the trench (USACE 1963). The dam was designed and constructed by the Albuquerque District. The outlet works was completed under the first contract. Construction of the embankment and spillway was started in March 1959 and completed in February 1963 by F. K. Mittry Construction Company of Los Angeles, Calif. The original grout curtain was included in this contract. During 1966 supplemental drilling and grouting operations were conducted. The work included grouting around the control shaft, a 500-ft grout curtain extension on the left abutment, horizontal drain holes in the left abutment, excavation of open drainage ditches in the downstream berm area, and installation of piezometers and observation wells (USACE 1966). Work began in April 1966 and was completed in January 1967. Continental Drilling Company, Los Angeles, Calif., was the contractor. Additional drilling and grouting were completed during 1979-80 from the top of dam and included extension of the curtain into the abutment. This work was done in two increments and under separate contracts. Continental Drilling Company was also the drilling and grouting contractor for these increments.

Geology

G2. Regionally the sedimentary rocks include those in age from Pennsylvanian through Pliocene. The igneous rocks of the area can be divided into the Precambrian intrusives in the San Pedro Mountains in the west, the Tertiary and Quaternary extrusives of the southern San Juan Mountains in the north, and northern Jemez Mountains in the south. Widespread disturbances at the end of the Cretaceous Period created a mosaic of irregular normal fault blocks or structural units which vary considerably in size, shape, and orientation. After a long erosional period which produced a peneplain, Tertiary sediments were deposited. Extensive crustal adjustments at the end of the Tertiary caused faulting and uplifting. This was followed in Quaternary time by many erosional cycles with volcanic interruptions. The site is located in a canyon approximately 350 ft deep varying in width from 300 ft at streambed level to 1,500 ft at the top. Upstream from the head of the canyon, the reservoir area is a wide valley eroded in soft shales and mudstones of Middle Triassic age. The abutment slopes range from near vertical sandstone ledges and cliffs to talus or overburden slopes as flat as 1 to 2.5 ft. The deep canyon is eroded through hard, resistant Poleo sandstone of the Lower Triassic and Abo sandstones and mudstones of the Permian age. Normal faulting occurs in the area, but no faults were observed in the construction area. Bedrock in the upper abutment slopes is a massive sandstone and the lower slopes and streambed are interbedded sandstone and mudstone. The outlet works are in the Abo mudstone and the access shaft penetrates the full abutment section. The unlined spillway is excavated in the Poleo sandstone. The mudstones are dense, well consolidated, and relatively impervious. The sandstones, particularly near the canyon walls, are a source of potential leakage due to open fractures, cracks, joints, and bedding planes.

Foundation Investigations

G3. Subsurface explorations and foundation investigations for the Abiquiu damsite consisted of 50 borings and visual examination of 16,000 lin ft of rock cores. Drilling footage of 5,474.7 ft included 470 ft of 2-1/8-in. coring, 72 ft of fishtail drilling, 4,550.3 ft of 5-3/8-in. coring and 382.4 ft of 3-in. drilling for the NX borehole camera.

G4. Drilling and coring footage for the various structures and for the borehole camera were as follows:

	Structure	No. of Holes	Footage
1.	Outlet Works		
	Tunnel	4	1056.3
	Intact Structure	8	680.1
	Outlet Structure	5	176.4
2.	Embankment	27	2968.8
3.	Spillway	3	210.7
4.	Borehole Camera	3	382.4
		50	5474.7

G5. The borehole photographs of holes NX-51, NX-52, and NX-53 beneath the embankment revealed an almost continuous section of fractured and jointed rock with weathering apparent along most fractures. The joints were predominantly high angle with no area of concentration in the section. The width of the fractures vary from 1/32 in. to greater than 1/4 in. Some of the fractures were healed and some were open. Based on the cores and borehole photos, a grouting program with four stages to a total depth of 140 ft was proposed (USACE 1963). Primaries on 40-ft centers in the valley section and 20-ft centers on the abutments were proposed.

Initial Contract

Technical considerations

G6. The plans and specifications outlined the work to be performed and the equipment to be used to install the grout curtain designed to reduce or prevent leakage and to protect the embankment (USACE 1959). There were eight pay items concerned with the drilling and grouting program. There was no item for mobilization or demobilization. The items included two types of grout hole drilling (rotary and percussion), exploratory drilling, pressure testing and washing, mixing and placing grout, furnishing cement for grout, and connections to grout holes.

Contractual considerations

G7. The contract for the embankment and spillway was a firm fixed price contract awarded to the lowest bidder. F. K. Mittry Construction Company was the prime contractor. The grouting subcontractor is unknown. Mr. Claude Matthews was the resident geologist in charge of the foundation and grouting. Mr. C. F. Johnston was the Albuquerque District Geologist and the designer of the grout program. Nothing in the available records indicates any major conflicts between the contractor or Corps personnel. The specifications contained the following:

> "The program shown on the drawing and described herein is tentative and is presented for the purpose of canvassing bids. The amount of drilling and grouting which actually will be required is unknown, and will be governed by conditions encountered as the work progresses."

It also stated that grouting mixes, pressures, the pumping rate and the sequence in which the holes are drilled and grouted will be determined in the field and shall be as directed by the Contracting Officer. There were no claims related to the drilling and grouting operations. There was an increase in the amount due for percussion drilling, core drilling exploratory holes, and for pressure testing and washing pursuant to paragraph SC-3, Variations in Estimated Quantities. The total amount for the modified items was $745.14.

Drilling and Grouting Methods

G8. A single line grout curtain was placed along the axis of the embankment from the base of the cutoff trench following completion of preliminary excavation to approximate grade. Grouting was at irregular time intervals as controlled by the progress of the abutment excavation.

Drilling

G9. Two-in. guide pipes were caulked or grouted into place for drilling. The specifications called for grout holes to be drilled with standard rotary or percussion drilling equipment. Payment was by the linear foot. Percussion drilling was used for the first stage (0-20 ft). Rotary drilling required no core recovery, and the type bit was optional. The minimum diameter of hole was to be 1-1/2 in. at point of maximum penetration. No grout hole was to be drilled at an angle greater than 45 deg except for the holes in the right abutment as was shown on the drawings. Drilling was to be done in accordance with stage grouting, split-spacing method. In practice the rotary holes were drilled using plug type diamond bits. Each hole was drilled to full depth of the particular zone being grouted unless a significant loss of drill water occurred. Several holes, constituting a section, were drilled and grouted to successive zones as a unit to facilitate observation of washing and pressure testing and placement of grout.

Washing and pressure testing

G10. This item was paid for by the hour. Specifications called for washing and pressure testing the holes prior to grouting. Air and water under pressure was to be used to remove washable materials. Pressures were not to exceed the maximum grouting pressure as directed by the contracting officer. Holes that could not build up pressures were to be washed for 5 min or for such time as material was being washed from the hole.

Grouting mixtures

G11. Specifications required mixtures as directed by the contracting officer. A neat cement grout was required. The water cement ratio would generally range between 3:1 and 0.6:1, with the greater part probably being at a ratio of 1:1. In practice the mixtures were neat cement and varied from 0.6:1 to 4:1.

Pressure

G12. Grouting pressures were to be as directed by the contracting officer and would vary with conditions encountered in the respective holes. It was anticipated that pressures would range from 20 to 200 psi but would not exceed 200 psi.

Refusal rate

G13. The specifications stated that the grouting of any one stage in each hole would be considered complete when the hole failed to take a sufficient quantity of grout in the opinion of the contracting officer to warrant further grouting, but that grouting of any stage would not be continued when the rate of grout take using the maximum required pressure was less than 1 cu ft in 10 min.

Connections to grout holes

G14. Payment for connections were set at $5 each (fixed bid price) when necessary for the purpose of injecting grout, as determined by the contracting officer. Payment was made regardless of the amount of grout actually injected.

Field procedures

G15. Conventional stage grouting procedures were followed; Zone 1 extended from the surface to 20 ft; Zone 2 from 20 to 50 ft; Zone 3 from 50 to 90 ft; and Zone 4 from 90 to 140 ft or bottom of hole in a few instances where a greater depth was required. Careful observation and review of records of grout mixtures, rate of placement and movement of grout in adjacent holes, and volume placed were used to determine the need for intermediate holes. Primary holes were spaced at 40-ft centers in the streambed and at 20-ft centers on the abutments. Streambed holes were split to 20- or 10-ft centers and abutment holes were split to 10- or 5-ft centers as required. Quantities of grout placed varied greatly from hole to hole. Records of grout takes indicated irregular zones of permeable material in the Abo formation due to the lenticular character of the sandstone in the formation. Most of the grout placed in the Poleo sandstone filled the open fractures. Movement of grout along bedding planes and joints was observed in some instances at distances over 50 ft from the hole being grouted. Grout mixtures and rate of placement were changed continually in an attempt to produce a relatively narrow zone of grout. Generally, the hole was started with a thin mixture and low pressure. If the area was tight and grout take low, pressures were revised to the allowable maximum and grouted to refusal. In areas where grout take was high and surface leaks often indicated extensive horizontal travel, a thick mixture was placed at low pressure. A maximum of 100 sacks of cement was established as a limit when no pressure could be developed. Then pumping was stopped for several hours, the grout was allowed to take initial set, and the hole flushed before final set. Additional grout was then placed until refusal at permissible pressure.

Equipment

G16. The specifications required a grout plant capable of supplying, mixing, stirring, and pumping the grout to the satisfaction of the contracting officer. It required a minimum capacity of 30 gpm of grout injected at a pressure not greater than 200 psi. The minimum equipment included two specially equipped air-driven pumps, a mechanical mixer, a mechanical sump, a tank for auxiliary water supply, pneumatic and mechanical double expanded packers, two water meters graduated in cubic feet and tenths, and other tools and equipment such as gages, hoses, compressors, and other items necessary to provide continuous supply of grout. The capacity of the mixer and sump was specified to be not less than 20 cu ft.

Records

G17. The contracting officer kept all records of operations with the necessary assistance and cooperation of the contractor.

Grout takes

G18. A total of 39,753 sacks of cement was placed in 22,476 ft of grout hole for a ratio of 1.77 cu ft of cement per linear foot of hole. The amount of grout placed varied considerably from hole to hole in different areas. Maximum grout take was 3,000 sacks in a 140-ft hole in the abutment sandstone.

Unexpected Geological Conditions Encountered During Construction

G19. No unusual conditions were encountered during construction of the embankment and spillway. Pneumatically placed mortar was used as required on the abutment slopes within the core zone to control disintegration of the foundation material.

Evaluation of Grouting

G20. NX core holes were drilled at selected locations to check on the effectiveness of grouting. Core recovery was excellent. Examinations of cores indicated that all fractures were filled with grout. An opportunity to visually examine the grouting developed when it became necessary to excavate an area on the left abutment at about elevation 6,120. The area had been grouted at an earlier date. As a result of change in design slopes, a shallow cut was made. Examination of the new backslope showed complete filling of all fractures within several feet of the axis of the embankment. The grout curtain was judged to be adequate for the design purpose.

Costs and Quantities

G21. Total costs of all drilling and grouting related items were $248,722. Government estimated prices are not available. The total bid cost (estimated quantities x contractor bid) was $349,100 (Table G1). The items for rotary drilling, pressure testing, placing grout, and cement in grout were two-part items. Quantities for rotary-grout hole drilling were 94 percent of the estimated; for exploratory drilling the quantities were 39 percent of the estimated; percussion drilling was 62 percent of the estimated; pressure testing and washing was 0.05 percent of the estimated; placing grout was 73 percent of the estimated; and furnishing cement was also 73 percent of the estimated.

Performance

G22. Initial flood control storage in the spring of 1965 caused excessive seepage through the left abutment into the access shaft to the control chamber and seepage through both left and right abutments to the embankment drainage blankets and to exit faces in the canyon walls downstream of the dam. Subsequent pool storage to elevation 6,186 in the fall of 1965 caused a marked increase in seepage volumes into the access shaft and through the abutments. A supplemental drilling and grouting program was initiated in 1966.

Supplemental Drilling and Grouting - 1966

Scope and summary of supplemental work

G23. Funds were requested in December 1965 for access shaft grouting and for 1,000-ft extensions of the existing single line grout curtain into each abutment. Funds were allocated early in 1966 and supplemental grouting to reduce volume of abutment seepage was initiated in early summer of 1966. The remedial work planned and initiated in 1966 consisted of (a) drilling and grouting around perimeter of access shaft, (b) 1,000-ft extensions of existing single line grout curtain into the left and right abutments, (c) installation of embankment piezometers to monitor water levels in the embankment drainage blankets, (d) installation of abutment piezometers to monitor effect of the grout curtain extensions, (e) drilling horizontal drain holes into the left abutment downstream of the embankment, and (f) construction of a ditch and collector system on the downstream berm to collect and convey seepage to free exits at the downstream rock toe. The drilling and grouting program was extensively modified during progress of the work. Initial grouting on the left abutment revealed that the existing single line curtain under the dam had not been adequately grouted during construction of the dam and that supplemental foundation grouting was required to reduce abutment seepage along this shortest path. Work within the limit of available funds was completed in January 1967. Brief descriptions of the work accomplished in 1966 are given in the following paragraphs (USACE 1967).

Access shaft

G24. Sixteen holes were drilled and grouted in the area surrounding the access shaft to stop leakage into the shaft. The operation consisted of drilling holes approximately 2 ft from the outside of the shaft lining on centers of about 5 ft. The holes were 3 in. in diameter and were drilled and grouted to elevation 6115 using stage and zone procedures. A total of 4,480 ft of hole was drilled and grouted. Average take per foot of hole grouted was 0.52 sacks of cement. Seepage into the shaft was almost entirely eliminated by the grouting program.

Drain holes

G25. Twelve 3-in. horizontal-drain holes were drilled approximately 110 ft into the left abutment downstream of the embankment slope contact on abutment rock. The holes were drilled into a fractured, conglomeratic (white) sandstone (elevation 6075) which was the major exit aquifer for the abutment seepage. The drain holes were very effective in intercepting and conveying seepage to a localized exit area.

Piezometers in embankment

G26. Nine piezometers were installed in the embankment to monitor water levels in the pervious-fill drainage blankets.

Piezometers in left abutment

G27. Five piezometers were drilled in the left abutment to monitor water levels in the abutment rock and to evaluate the effectiveness of the supplemental drilling and grouting.

Drainage ditches on downstream berm

G28. Abutment and drainage blanket seepage caused ponding of water on the downstream berm during the pool storage periods in 1965. Open drainage ditches were excavated into the berm to reduce the water level in the berm area, to collect seepage from both abutments, and to convey accumulated seepage to controlled exit points.

Supplemental grouting and extension of single line grout curtain on left abutment

G29. Work accomplished consisted of a 500-ft extension of the single line grout curtain on the left abutment and regrouting and deepening the existing single line curtain under the embankment on the left abutment. Approximately 500 ft of the existing single line curtain was regrouted and deepened. Funds limitation precluded completion of the remaining 500-ft extension of the grout curtain on the left abutment and the 1,000-ft extension of the grout curtain on the right abutment. It was the District's recommendation that no further work be performed at that time (January 1967) in view of the satisfactory performance of the project.

Technical Considerations

G30. The plans and specifications for the 1966 contract provided for drilling and grouting of the control shaft, extension of the grout curtain, and drilling abutment drain holes (USACE 1966). There were 10 items for this work. By several contract modifications the work was reduced due to limited funds. Modifications, however, resulted in seven additional items related to drilling and grouting, while reducing the work originally anticipated in the initial 10 items. Original items included mobilization and demobilization, four items for drilling different size holes for shaft and curtain grouting, pipe for holes, mixing and placing grout, connections, pressure washing and testing, and drilling drain holes. Additional items included two items for drilling different size split-spaced grout holes, pipe for split-spaced holes, drilling pipe for split-spaced holes, mixing and placing grout in mudstone formations, stage grouting 3-in. grout holes, and two items for drilling different size holes through compacted fill. The exploration data for the construction of the dam was available for the design and performance of remedial work. The information derived from the initial drilling and grouting construction was also available to the designers. Squeezing of the mudstone was not anticipated and necessitated the major part of modifications. Additional investigations may have helped to identify the mudstone problem. This problem is discussed in greater detail in paragraphs 42 through 46 of this section.

Contractual Considerations

G31. The contract for the supplemental grouting was a firm fixed price contract awarded to the lowest bidder. Continental Drilling Company was the prime contractor. Messrs. Claude Matthews and Tilden McDowell were the designers for the Albuquerque District. Mr. Jerry Langenfeld was the Government representative at the site. Specifics of the relations of the contractor and the Corps are not known, but nothing in the available records indicates any major conflicts. The specifications contained statements that the program shown in the drawings and in the specifications was presented for the purpose of canvassing bids and that the amount of drilling and grouting actually required was unknown and would be governed by conditions encountered as the work progressed. Another statement gave the contracting officer the option of deleting any portion of the grout curtain extension. The specifications also stated that the grouting mixtures, the pressures, the pumping rate, and the sequence in which the holes were to be drilled and grouted would be determined in the field as directed. There was a differing site condition clause, and it was determined that conditions related to the drilling through walls in vicinity of the control shaft were different which resulted in modification to the contract. Other modifications were caused by expenditures of available funds and by technical changes caused by squeezing mudstone and required methods for drilling through the compacted fill. There were no claims litigated or arbitrated. The original contract was $496,980, while the total contract amounted to $643,661.

Drilling and Grouting Methods

General

G32. The work to be performed under the contract required drilling and grouting around the control shaft and a 1000-ft grout curtain on each abutment. The plans and specifications included the usual equipment, methods, and requirements. By several modifications the work was reduced to grouting the control shaft, a 500-ft curtain extension on the left abutment, and regrouting and deepening a section of curtain on the axis of the dam under the compacted fill. The modifications were required in large part to adjust to conditions encountered at the site. The additional cost and need to limit the program to the available funds was brought about in part due to the more costly methods and procedures required to drill and grout through the mudstone and the embankment. Therefore, the original contemplated scope of work was reduced. Procedures were developed and modified to meet the individual conditions as the work progressed. The specifications were standard, listing the required equipment for drilling and grouting, such as split-spacing methods, limitations on angles, depths, the stage grouting method and procedures, washing and pressure testing, pressures, mixtures, and other standard items. Rotary-type equipment was used. Tricone-rock bits were used on holes greater than 3 in.

and fishtail and diamond plug bits were used in drilling the 1-3/8-in. holes. The methods and procedures varied considerably to suit the actual conditions. The following paragraphs describe the operations for the control shaft, the left abutment under the original contract, modifications 2, 4, and 6, piezometer installation, and horizontal drain holes as included in the drilling and grouting report. Results and conclusions from the report are also included.

Control shaft drilling and grouting

G33. Sixteen holes were drilled around the control shaft on approximately 5-ft centers and about 2 ft from the outside of the lining of the shaft. During the drilling of these holes considerable delay was caused by several conditions not indicated on the contract drawings. Imbedded in the floor slab of the control shaft building were several electrical conduits, which made it necessary to break through the concrete slab before drilling could start. Concrete from 2-1/2 to 6 ft thick was found underlying the floor slab. Reinforcement in the concrete made it necessary to core the holes to a depth of approximately 3 ft, and in some instances required the use of a cutting torch. Reinforced concrete was also encountered in some holes at depths of 12, 22 and 39 ft.

G34. The 16 holes were first drilled from the floor of the Operations Building to elevation 6350 (crest of spillway) using a 5-in. bit. Three and one-half-in. grout pipe was then installed to this elevation. Three-in. holes were then drilled to elevation 6115 by the stage and zone grouting procedure. The first zone extended downward from the bottom of the grout pipe 60 ft. The second zone extended 60 ft downward from the bottom of the first and the third extended 60 ft downward from the bottom of the second. The fourth zone extended 55 ft downward from the bottom of the third zone placing the lower limit of grouting at elevation 6115. A stage consisted of a partial depth of a zone marked by the loss of drill water or a complete zone where no water loss occurred.

G35. Holes were washed and then pressure tested for 5 min before grouting the first three zones. Pressure used in testing these three zones did not exceed 20 psig (psi at the gage). Holes were not pressure tested in the fourth zone.

G36. In zones where pressure was used in grouting, grout was injected by means of a header at the top of the hole. In zones that were grouted under gravity alone, an EX size rod was used to inject the grout to the bottom of the hole. The use of the EX rod proved to be very effective in getting grout to the bottom of holes where considerable caving had occurred. The caving was encountered in the mudstone zones of the formation with the most serious caving being encountered at approximately elevation 6215 and below.

G37. Grouting in these holes started with a water-cement ratio by volume of 3.0 and was decreased at the discretion of the inspector to a ratio of 0.8. Usually the mixture was changed after 12 to 16 sacks of each mixture had been injected into a hole, thus the grout takes were small. In general, the rate at which grout was injected varied from 3.0 cu ft/min to 0.1 cu ft/min at which time the zone or stage was considered grouted.

G38. Seepage into the shaft was almost entirely eliminated by the grouting program. The use of thinner grout mixtures for a larger number of batches and the possible use of higher grouting pressures should be considered in any future grouting program around the control shaft.

G39. A total of 4480 ft of hole was drilled and grouted with 2317.5 sacks of cement being placed to give an average take of 0.52 sacks of cement per foot of hole grouted. However, the grout take was not uniform, and a large part of the grout placed was in the sandstone sections at elevations of about 6315± and 6270±.

Left Abutment Drilling and Grouting Under the Original 1966 Supplemental Contract

G40. Thirty-one primary holes were started under the original contract requirements. These holes extended the grout curtain 500 ft into the north abutment on 20-ft centers. Three-in. holes were drilled from the ground surface to elevation 6350 and 2-in. pipes were installed to this elevation. One and three-eighth-in. holes were then drilled by the zone and stage method to elevation 6042. The first zone extended downward from the bottom of the grout pipe 50 ft. The second zone extended downward from the bottom of the first zone 50 ft. The third zone extended 100 ft downward from the bottom of the second zone. The fourth zone extended downward from the bottom of the third zone to the bottom of the hole at elevation 6042.

G41. All holes were washed and pressure tested using from 20 to 25 psig for 5 min prior to grouting operations. The holes were then started with a grout mixture of 3:1 water-cement ratio by volume and thickened every 25 to 50 sacks until the water-cement ratio was 0.8:1. The rate at which the grout was injected varied from 3.5 cu ft/min to 0.1 cu ft/min at which time the zone or stage was considered grouted. A stage of a hole was also considered grouted after injecting approximately 500 sacks in that stage.

G42. Due to serious caving and squeezing off of the holes in the mudstone zones, it was not possible to place grout in these zones and a number of holes were lost due to stuck rods. Only three of the original 31 holes could be completed to the required depth and the contract was modified in an attempt to overcome the serious caving problem. The method of drilling grout holes was modified under Modification 2 to require the use of perforated 2-in. casing through the mudstone to overcome the caving problem.

Drilling and Grouting Under Modification 2

G43. Thirty-one split-spaced holes were drilled under this modification along the 500-ft curtain on 10-ft centers. Three-in. holes were drilled from the ground surface into the mudstone formation and cased with 2-in. pipe. This portion of the operation required drilling about 270 ft or to elevation 6080±. The pipe within the mudstone formation was perforated by four equally spaced 3/8-in. holes at 1-ft intervals. After grouting the casing in place, 1-3/8-in. holes were drilled to elevation 6042 using the zone and stage drilling method.

G44. To eliminate caving, all holes were washed but not pressure tested. When grouting the mudstone zone, the pipe was cleaned of all cuttings and an EX rod was lowered to within 6 in. of the bottom of the hole. Grout was then injected through the rod, forced to the surface and vented through a stuffing box placed at the collar of the hole so that pressures could be regulated. The grout was circulated through the grout plant where all larger cuttings were screened out and then back into the hole. Zones and stages of grout holes below the mudstone were grouted using a header at the top of the hole.

G45. The grout used varied from a water-cement ratio of 3.0 to 0.8 and was thickened every 50 sacks. The rate of grout injection varied from 3.8 cu ft/min to 0.1 cu ft/min at which time the zone was assumed grouted. A maximum of 500 sacks during one hookup was placed in a zone or stage.

G46. During the preparation of Modification 2, it was assumed that the existing grout curtain above about elevation 6100 was adequate and the use of perforated casing through the mudstone section would provide adequate facility for any necessary grout placement. The amount of grout placed in this upper level indicated the need for more extensive grouting, and Modification 4 was prepared.

Observation Holes - Modification 3

G47. During the drilling of the secondary holes, it became evident that a mean of determining the direction of the flow of water in the north abutment was necessary. To accomplish this, as well as to ascertain whether the curtain was diverting the flow of water, five observation wells were drilled. Three holes were drilled perpendicular to the grout curtain at Station 0+70. The first was drilled 130 ft upstream from the curtain and designated hole P-10. The second and third holes were located 200 and 500 ft downstream from the curtain and numbered P-11 and P-12, respectively. The two remaining holes, P-13 and P-14, were drilled parallel to and 200 ft downstream from the curtain at Stations 3+30 and 5+00.

G48. The observation holes were 3 in. in diameter drilled from natural ground 310 ft± into a white sandstone. The holes were cased with 205 ft of standard 2-in. pipe and a bottom perforated section of 105 ft. After holes were cased to 310 ft and grouted in, they were completed by drilling a 1-3/8-in. hole to elevation 6042±. All holes have functioned adequately with the exception of P-10 which was grouted from the curtain by an interconnection. Prior to the grouting of P-10, the differential in water surface from upstream of the curtain to downstream of the curtain was approximately 23 ft as shown by piezometers P-10 and P-11.

G49. Data obtained from water surface readings upstream and downstream of the grout curtain prior to draining the reservoir (November 1966) indicate that some of the rock in the north abutment is still open and has not been appreciably affected by the grout program. The seepage rate in the abutment rock appears to vary correspondingly with the pool level. Daily observation of the holes after implementing split spacing procedures on the north abutment supports this idea. Rates of seepage were the greatest (0.82 cu ft/sec) when pool elevations were the highest and correspondingly lower (0.01 cu ft/sec) with the pool empty. The piezometric surface, as shown by the observation holes, slopes back into the abutment on a high pool but reverses when the pool is pulled down indicating the rock is still fairly open and draining.

Drilling and Grouting Under Modification 4

G50. Forty-one tertiary holes were drilled under this modification. They extended along the curtain for approximately 400 ft and reduced the spacing between holes along most of the curtain to 5 ft. In addition, three holes were drilled and grouted on the axis of the dam using procedures established by Modification 2. These holes were drilled to evaluate the grout curtain placed under DA-29-005 CIVENG-59-10 (the original contract) and to remedy possible defects in the existing curtain.

G51. For those holes on the G alignment 5-in. holes were drilled from the ground surface to 2 ft into firm rock, and 4-in. pipe was installed to the bottom of the hole at an average depth of 10 ft. Three-in. holes were then drilled and grouted from the bottom of the 4-in. pipe by the stage zone method through the mudstone formation. The first zone to be grouted extended from ground surface down to elevation 6350. The second zone extended 50 ft downward from the bottom of the first. The third zone extended 50 ft downward from the bottom of the second. The fourth zone extended from the bottom of the third zone through the mudstone formation to elevation 6080±. The holes were then cased with 2-in. pipe using perforated pipe in the mudstone section. After grouting in the casing, 1-3/8-in. holes were then drilled and grouted to full depth using stages and zones. The fifth zone extended from the bottom of the 2-in. pipe through the conglomeratic sandstone. The sixth zone extended downward from the bottom of the fifth zone to elevation 6042.

G52. Holes under this modification were washed and pressure tested. The duration of the test was increased to 10 min, and additional water was injected into the holes for 5 min immediately prior to grouting. The longer pressure tests and additional 5 min of washing proved to be very effective in getting the sandstone above elevation 6070 to take grout.

G53. Grout was injected in the zones above the mudstone formation through a packer placed in the 4-in. pipe at the top of the hole. Before grouting through the 2-in. pipe which extended from the ground surface to the base of the mudstone, approximately 10 to 20 ft of the top of the pipe was grouted in to allow for pressure grouting.

G54. When grouting the mudstone zone, EX size rod was lowered to within 6 in. of the bottom of the hole and grout was injected through the rod as when grouting the mudstone in Modification 2. Zones and stages below the 2-in.

casing were grouted by means of a header at the top of the hole. Grout used in this modification varied from a water-cement ratio of 3.0 to 0.8 and was thickened every 100 sacks. Pressures used were limited to 1 psi per foot of cover and a maximum pressure of 150 psig. The rate of grout injection varied from 3.8 cu ft/min to 0.1 cu ft/min at which time the zone or stage was assumed grouted or when a maximum of 500 sacks of cement had been placed in any single stage.

G55. During the drilling of some holes, fluorescein dye was injected in an attempt to determine the direction and rate of seepage through the abutment. Samples of the seepage water were taken six times a day for 4 days after each dye injection; no samples contained any dye.

G56. The need to extend the grout curtain along the axis and to a greater depth was indicated due to large takes in some holes. Modification 6 was prepared to provide for this work. Modification 5 deleted requirements for completion of outer 500 ft of grout curtain on the north abutment.

Drilling and Grouting Under Modification 6

G57. Twenty-seven primary holes and 11 secondary holes were drilled and grouted under this modification. The primary holes extended along the axis of the dam for about 500 ft on 20-ft centers. Secondary holes were on 10-ft centers and split the primary holes where required. This required drilling through the compacted impervious fill of the dam. Drilling and grouting procedures varied with the depth of the fill and the position of the mudstone zone in the foundation. Three- and five-in. holes were drilled either through the embankment or mudstone. Pipe was then set and grouted in. The holes were then reduced and drilled into the foundation using stage and zone procedures. The white, conglomeratic sandstone, from elevation 6100± to elevation 6070± was grouted as a zone. The underlying sandstone and mudstone from elevation 6070± to elevation 6015± was grouted as a zone with the deepest zone extending from elevation 6015± to elevation 6000± bottom of the curtain.

G58. Before grouting all holes were washed and zones above the depth of 300 ft were pressure tested. Pressures used varied with the depth of the hole and ranged from 20 psig to 150 psig.

G59. All grout was injected into the holes by the use of a header. Grouting in those holes started with a grout mixture with a water-cement ratio by volume of 3:1 and was thickened every 50 sacks until the water-cement ratio was 0.8:1. If the hole remained open after 50 sacks of 0.8:1 grout had been injected, intermittent grouting was used in an attempt to control the travel of the grout. Each zone was considered grouted after 300 cu ft of cement had been injected or when the rate at which grout was being placed became less than 0.1 cu ft/min.

G60. Grouting pressure used to grout 2-in. or 4-in. pipe into place through the fill were carefully controlled and did not exceed 20 psig. In the first zone or stage below the pipe, total grouting pressure at the top of the zone did not exceed 0.9 psi per foot of cover. Below this level and after grouting of an upper zone or stage the total pressure did not exceed 1 psi per foot of cover. In the reach of holes where a considerable thickness of mudstone overlies the conglomeratic sandstone, and after all overlying zones had been grouted, the total grouting pressure in the sandstone zone and below was increased to 1.25 psi per foot of cover. The pressure was increased to 1.25 psi/ft only if two or more stages above had been grouted and in all cases the maximum gage pressure used was 150 psi.

G61. During drilling operations through the impervious core section of the embankment some loss of drilling fluid occurred. These holes were drilled using aquagel. Loss of circulation was recorded in seven holes. When loss of circulation occurred, further advance was stopped and the drilling mud thickened until circulation was regained. In one hole approximately 144 cu ft of drilling mud was pumped into it over a period of about 4 hr to regain circulation. This was the maximum volume lost in any hole.

Horizontal drain holes

G62. Twelve horizontal drain holes were drilled into the north abutment. These holes were drilled in a medium hard, coarse-grained to conglomeratic, fractured sandstone at elevation 6075. The first hole is approximately 15 ft downstream from the intersection of the slope of the embankment and elevation 6075. All holes were 3 in. in diameter and extended 110 ft into the abutment rock. The first three holes were drilled on 1-ft centers and at various angles to form a fan, which would provide for a distance of 5 ft between holes at 110 ft. The fourth hole was drilled 1 ft from the third and is perpendicular to the face of the abutment and was 5 ft from the third hole at the 110-ft depth. The remaining eight holes were drilled perpendicular to the face of the abutment on 5-ft centers.

G63. The purpose of the drain holes was to lower the level of water in the sandstone and to localize the seepage.

G64. These drain holes functioned adequately and yielded water throughout the period of reservoir storage. Additional holes of larger diameter and to greater depths would probably be of value in controlling the water level in the abutment.

Piezometer installation
under Modification No. 1

G65. The initial modification of the contract was for installation of embankment piezometers. Piezometer numbers P-6 through P-9 were installed by contractor personnel and piezometer numbers P-1 through P-5 were installed by Albuquerque District personnel.

G66. In all cases, the piezometers were drilled downstream from the axis and were bottomed in the drainage blanket. All the piezometers are functioning properly with the exception of P-9 which is thought to be bottomed out too shallow. Data from this hole indicate that it did not reach the drainage blanket and is bottomed in the fill portion of the embankment.

G67. The primary purpose of the piezometers was to reflect the water surface, evaluate possible seepage paths, and give an indication of the pore pressure. Present data show that the piezometric surfaces in the embankment are higher than anticipated indicating that either an excessive amount of water is entering the drainage blanket or that the blanket does not carry off the water as originally anticipated.

G68. Any supplemental work done should include additional piezometers both in the embankment and on the abutments. It has been found that there are not enough piezometers to definitely establish the movement of ground water through the embankment and abutments. Additional piezometers would give a better indication as to seepage paths and permit a more accurate evaluation of existing conditions.

Results and Conclusions

G69. A Parshall flume was installed 11 October 1965 to measure seepage from the north abutment. Pool level was at elevation 6141± and the initial flow rate was 0.82 cu ft/sec. Daily readings until 4 November 1966 with a constant pool of elevation 6140± varied from 0.78 to 0.80 cu ft/sec.

Depletion of storage at Abiquiu commenced on 4 November 1966 and pool level was 6066 by 20 January 1967. The following tabulation illustrates effects of draining the pool:

Date	Elevation of Pool	Seepage from North Abutment
4 November 1966	6140	0.78 cu ft/sec
10 November 1966	6131	0.68 cu ft/sec
18 November 1966	6116	0.45 cu ft/sec
25 November 1966	6092	0.24 cu ft/sec
2 December 1966	6092	0.16 cu ft/sec
9 December 1966	6085	0.11 cu ft/sec
16 December 1966	6074	0.09 cu ft/sec
23 December 1966	6070	0.09 cu ft/sec
30 December 1966	6069	0.07 cu ft/sec
6 January 1967	6068	0.03 cu ft/sec
12 January 1967	Completion of Grouting	0
13 January 1967	6067	0.02 cu ft/sec
20 January 1967	6066	0.02 cu ft/sec

The water level in the north abutment, as indicated by piezometer readings during this time interval, was lowered substantially.

G70. Grouting operations were physically completed on 12 January 1967, at which time available funds had been expended, and final acceptance of all work was made on 31 January 1967. Some of the grouting on the axis of the embankment under Modification 6 was done during the time storage was being depleted and after the pool was emptied. Some of the reduction in volume of seepage from the north abutment was caused by grouting operations and not entirely the result of lowering the pool storage level. Once the pool had been drained, it became impossible to evaluate the effectiveness of the grouting program by observing the seepage from the north abutment.

G71. Available data from Abiquiu including measured seepage from the north abutment and water levels from embankment and abutment piezometers do not clearly indicate that the grouting program was more than partially effective in reducing the amount of seepage through the north abutment. The highly successful grouting operation around the control shaft shows that the abutment rock can be successfully grouted. The effectiveness of the curtain grouting cannot be fully evaluated until such time as a pool is again stored.

G72. Drilling and grouting procedures for any future program should be similar to those used in Modifications 4 and 6, with the possibilities of using larger diameter holes and the use of drill rods to within 1/2 ft of the bottom of the holes to inject grout in zones where caving occurs. This procedure of placing grout was used in the mudstone zones under Modification 2, but that was found to be unnecessary in cased holes. If this procedure of grouting were used, the hole should be at least 1 in. in diameter larger than the rods used to grout through.

G73. The results of this contract indicate that the distance between holes may have to be reduced to 2-1/2 ft on centers in some areas, and the use of 500 cu ft of cement in each zone in primary holes may be necessary. Grout should be placed in all split-spaced holes until the grout take in the holes becomes less than 0.1 cu ft/min or complete refusal occurs. The quantity of grout placed under Modification 6 in a previously grouted area indicates the grouting completed under the embankment contract was inadequate and raises the question that the entire length of the axis may require future treatment.

Grout takes

G74. The control shaft took 2,317 sacks of cement in 4,480 ft of hole for an average take of 0.52 sacks per foot of hole. Grout take was not uniform and a large part of the grout was placed in the sandstone section. The drilling for the grout curtain came to 49,740 ft with 50,660 sacks of cement being placed for a ratio of 1.02 sacks per linear foot of hole. The totals for the contract were 54,220 ft drilled and 52,977 sacks placed for a ratio of 0.98 sacks per foot of hole.

Unexpected Geological Conditions Encountered

G75. The conditions encountered in the mudstone required modification of methods and procedures as described in paragraphs 57-60. Additional prior exploration may have indicated a potential problem in this material which could have been designed for originally.

Evaluation of Grouting

G76. Seepage into the shaft was almost entirely eliminated by the grouting. It was recommended by the Albuquerque District that no further work be performed at the time in view of the satisfactory performance of the project to that date.

Cost and Quantities

G77. The original contract items and prices are shown on Table G2. The final contract items, quantities, and costs are shown on Table G3 (USACE 1968).

Performance

G78. A reconnaissance report (USACE 1978) stated that maximum flood control pool experienced was elevation 6220 in June 1973. Abutment seepage observed during the initial flood control storage in 1965 was still a recurring and continuing problem during each flood control storage operation. Seepage showed a direct relation to pool elevation but no apparent increase in volume with repeated cycles of flood control storage. Seepage was clear with no evidence of abutment material movement. It was concluded that higher pool elevations could be expected to cause large increases in volume which could lead to downstream abutment and dam safety problems. Specifically, the remedial shaft grouting was successful in reducing seepage into the shaft and no further remedial grouting was required. The remedial work on the left abutment in 1966, supplemental grouting of the embankment foundation, 500-ft extension of the single line grout curtain and installation of horizontal drain holes into abutment rock downstream of the toe, were very effective in reduction of abutment seepage into the embankment drainage blankets and emerging from the downstream canyon wall. Data from seepage monitoring showed that abutment seepage was being shunted into the abutment and was passing around the end of the grout curtain with a seepage gradient to the embankment foundation area downstream of the grout curtain and to the horizontal drains. The seepage pattern through the right abutment was slower to develop and to be detected due to a longer seepage path and because exit points from the canyon wall were masked by talus. The seepage path through the right abutment is very similar to that through the left abutment before the remedial grouting and drain holes were completed. Data from the embankment piezometers installed in 1966 indicated internal piezometric water levels well above the horizontal streambed drainage blanket. Design stability analyses for seepage conditions assumed that the piezometric water level would be contained within the horizontal drainage blanket. Seepage condition stability analyses using observed piezometric data and projected data for full flood control pool showed adequate and acceptable factors of safety. The piezometric water levels showed a direct relation to pool elevation changes and the increase or decrease of abutment seepage into the embankment drainage blanket. The data also showed that the magnitude of water-level response to pool storage in piezometers adjacent to the left embankment was less than for piezometers adjacent to the right abutment, a further indication of the beneficial effect of the 1966 left abutment grouting and drainage work. It was concluded that the present system should be supplemented by additional piezometers prior to a proposed supplemental grouting and drainage program. Besides the piezometers the proposed program would include: (a) modification of the downstream drainage system to provide horizontal drain holes into the right abutment, an embankment toe drain collector pipe, and an improved seepage collection and measurement system; (b) regrouting and deepening the existing single-line grout curtain under the embankment on the right abutment side; and (c) a 500-ft extension of the grout curtain on the left abutment and a 1000-ft extension on the right abutment.

Supplemental Grouting Increments I and II - 1978-80

Technical considerations

G79. The supplemental grouting consisted of regrouting and deepening the single-line grout curtain under the embankment, a 1000-ft extension of the grout curtain on the right abutment, and a 500-ft extension on the left abutment. Drilling and grouting was done by zones using the split spacing, stage grouting procedures. The supplemental work was performed in two increments under two separate contracts. The plans and specifications (USACE 1978, 1980) outlined the work to be performed, the equipment required, and the drilling and grouting procedures. There were seven pay items for drilling and grouting, including: mobilization and demobilization, drilling grout holes (with three subitems for three different hole sizes), pipe for grout holes (with two subitems for different pipe sizes), pressure washing and pressure testing, Portland cement in grout, placing grout, and connections to grout holes. Both contracts had the same pay items and were alike with the exception of different hole sizes and method of payment of placing grout. In Increment I the unit was by the cubic foot while in Increment II the unit was by the hour. Increment I also included installation of a drainage system on the downstream embankment.

Contractual considerations

G80. The contracts for Increments I and II were firm fixed-price contracts awarded to the lowest bidder. Kent Knowlin Construction, Inc., was the prime contractor for Increment I. Continental Drilling, US, a Division of R. F. Thies, Inc., and R. O. Theis, individual, were the subcontractor for Increment I and the prime contractor for Increment II. The contracts overlapped and both were completed by 1980. The scheduled completed time for Increment I was 400 days while the actual completion time was 580 days. The scheduled completion time for Increment II was 360 days, whereas, the actual completion time was 391 days. Time extensions were given to complete drilling and grouting since the estimated drilling was exceeded prior to the contract time schedule. Mr. Victor Huesinger of the Albuquerque District Geotechnical Section was the designer. Messrs. Jim McAdoo and Mel Smith were the Corps personnel at the project. There were no design changes or modifications. The specifications included a clause that the program was tentative and presented for the purpose of canvassing bids and that the amount of drilling and grouting was unknown and would be governed by the conditions encountered. There was also a differing site conditions clause. The drilling and grouting procedures were directed by the contracting officer. The contractor claimed differing contract conditions due to additional drilling quantities and a decrease of grouting quantities on both contracts due to a lack of groutable voids. He also claimed for an excessive amount of redrill caused by direction of Corps personnel, interconnection or grout running back into hole from higher elevation. The claims for Increment I have gone to litigation. Any action for Increment II is pending outcome from Increment I. Another claim for pressure testing and washing was negotiated. The Corps personnel on the job were experienced. Under Increment I the contractors' managers were not proven. Increment II had proven managers and personnel. The contractor's equipment was adequate, but numerous breakdowns occurred during the first 6 months of Increment I. The relationship between the Corps and the contractor was businesslike and only occasionally adversary.

Drilling and Grouting Methods

G81. The specifications for Increments I and II contained detailed procedures for drilling and grouting, especially through the embankment and the mudstone of the abutments. These were methods developed during the prior contract. Generally, the specifications outlined the beginning hole size in certain sections and the setting of pipe through the embankment or mudstone in the abutments, and the procedures for grouting the annular space between the pipe and the drilled holes. Subsequent hole size reduction was specified together with the procedures, mixtures, and allowable pressures for grouting the foundation below the embankment or mudstone. The zones, spacing, and requirements for pressure testing were also specified.

G82. The contractor proposed using air foam for the embankment drilling, and it was adopted. All drilling was by rotary type. Redrill was a major problem. Initially the Corps tried to work with the contractor to eliminate the redrill, but none of the Corps' suggestions were used. The contractor finally stated that he wanted to be paid to redrill any hole that was difficult to reenter and that payment should start when redrilling was initiated. The Corps personnel viewed this as unreasonable and would not pay for any redrilling unless the contractor was directed not to wash a hole (as stated in specifications).

Grouting mixtures

G83. Mixtures were composed of cement and water and ranged from 3:1 to 1:1. Criteria for mixture change was at least 25 sacks of a given mixture.

Pressure

G84. Pressures were no more than 0.7 lb/ft of depth under the embankment and 1.0 lb/ft on the abutments. Gage pressure was monitored at the header. Specification limited pressure not to exceed 150 psig.

Refusal

G85. Refusal was described in the specifications as refusal of a hole to take any grout at three-fourths of the maximum pressure required for that stage. In practice no more than 300 sacks per hole were pumped into the embankment foundation and 500 sacks per hole in the abutment.

Connections

G86. Connections were set at $5 each. If packer grouting method was used, a payment for at least one connection was made for each packer setting in a hole.

Field Procedures

G87. All drilling and grouting were done in accordance with the stage grouting, split-spacing method. The contractor elected to work in sections of 100 ft to facilitate the grouting operations (USACE 1982). As a practical matter, the work was actually done in 500-ft sections.

G88. The casing holes to the top of the first groutable zone were drilled in each reach. Primaries on the embankment were 20 ft on centers and the abutment primaries were 10 ft on centers in both contracts. Under the Stage I increment the contractor set all of his 2-in. or 4-in. casing prior to grouting the first groutable zone. The 3-in. holes were drilled using water, and the 5-in. holes were drilled using Baroid Drill Foam, an air-foam medium. The contractor had requested using drill foam in lieu of water or mud on or about 10 November 1978 and approval was given on 16 November 1978. The casing was grouted in each hole by pumping 2:1 water-cement grout through the casing until the grout flowed out around the casing at the surface. Pressures used for grouting in the casing were 15 psi gage pressure.

G89. Zone 1 and all subsequent zones were then drilled using water to the full depth of the zone unless a water loss occurred. In the event of a water loss, drilling was stopped and the hole pressure tested and grouted. The zone was then completed prior to proceeding to the next zone.

G90. Pressure testing was performed on each zone or stage within a zone except on Zone 4, the upper mudstone. The holes were pressure tested using water at no more than 0.9 psi per foot of depth. Pressure testing under the embankment was no more than 0.7 psi per foot of depth. Most stages and zones were tested for a total of five minutes.

G91. The initial grout mixture for the vast majority of zones and stages was 3:1 water-cement ratio. Type II cement was used for all grouting, and no admixtures were used at anytime. Several holes in the left abutment were grouted using thinner mixtures to ascertain if Zones 5 or 6 would take more grout. In approximately five holes a 5:1 water-cement ratio was tried and with the contractor's agreement a 10:1 water-cement mixture was tried in three holes. Grout takes were not appreciably higher using these thinner mixtures.

G92. Pressures used for grouting were kept below 0.9 psi per foot of depth. Grouting pressure below the embankment was held to 0.7 psi per foot of depth. All grout pressures were figured using gage pressure and the weight of the grout column. Total hole pressures were kept below the limits stated above.

G93. Split-spacing determinations were made based on total sacks placed in the zone minus the sacks needed to fill the hole. Generally a figure of 50 sacks was used for the upper three zones and 25 sacks for the lower three zones. Quantities in Zone 5 and especially Zone 6 on both abutments were especially low. Based on the low takes in Zone 6 of Increment I, the rest of Zone 6 was deleted. Zone 6 was also deleted in all of Increment II except for five check holes on the left abutment. In any section or reach along the grout curtain all split spacing was completed prior to proceeding to a lower zone.

G94. The special treatment for Zone 4, the upper mudstone, consisted of drilling the full depth of the zone then immediately setting the 2-in. casing and grouting the zone. No pressure testing was performed in Zone 4. Grouting was performed using a stuffing box at the surface. Grout was pumped through the 2-in. casing until grout flowed from the stuffing box stopcock. Once the flow of grout was the same color and consistency of the grout being pumped into the hole, the stopcock was closed and the zone was pressure grouted. The decision to drill and grout in a continuous operation was based on the squeezing effect the mudstone had during a prior remedial-grouting contract and piezometer installation on both abutments.

Equipment

G95. The specifications contained a listing of required equipment. The grout plant should be capable of supplying, mixing, and stirring to the satisfaction of the contracting officer. A minimum capacity of 30 gpm of grout injected at pressure of 150 psi was required. The pump was to be the Robbins & Myers Moyno or equivalent. All other equipment as necessary to perform the program was required. As a special requirement, the contractor was required to provide a standby plant of the capacity specified.

Records

G96. A quality control paragraph required the contractor to perform certain quality control work. It stated that "while the government will control all operations, the contractor will furnish satisfactory drilling and grouting equipment and keep it in good mechanical condition and will keep records of all operations as required in this section" (USACE 1978). Records were to be made available to the contracting officer at all times.

Grout takes

G97. Table G4 shows drilling footage, grout takes, and ratios of grout takes to feet of hole (sacks/ft) by sections and zones for Increments I and II (USACE 1982).

Unexpected Geological Conditions Encountered During Construction

G98. There were no unexpected conditions encountered. The previous remedial grouting had identified problems, and procedures and methods developed then were used in these contracts. Additional information was available from the initial explorations and piezometer installations. The grouting contractor also made a site visit and core logs were included in the specifications. A preconstruction conference was held and included the resident engineer, construction representative, and geotechnical personnel for the Corps. The contractor had in attendance the project manager, drilling and grouting superintendent, and district manager.

Evaluation of Grouting

G99. The supplemental grouting was judged to be adequate upon completion of the program.

Costs and Quantities

G100. The drilling and grouting schedule with estimated quantities and contractor's bid prices for Increment I are as follows:

	SCHEDULE A	Government Estimate				Contract	
Item No.	Description of Bid Item	Estimated Quantity	Unit	Unit Price	Estimated Amount	Unit Price	Estimated Amount
1	Curtain Drilling & Grouting						
	a. Mobilization & Demobilization Including Site Work	Job	Lump Sum	---	$232,063	---	$120,000

Item No.	SCHEDULE A Description of Bid Item	Government Estimate Estimated Quantity	Unit	Unit Price	Estimated Amount	Contract Unit Price	Estimated Amount
	b. Drilling Grout Holes						
	(1) Drilling 5-in. Holes	9,000	lin ft	$10.96	98,640	$14.40	129,600
	(2) Drilling 3-in. Holes	27,000	lin ft	8.03	216,810	10.80	291,600
	(3) Drilling 1-3/8-in. Holes	17,500	lin ft	7.82	136,850	10.80	189,000
	c. Pipe for Grout Holes						
	(1) 4-in. Pipe	9,000	lin ft	7.87	70,740	9.00	81,000
	(2) 2-in. Pipe	36,000	lin ft	2.60	93,600	3.60	129,600
	d. Pressure Washing & Pressure Testing	250	Hr.	179.22	44,805	120.00	30,000
	e. Portland Cement in Grout	66,300	CWT.	4.49	297,687	6.36	421,668
	f. Placing Grout	70,600	cu ft	3.26	230,156	7.20	508,320
	g. Connections to Grout	810	Ea.	5.00	4,050	5.00	4,050

The total actual quantities and costs were as follows for Increment I:

Item No.	Description	Estimated Quantity	Unit	Total Quantity To Date	Unit Price	Amount
	SCHEDULE A					
1	Curtain Drilling & Grouting					
	a. Mobilization & Demobilization Including Site Work	Job	Lump Sum	Job	120,000.00	120,000.00
	b. Drilling Grout Holes					
	(1) Drilling 5-in. Holes	9,000	lin ft	11,117	14.40	160,084.80
	(2) Drilling 3-in. Holes	27,000	lin ft	48,940.5	10.80	528,557.40
	(3) Drilling 1-3/8-in. Holes	17,500	lin ft	21,216.5	10.80	229,138.20
	c. Pipe for Grout Holes					
	(1) 4-in. Pipe	9,000	lin ft	10,956	9.00	98,604.00
	(2) 2-in. Pipe	36,000	lin ft	54,363	3.60	195,706.80

Item No.	Description	Estimated Quantity	Unit	Total Quantity To Date	Unit Price	Amount
	SCHEDULE A					
	d. Pressure Washing & Pressure Testing	250	Hr.	240.5	120.00	28,860.00
	e. Portland Cement in Grout	66,300	CWT	59,721.58	6.36	379,829.25
	f. Placing Grout	70,600	cu ft	63,225.75	7.20	455,225.40
	g. Connections to Grout Holes	810	ea.	1,221	5.00	6,105.00

A tabulation of variation in quantities for Increment I follows:

Item	Unit Price	Original Quantity	Actual Quantity	Variance	Amount
1b(1)	14.40	9,000	11,117.0	2,117.0	$ 30,484.80
1b(2)	10.80	27,000	48,940.5	21,940.5	236,957.40
1b(3)	10.80	17,500	21,216.5	3,016.5	40,138.20
1c(1)	9.00	9,000	10,956.0	1,956.0	17,604.00
1c(2)	3.60	36,000	54,363.0	18,363.0	66,106.80
1d	120.00	250	240.5	-9.5	-1,140.00
1e	6.36	66,300	59,721.58	-6,578.42	-41,838.75
1f	7.20	70,600	63,225.75	-7,374.25	-53,094.60
1g	5.00	810	1,221.0	411.0	2,055.00

The drilling and grouting schedule, estimated quantities, and contractor's bid prices for Increment II are as follows:

Item No.	SCHEDULE A Description of Bid Item	Government Estimate Estimated Quantity	Unit	Unit Price	Estimated Amount	Contract Unit Price	Estimated Amount
1	Curtain Drilling & Grouting						
	a. Mobilization & Demobilization Including Site Work	job	Lump Sum	---	$ 252,350.00	---	$ 60,000
	b. Drilling Grout Holes						
	(1) Drilling 6-in. Holes	14,000	lin ft	$13.35	186,900.00	$12.00	168,000
	(2) Drilling 3-1/2-in. Holes	28,600	lin ft	8.78	251,108.00	8.00	228,800

Item No.	SCHEDULE A Description of Bid Item	Government Estimate Estimated Quantity	Unit	Unit Price	Estimated Amount	Contract Unit Price	Contract Estimated Amount
	(3) Drilling 1-3/8-in. Holes	21,300	lin ft	8.65	184,245.00	9.00	191,700
	c. Pipe for Grout Holes						
	(1) 4-in. Pipe	14,000	lin ft	8.05	112,700.00	8.00	112,000
	(2) 2-in. Pipe	42,000	lin ft	3.06	130,356.00	3.00	127,800
	d. Pressure Washing & Pressure Testing	250	Hr	190.00	47,500.00	150.00	37,500
	e. Portland Cement in Grout	83,100	cu ft	5.30	440,430.00	6.00	498,600
	f. Placing Grout	2,700	Hr	113.00	305,100.00	100.00	270,000
	g. Connections to Grout Holes	900	ea.	5.00	4,500.00	5.00	4,500
	TOTAL ESTIMATED AMOUNT OF SCHEDULE A				$1,915,189.00		$1,698,900
	Acceptance Period - Calendar Days						30

The total actual quantities and costs for Increment II were as follows:

Item No.	Description	Estimated Quantity	Unit	Total Quantity To Date	Unit Price	Amount
	SCHEDULE A					
1	Curtain Drilling & Grouting					
	a. Mobilization & Demobilization Including Site Work	Job	Lump Sum	Job	$60,000	$ 60,000
	b. Drilling Grout Holes					
	(1) Drilling 6-in. Holes	14,000	lin ft	21,096	12	253,152
	(2) Drilling 3-1/2-in. Holes	28,000	lin ft	55,492	8	443,936
	(3) Drilling 1-3/8-in. Holes	21,300	lin ft	11,067	9	99,603
	c. Pipe for Grout Holes					
	(1) 4-in. Pipe	14,000	lin ft	20,816	8	166,528
	(2) 2-in. Pipe	42,000	lin ft	57,326	3	171,978

Item No.	Description	Estimated Quantity	Unit	Total Quantity To Date	Unit Price	Amount
	SCHEDULE A					
d.	Pressure Washing & Pressure Testing	250	Hr	72	150	10,800
e.	Portland Cement in Grout	83,100	cu ft	59,362	6	356,172
f.	Placing Grout	2,700	Hr	1,822	100	182,200
g.	Connections to Grout Holes	900	ea.	1,090	5	5,450
					TOTAL	$1,749,819

A tabulation of variation in quantities for Increment II follows:

Item	Original	Actual	Variation	Unit Price	Amount
1b1	14,000	21,096	+7,096	$ 12	$ 85,152
1b2	28,600	55,492	+26,892	8	215,136
1b3	21,300	11,067	-10,233	9	-92,097
1c1	14,000	20,816	+6,816	8	54,528
1c2	42,600	57,326	+14,726	3	44,178
1d	250	72	-178	150	-26,700
1e	83,100	59,362	-23,738	6	-142,428
1f	2,700	1,822	-878	100	-87,800
1g	900	1,090	+190	5	950
					$ 50,919

A summary of the costs and quantities, estimated and actual for both increments are as follows:

	Government Estimate Amount	Bid Amount	Actual Amount
Inc. I	1,425,401.00	1,904,838.00	2,202,110.80
Inc. II	1,915,189.00	1,698,900.00	1,749,819.00

Performance

101. The piezometers and drains are read monthly to monitor the grout curtain performance, but the pool has been relatively low and stable since the

completion of the contracts. There have been no problems noted since completion and no evidence of distress under experienced conditions which would affect performance (USACE 1981). Monitoring of the curtain will continue throughout the periodic inspection program.

References

US Army Corps of Engineers. 1959. Embankment and Spillway, Abiquiu Dam, Rio Chama, New Mexico, Albuquerque District, Albuquerque, N. Mex.

____________. 1963. Foundation Report Embankment and Spillway Constructed Under Contract No. DA-29-005-CIVENG-59-10, Albuquerque District, Albuquerque, N. Mex.

____________. 1966. Specifications - Drilling and Grouting, Abiquiu Dam (Supplemental), Albuquerque District, Albuquerque, N. Mex.

____________. 1967. Supplemental Grouting Report, Contract No. CIVENG-29-005-66-32, Albuquerque District, Albuquerque, N. Mex.

____________. 1968. Payment Estimates - Contract No. DA-29-005-CIVENG-66-43, Albuquerque District, Albuquerque, N. Mex.

____________. 1978. Reconnaissance Report on Supplemental Grouting and Drainage System, Rio Arriba County, Abiquiu Dam, New Mexico, Albuquerque District, Albuquerque, N. Mex.

____________. 1979. Abstract of Bids, Supplemental Grouting, Increment II, Abiquiu, New Mexico, Albuquerque District, Albuquerque, N. Mex.

____________. 1980. Specifications - Supplemental Grouting, Increment II, Abiquiu Dam, Albuquerque District, Albuquerque, N. Mex.

____________. 1981. Abiquiu Dam Periodic Inspection Report No. 3, Albuquerque District, Albuquerque, N. Mex.

____________. 1981. Payment Estimate - Contract Performance, Supplement A, Grouting and Drainage System, Rio Arriba County, Abiquiu, New Mexico, Albuquerque District, Albuquerque, N. Mex.

____________. 1978. Specifications - Supplemental Grouting, Increment I, Abiquiu Dam, Albuquerque District, Albuquerque, N. Mex.

____________. 1982. Grouting Report for Increments I and II, Abiquiu Dam, Albuquerque District, Albuquerque, N. Mex.

Table G1

Abiquiu - Initial Construction - Estimated and Actual Quantities and Cost

Item	Description	Estimated Quantities	Unit Bid Price	Bid Amount	Actual Quantities	Actual Cost
20	Diamond Drilling, Rotary 1-1/2-in.-diam Grout Holes					
	(a) First Subitem	10,000 lin ft	$ 3.00	$ 30,000	10,000 lin ft	$ 30,000.00
	(b) Second Subitem	8,000 lin ft	$ 3.00	24,000	6,884 lin ft	20,652.00
		18,000 lin ft		$ 54,000	16,884 lin ft	$ 50,652.00
21	Core Drilling, Exploratory Holes, 3-in. diam					
	(a) First Subitem	2,500 lin ft	$ 7.00	$ 17,500	1,565 lin ft	$ 10,955.00
	(b) Second Subitem	1,500 lin ft	$ 7.00	10,500	--	--
		4,000 lin ft		$ 28,000	1,565 lin ft	$ 10,955.00
22	Percussion Drilling, 1-1/2-in. diam	6,300 lin ft	$ 2.50	$ 15,750	3,890 lin ft	$ 9,725.00
23	Furnishing and Placing Steel Pipe and Fittings for Grout and Exploratory Holes	2,300 lb	$ 1.00	$ 2,300	3,296 lb	$ 3,296.00
24	Pressure Testing and Washing					
	(a) First Subitem	500 hr	$12.00	$ 6,000	42.5 hr	$ 510.00
	(b) Second Subitem	400 hr	$12.00	4,800	--	--
		900 hr		$ 10,800	42.5 hr	$ 510.00

(Continued)

Table G1 (Concluded)

Item	Description	Estimated Quantities	Unit Bid Price	Bid Amount	Actual Quantities	Actual Cost
25	Mixing and Placing Grout					
	(a) First Subitem	30,000 cu ft	$ 2.25	$ 67,500	30,000 cu ft	$ 67,500.00
	(b) Second Subitem	25,000 cu ft	$ 2.25	56,250	9,941 cu ft	22,367.25
		55,000 cu ft		$123,750	39,941 cu ft	$ 89,867.25
26	Furnishing Cement for Grout					
	(a) First Subitem	30,000 cu ft	$ 2.00	$ 60,000	30,000 cu ft	$ 60,000.00
	(b) Second Subitem	25,000 cu ft	$ 2.00	50,000	9,941 cu ft	19,882.00
		55,000 cu ft		$110,000	39,941 cu ft	$ 79,882.00
31	Connections to Grout Holes	900 ea.	$ 5.00	$ 4,500	767 ea.	$ 3,835.00
	TOTAL			$349,100		$248,722.00

Table G2

Drilling and Grouting Prices

Original Contract for Supplemental Grouting - 1966

Item No.	Description	Estimated Quantity	Unit	Unit Price
	Schedule A			
1	Drilling & Grouting			
	a. Mobilization & Demobilization for Drilling & Grouting	Job	Lump Sum	$65,000.00
	b. Drilling 5-in. Grout Holes for Control Shaft	800	lin ft	7.40
	c. Drilling 3-in. Grout Holes for Control Shaft	4,000	lin ft	5.40
	d. Drilling 3-in. Grout Holes for Grout Curtain	8,000	lin ft	7.00
	e. Drilling 1-3/8-in. Grout Holes for Grout Curtain	30,000	lin ft	2.30
	f. Pipe for Grout Holes	36,000	Lb	0.50
	g. Mixing & Placing Grout	80,000	cu ft	3.05
	h. Connections to Grout Pipe	1,500	ea.	6.00
	i. Pressure Washing & Testing Grout Holes	60	Hr	15.00
	j. Drilling 3-in. Drain Holes	1,400	lin ft	5.40

Table G3

Final Drilling and Grouting Prices

Final Contract for Supplemental Grouting - 1966

Item No.	Description	Contract: Quantity and Unit	Contract: Unit Price	Contract: Amount	Total To Date: Quantity and Unit	Total To Date: Amount
	Schedule A					
1	Drilling & Grouting					
	a. Mobilization & Demobilization for Drilling & Grouting	Job Lump Sum	80,892.82	80,892.82	Job Lump Sum	80,892.82
	b. Drilling 5-in. Grout Holes for Control Shaft	800 lin ft	7.40	5,920.00	720 lin ft	5,328.00
	c. Drilling 3-in. Grout Holes for Control Shaft	4,000 lin ft	5.40	21,600.00	4,013 lin ft	21,673.44
	d. Drilling 3-in. Grout Holes for Grout Curtain	775 lin ft	7.00	5,425.00	14,654.6 lin ft	102,582.20
	e. Drilling 1-3/8-in. Grout Holes for Grout Curtain	5,750 lin ft	2.30	13,225.00	9,147.9 lin ft	21,040.17
	f. Pipe for Grout Holes	43,000 Lb	0.50	21,500.00	55,686.9 Lb	27,843.45
	g. Mixing & Placing Grout	42,550 cu ft	3.05	129,777.50	41,060 cu ft	125,233.00
	h. Connection to Grout Pipe	900 Each	6.00	5,400.00	864 ea	5,184.00
	i. Pressure Washing & Testing	40 Hr	15.00	600.00	235.35 Hr	3,530.25
	j. Drilling 3-in. Drain Holes	1,400 lin ft	5.40	7,560.00	1,320 lin ft	7,128.00
	k. Drilling 3-in. Grout Holes for Split-Faced Grouting	8,100 lin ft	6.00	48,600.00	10,610 lin ft	63,660.00
	l. Drilling 1-3/8-in. Grout Holes for Split-Faced Grouting	3,400 lin ft	3.50	11,900.00	7,897.5 lin ft	27,641.25

(Continued)

Table G3 (Concluded)

Item No.	Description	Contract: Quantity and Unit	Contract: Unit Price	Contract: Amount	Total To Date: Quantity and Unit	Total To Date: Amount
m.	Pipe for Split-Spaced Grout Holes	19,000 Lb	0.50	9,500.00	56,808 Lb	28,404.00
n.	Drilling Pipe for Split-Faced Grout Holes	11,000 Lb	0.75	8,250.00	26,636.4 Lb	19,977.30
o.	Mixing and Placing Grout in Mudstone Formations	1,930 cu ft	4.05	7,816.50	7,666 cu ft	31,047.30
p.	Drilling 3-in. Grout Holes for Observation	880 lin ft	6.00	5,280.00	910 lin ft	5,460.00
q.	Drilling 1-3/8-in. Grout Holes for Observation	180 lin ft	3.50	630.00	137 lin ft	479.50
r.	Pipe for Observation Holes	2,090 Lb	0.50	1,045.00	2,142 Lb	1,071.00
s.	Drilled Pipe for Observation Holes	1,080 Lb	0.75	810.00	1,134 Lb	850.50
t.	Stage Grouting 3-in. Grout Holes	5,000 cu ft	3.05	15,250.00	4,251 cu ft	12,965.55
u.	Drilling 3-in. Grout Holes Through Compacted Fill	5,000 lin ft	6.00	30,000.00	6,024 lin ft	36,144.00
v.	Drilling 5-in. Grout Holes Through Compacted Fill	700 lin ft	8.00	5,600.00	1,152 lin ft	9,216.00
	Piezometers, Complete	Job Lump Sum	6,309.49	6,309.49	Job Lump Sum	6,309.49
			TOTAL	442,891.31		643,661.22
		Final Adjusted Estimated Quantity		200,769.91		
				643,661.22		

Table G4

Abiquiu Increments I and II
Combined Drilling and Grouting Quantities and Rates of Grout Takes

Zones		14+70 to 19+79A	0+05 to 5+00 s	5+05 to 10+00 s	5+00 to 10+00 g	Total
C	sacks	3502.5	5417.0	8716	270.5	17,906
	ft	23524	10416	19061	1822	54,823
	sacks/ft	0.15	0.52	0.46	0.15	0.33
1	sacks	143.6	5403.8	4316	4755.5	14,618.9
	ft	690	5398	6427	6730	19,245
	sacks/ft	0.21	1.00	0.67	0.71	0.65
2	sacks	177.6	7624.5	5644.25	7568.5	21,014.85
	ft	1110	5236	6048	7495	19,889
	sacks/ft	0.16	1.46	0.93	1.01	0.89
3	sacks	2786	4493.0	4178.25	9757	21,214.25
	ft	1483	5690	5686	7283	20,142
	sacks/ft	1.88	0.79	0.73	1.34	1.19
4	sacks	2572.2	2447	1939	7015.5	13,973.7
	ft	1502	4950	4717	7976	19,145
	sacks/ft	1.71	0.49	0.41	0.88	0.87
5	sacks	11252.1	3337	1062.5	2624.5	18,276.1
	ft	6168	5906	4658	5931	22,663
	sacks/ft	1.82	0.57	0.23	0.44	0.77
6	sacks	10798.9	86		21.5	10,906.4
	ft	8061	368		162	8,591
	sacks/ft	1.34	0.23		0.13	0.57
Totals						
	sacks					117,910.2
	ft					164,498.0
	sacks/ft	1.04	0.72	0.57	0.67	0.72
	sacks (minus casing)					100,004.2
	ft (minus casing)					109,675.0
	sacks/ft (minus casing)					0.91

PROJECT H: EUFAULA DAM

(This case history was developed with the assistance of Arthur Burkart and Eugene Gilbert, Tulsa District)

Location and Description of Project

H1. The Eufaula Dam is located on the Canadian River approximately 12 miles east of Eufaula, Okla. It consists of a 1,215-ft-long concrete gravity section constructed in 24 monoliths and flanked by earth embankments at each end and a powerhouse. Plate I-H1 shows the general layout. The gravity section consists of four right nonoverflow monoliths, 12 spillway monoliths, four power intake monoliths, and four left nonoverflow monoliths. The height of the dam is approximately 175 ft. The structure was constructed for flood control and hydroelectric power. It was designed and constructed by the Tulsa District. First stage cofferdam and initial excavation began in May 1959 and was completed in December 1959. The spillway, powerhouse foundation, and power intake contract began in February 1960 and was completed in April 1963. The prime contractor for the concrete structure was Teton-Green-Winston, and the subcontractor for drilling and grouting was Continental Drill and Grouting Company.

Geology

H2. The project is on the eastern border of the Prairie plains subdivision of the Osage Plains physiographic province. Bedrock is sedimentary and Pennsylvanian in age (USACE 1958). Maximum relief in the area is approximately 350 ft. Regional dip is westward 40 to 60 ft per mile. The ridge and plain topography is due to unequal resistance to erosion with sandstone capping elongated hills and shale forming the valleys. Some westward and southwest trending folds and faults related to the Ozark dome uplift also influence the structure of the area. A normal fault of approximately 100-ft throw dips 41 deg into the toe of the left abutment. Formations underlying the site are listed below in descending order:

Formation	Member	Foundation Rock For
Boggy	Blue jacket sandstone	Abutments
	shale (235 ft)	Embankments, stilling basin
Savanna	Spiro sandstone (14 ft)	Spillway
	shale (18 ft)	
	Sandstone (2 to 3 ft)	
	Shale	

H3. The Bluejacket sandstone caps the abutments. The basal shale assigned to the Boggy formation is hard, silty to clayey, fissile to blocky and in the lower portion a 1-ft coal bed (Rowe coal) occurs with underlying soft shale and underclay. The Spiro sandstone is hard, gray, fine grained, and fossiliferous.

Foundation Investigations

H4. The Definite Project Report (USACE 1949) was based on findings from 92 core borings made in 1943, 1947, and 1948. After the definite project report, an additional 118 holes totaling more than 11,000 ft were drilled to explore the foundation conditions of various features. Thirty-four holes were drilled to explore a proposed spillway location; 17 holes were drilled to complete design explorations in the selected spillway area; 13 holes were drilled in the powerhouse area; and 54 holes were drilled in the fault zone at the back of the left abutment including 16 holes drilled from the bottom of the exploratory excavation to the top of rock over the fault zone.

Technical Considerations

H5. A grout curtain was provided for the full length of the concrete dam and embankment (USACE 1961). See Plates I-H2 through I-H12 for sections and grouting profiles. The majority of the right embankment (from the bottom of the cutoff trench) grouting was performed by District personnel. The drilling and grouting of the major fault zone and the curtain between monolith 24 and the base of the left abutment was also performed by District forces. The contract part of the grout program was divided into four distinct parts by nature of scheduling and characteristics peculiar to each. Drilling and grouting of the right embankment to the first stage cofferdam, the grout curtain beneath the gallery, and the grout curtain on the left abutment was done by contract. The plans and specifications described the work to be performed and the equipment necessary for the grout program. The plans and specifications were not available for review nor were data available on estimated and actual costs. Pay items were provided for mobilization and demobilization, drilling grout holes, drilling drain holes, pressure testing, cement, placing grout, and connections to grout holes. The grouting program was designed by Mr. Alan Stone, District Geologist. The contract drilling and grouting was performed under the terms of the plans and specifications.

Contractual Considerations

H6. The contract for the spillway was a firm fixed price contract awarded to the lowest bidder. Continental Drilling and Grouting Company was the subcontractor for the drilling and grouting. Mr. William Boland was the resident engineer for the Corps. Mr. Lawson Jackson was the project geologist and was assisted by Messrs. Wayne McIntosh and Ted Jabara. Mr. Leo Broadrick was the subcontractor's representative at the site. No major conflicts between the prime contractor, subcontractor, or the Corps occurred and relations at the field and management level were excellent. There were no claims relating to drilling and grouting.

Drilling and Grouting Methods

H7. All grouting and drilling were done by Continental Drilling and Grouting Company. Pipes through which the curtain grout holes and drain holes were drilled were installed by the prime contractor. The grouting from the gallery and grouting the right cutoff between the cofferdam and the spillway were done after concrete reached its full height, or essentially so. The grouting up the left abutment proceeded fill placement.

Drilling

H8. Grout holes were drilled with Chicago Pneumatic 55 and 65 drills and drain holes were drilled with a Boyle drill and a Chicago Pneumatic 65. All drills were air-operated rotary type. AX fishtail bits were used in the shale and AX diamond coring or plug bits were used in the sandstone for the grout holes. NX diamond coring bits were used in the sandstone for the drain holes and NX roller bits were used in the shale. Core recovery was not required. Holes in the embankment cutoff trench were drilled on 20-ft centers initially and split spacing used when necessary. The holes were drilled on the axis and inclined 30 deg to intersect the predominant structure. Pipe had been installed through the concrete from the foundation to the gallery floor prior to concrete placement on a minimum of 10-ft centers. The inclination and direction of pipe were dictated by structural features in the foundation. They were inclined upstream and either to left or right. The angles varied but were generally about 15 deg. Additional pipe had been installed initially when desirable. During drilling and grouting operations if additional holes were required, they were drilled through the concrete.

Washing and pressure testing

H9. Each hole was pressure tested and washed prior to grouting and paid for by the hour.

Grouting mixtures

H10. All grouting was done with a mixture of cement and water. The mixtures varied according to the conditions encountered. Generally a starting mixture of 3:1 was used and thickened as necessary. Mixtures varied from 4:1 to 0.6:1 with the majority of the grout being 1:1.

Pressure

H11. Pressures varied according to the conditions encountered and the characteristics of the hole being grouted. Under the embankment, pressures ranged from 0 to 50 psi with the vast majority of the holes being grouted at pressures of 0 to 25 psi. In the gallery the maximum pressure in the first zone was generally about 50 psi and the same or slightly higher in the second zone. Pressure was built up gradually to the maximum depending on the mixture and grout take.

Refusal

H12. The refusal rate was defined as grout take of less than 1 cu ft in 10 min. Refusal was eventually met in all holes from the gallery. On the right embankment near the spillway, the majority of holes were grouted to refusal in the lower zones while breakouts in the upper shale would still occur. This was concentrated in the upper 2 or 3 ft below the surface. Continued grouting in these zones resulted in no improvement and the decision was to excavate below that level prior to backfilling.

Field Procedures

Right embankment

H13. Holes started on 20-ft centers and were split spaced as required. Grouting was performed in two zones, with the first zone to a depth of 25 ft and the second to a depth of 25 ft below the first. Breakouts were profuse and generally no pressures could be obtained. In those cases the grout was thickened and the hole filled with thick grout, allowed to set, and then redrilled. It was necessary to use packers in many cases. The majority of holes were grouted to refusal in the lower zone but the upper 2 to 3 ft of shale in the first zone could not be grouted and the decision was made to remove it prior to backfill. Grouting of this portion started 17 October 1961 and was completed 29 December 1961.

Gallery

H14. Two zones were specified beneath the concrete portion of the dam. The first zone varied in depth and was to intersect the contact of the foundation sandstone and the underlying shale. This zone averaged about 14 ft. The second zone extended downward 20 to 40 ft, but the total depth was limited to 60 ft. The primary holes were drilled to about the maximum depth while the intermediate holes were about 15 ft or less, depending on grout take. The holes were drilled and grouted by the split spacing, stage grouting methods. The first series of holes (20-ft centers) were drilled to first zone, pressure tested, and grouted. Any additional holes on closer centers were then drilled and grouted for first zone. After all the first zone holes in a section had been completed, the primary holes were then deepened to second zone and grouted. Third series holes generally went only to first zone. The first zone generally had the higher grout take of the two zones, but even then was relatively small. Exceptions to that occurred in monolith 7 where a fault zone was located beneath the gallery and takes were considerably higher than normal. Additional pipe had been installed in the zone and run to the gallery for grouting. These were all interconnected and grouted prior to foundation grouting in that section. Holes were backfilled with thick grout after pressure grouting was complete, the nipples removed and the gutter finished over. This portion of the drilling and grouting started 18 January 1962 and was completed 28 March 1962.

Fault zone grouting

H15. The extension of the curtain grouting from the end monolith to the base of the left abutment, together with the fault zone grouting was done by District personnel. The same pattern was followed as in the gallery and holes were drilled to full depth and packer grouted. After completion of the curtain several holes were drilled to intersect fault zone at various depths upstream and downstream of the axis. All holes were packer grouted and the take was not abnormally high. A maximum pressure of 50 psi was used in the bottom setting for the grout curtain. Drilling and grouting operation in this area started 10 May 1962 and were completed on 31 May 1962.

Left abutment

H16. Holes were drilled to full depth and packer grouted at different depths unless stopped due to water loss in which case the hole was grouted before reaching full depth. Holes were drilled through nipples set in rock, generally on an angle not over 30 deg, and to a maximum depth of 100 ft. The split spacing method was used with primary holes on 10-ft centers. In many instances posts were set vertically on predetermined centers (5 ft) and several holes drilled at different angles in both directions on the axis from the same post. This allowed for flexibility without lost time in grouting nipples in the rock each time. Holes were angled in both directions along the axis to intersect the structural features in the rock and to maintain a spacing of the holes of approximately 10 ft at depth. Depths of stops varied but generally the deepest stop was 40 ft with pressures of 40 to 50 psi. Mixtures varied, but the largest amount was placed at a 1:1 mixture. Grouting of the abutment started 2 April 1962 and was completed 4 June 1962.

Equipment

H17. Grout was mixed in a mixing tank and then dumped into an agitator from which it was pumped to the header. When grouting in the gallery, the contractor had a mixing tank, agitator, and pump outside of the gallery at the same location where the cement was stored. The grout was mixed there and then pumped through a line to another agitator in the gallery. The line was then blown out to push all the grout into the agitator in the gallery. From there the grout was pumped to the header. This method proved satisfactory and eliminated the problems of hauling and storing cement in the gallery, in addition to eliminating the dust from the gallery which is an objectionable feature of the mixing operation.

Grout takes

H18. The highest take per hole on the right embankment was 134 sacks; for the left abutment 234 sacks; and for the gallery 105 sacks. The following is a drilling and grouting summary:

Location	Footage	Mix Ratio (water:sacks) 4:1	3:1	2:1	1:1	0.8:1	0.6:1	Total	Ratio
Right embankment (mono. 1 to 1st stage cofferdam)	1440.4	0.0	213.6	154.4	361.0	0.0	216.0	945.0	0.66/ft
Concrete dam from gallery	6776.9	2.5	393.9	348.3	635.4	0.0	0.0	1380.1	0.2/ft
Left abutment (curtain)	4361.4	36.1	707.4	441.9	733.6	236.0	77.6	2232.7	0.5/ft
Fault zone (right abutment)	1222.0	89.8	6.1	11.2	22.2	0.0	0.0	129.3	0.1/ft
TOTALS	13800.7	128.4	1321.1	955.8	1752.2	236.0	293.6	4687.1	0.34/ft
Percent of Total		2.8	28.2	20.4	37.4	5.1	6.1		

Unexpected Geological Conditions Encountered During Construction

H19. No major unexpected geological conditions were encountered. A fault was found in the spillway excavation which required some additional excavation and cleaning. Pipes were set for future grouting and run to the gallery. They were grouted during curtain grouting operations. The major fault at the base of the left abutment was grouted but took no significant volume of grout.

Evaluation of Grouting

H20. The program resulted in a relatively tight foundation and was judged to be adequate after construction.

Costs and Quantities

H21. No estimated or actual costs were available for review. No estimated quantities were available either. The actual quantities are shown in paragraph 18.

Performance

H22. The performance has been monitored since the time the project became operational. Flow from drain holes is monitored and has shown no significant increase. The structures are inspected under the periodic safety inspection program and no leakage has been observed (USACE 1967, 1981). There has been no need for remedial grouting.

References

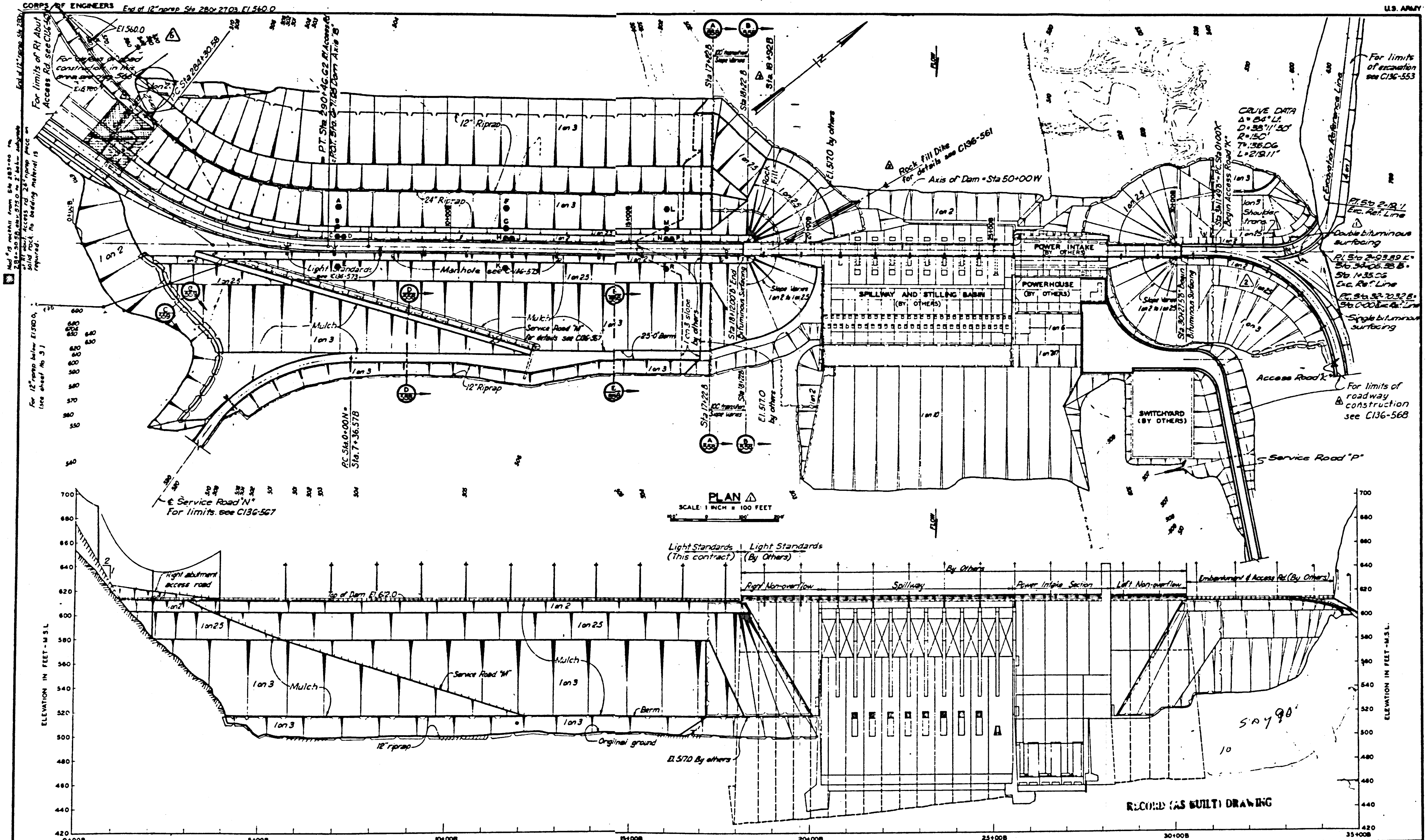
US Army Corps of Engineers. 1949. Definite Project Report, Eufaula Dam, Tulsa District, Tulsa, Okla.

____________. 1958. Design Memorandum No. 15, Geology, Soils, and Structural Foundations, Tulsa District, Tulsa, Okla.

____________. 1961. Foundation Report - Number V, Eufaula Dam, Right Embankment Section, Left Embankment and Drilling and Grouting, Tulsa District, Tulsa, Okla.

____________. 1967. Periodic Inspection and Continuing Evaluation of Completed Civil Works Structures, Eufaula Dam, Canadian River, Oklahoma, Tulsa District, Tulsa, Okla.

____________. 1981. Periodic Inspection Number 4, Eufaula Dam, Tulsa District, Tulsa, Okla.



DOWNSTREAM ELEVATION

NOTES:

1. For general notes see C136-553
2. Symbol ● denotes a piezometer
3. For piezometer locations see C136-570
4. For plan of work by others see C136-555

DATE	DESCRIPTION	CHKD	REC.	APPR.
3-15-6?	6 [illegible]			
10-29-63	5 Note added on plan at rt abutment	WEH		
?-15-63	4 Note on PLAN revised.	WEH		
9-12-62	3 Added Rock fill dike.			
5-16-62	2 Guide posts deleted			
5-11-6?	1 Plan at lt abutment revised	WEH		
	REVISION			

ARKANSAS RIVER WATERSHED — CANADIAN RIVER, OKLAHOMA

EUFAULA DAM

COMPLETION OF EMBANKMENT

GENERAL PLAN AND ELEVATION

IN 73 SHEETS — SCALE: AS SHOWN — SHEET NO. 4

U.S. ARMY ENGINEER DISTRICT, TULSA, CORPS OF ENGINEERS, FEB 2 1960

SUBMITTED — APPROVAL RECOMMENDED — APPROVED

Chief Design Branch "A" — Chief Engrg. Div — Col. Corps of Engineers District Engineer

DRAWN: W.L.A. J.L.J. TRACED: V.L.A. CHECKED: J.L.J. L.C.

TO ACCOMPANY SPECIFICATIONS ISSUED UNDER INVITATION NO. CIVENG-34-066-62-104

C136-554.

CONTRACT 62-2512

PLATE I-H1

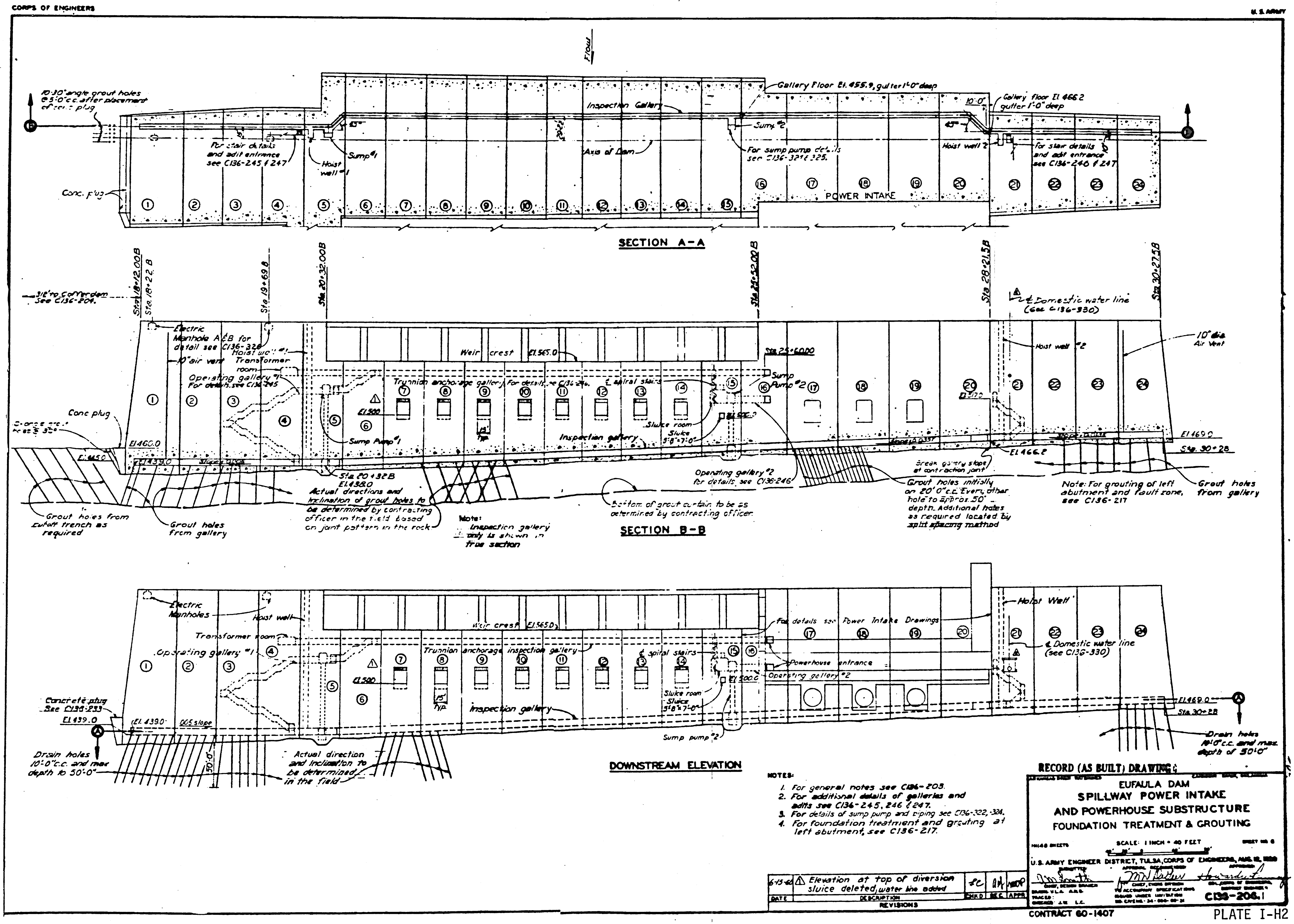
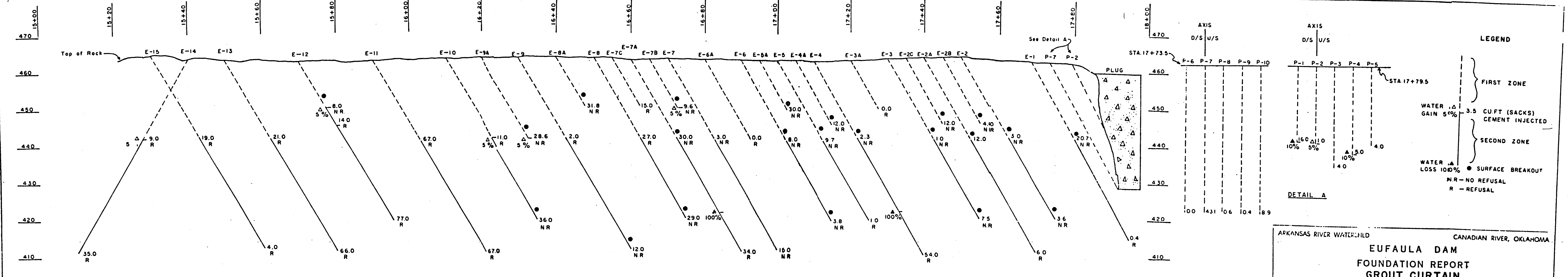

CORPS OF ENGINEERS
U.S. ARMY
SECTION A-A
Inspection Gallery
Gallery Floor El. 455.9, gutter 1'-0" deep
Gallery floor El. 466.2 gutter 1'-0" deep
Axis of Dam
Conc. plug
Hoist well #1
Sump #1
Sump #2
Hoist well #2
For stair details and adit entrance see C136-245 & 247
For sump pump details see C136-324 & 325
For stair details and adit entrance see C136-246 & 247
POWER INTAKE
SECTION B-B
Weir crest El. 565.0
Trunnion anchorage gallery, for details see C136-246
Inspection gallery
Operating gallery #1 For details see C136-245
Operating gallery #2 for details see C136-246
Transformer room
Electric Manhole A & B for detail see C136-328
10" air vent
Sump Pump #1
Sump Pump #2
Sluice room
Conc plug
Grout holes from cutoff trench as required
Grout holes from gallery
Actual directions and inclination of grout holes to be determined by contracting officer in the field based on joint pattern in the rock
Note: Inspection gallery only is shown in true section
Bottom of grout curtain to be as determined by contracting officer
Grout holes initially on 20' 0" c.c. Every other hole to approx. 50' depth. Additional holes as required located by split spacing method
Note: For grouting of left abutment and fault zone, see C136-217
Domestic water line (See C136-330)
10" dia. Air Vent
DOWNSTREAM ELEVATION
Electric Manholes
Hoist well
Hoist Well
Weir crest El. 565.0
Trunnion anchorage inspection gallery
Inspection gallery
For details see Power Intake Drawings
Powerhouse entrance
Operating gallery #2
Domestic water line (see C136-330)
Concrete plug See C136-233
Drain holes 10'-0" c.c. and max depth to 50'-0"
Actual direction and inclination to be determined in the field
Sump pump #2
NOTES:
1. For general notes see C136-208.
2. For additional details of galleries and adits see C136-245, 246 & 247.
3. For details of sump pump and piping see C136-322, -324.
4. For foundation treatment and grouting at left abutment, see C136-217.
6-15-61 Elevation at top of diversion sluice deleted, water line added
DATE DESCRIPTION CHKD REC APPR
REVISIONS
RECORD (AS BUILT) DRAWING
EUFAULA DAM
SPILLWAY POWER INTAKE
AND POWERHOUSE SUBSTRUCTURE
FOUNDATION TREATMENT & GROUTING
SCALE: 1 INCH = 40 FEET
U.S. ARMY ENGINEER DISTRICT, TULSA, CORPS OF ENGINEERS
C136-206.1
CONTRACT 60-1407

PLATE I-H2



ARKANSAS RIVER WATERSHED CANADIAN RIVER, OKLAHOMA

EUFAULA DAM

FOUNDATION REPORT

GROUT CURTAIN

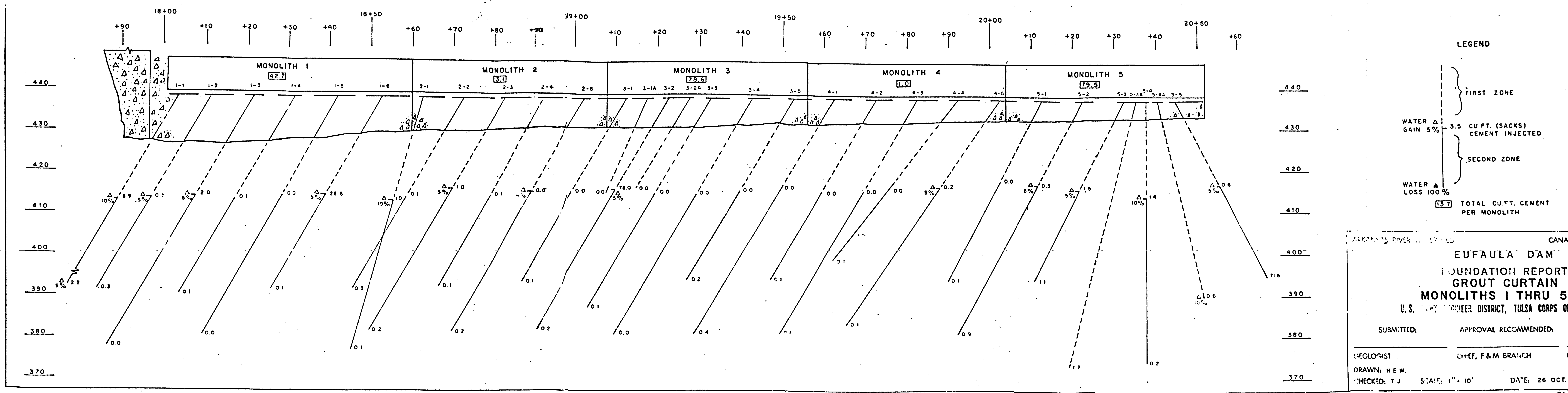
STA. 15+10 to STA. 18+00

U. S. ARMY ENGINEER DISTRICT, TULSA CORPS OF ENGINEERS

SUBMITTED:	APPROVAL RECOMMENDED:	APPROVED:
GEOLOGIST	CHIEF, F & M BRANCH	RESIDENT ENGINEER

DRAWN: J.L.W.
CHECKED: L.E.J. SCALE: 1" = 10' DATE: 2 OCT. 1962 FILE NO.:

PLATE I-H3



CANADIAN RIVER, O

EUFAULA DAM

FOUNDATION REPORT

GROUT CURTAIN

MONOLITHS I THRU 5

U.S. ... ENGINEER DISTRICT, TULSA CORPS OF ENGINEERS

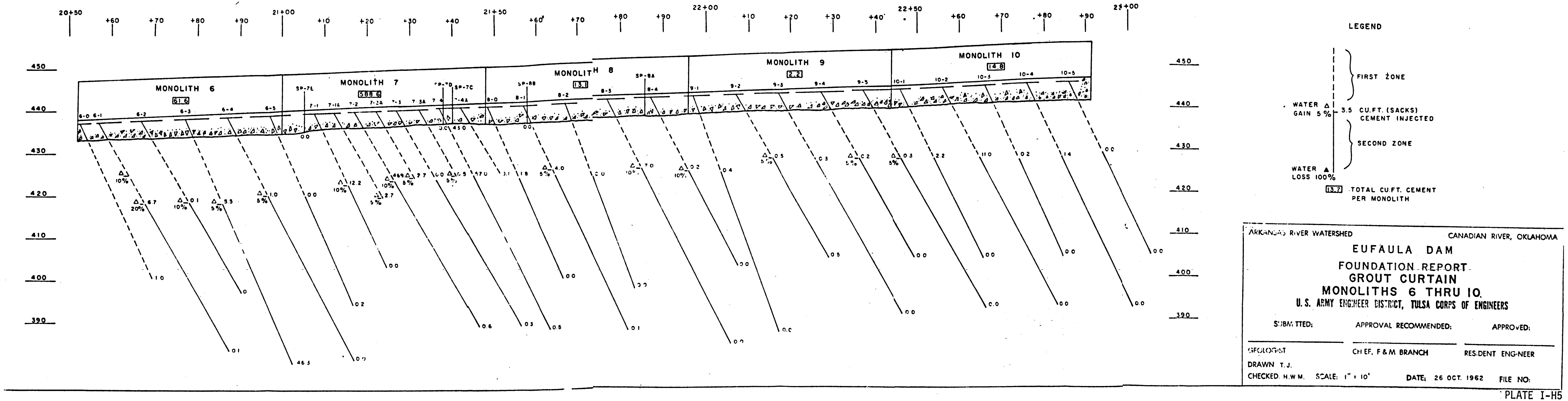
SUBMITTED: APPROVAL RECOMMENDED: APPROV

GEOLOGIST CHIEF, F&M BRANCH RESIDENT ENG

DRAWN: H.E.W.

CHECKED: T.J. SCALE: 1" = 10' DATE: 26 OCT. 1962 FILE

PLATE I-H4



ARKANSAS RIVER WATERSHED — CANADIAN RIVER, OKLAHOMA

EUFAULA DAM

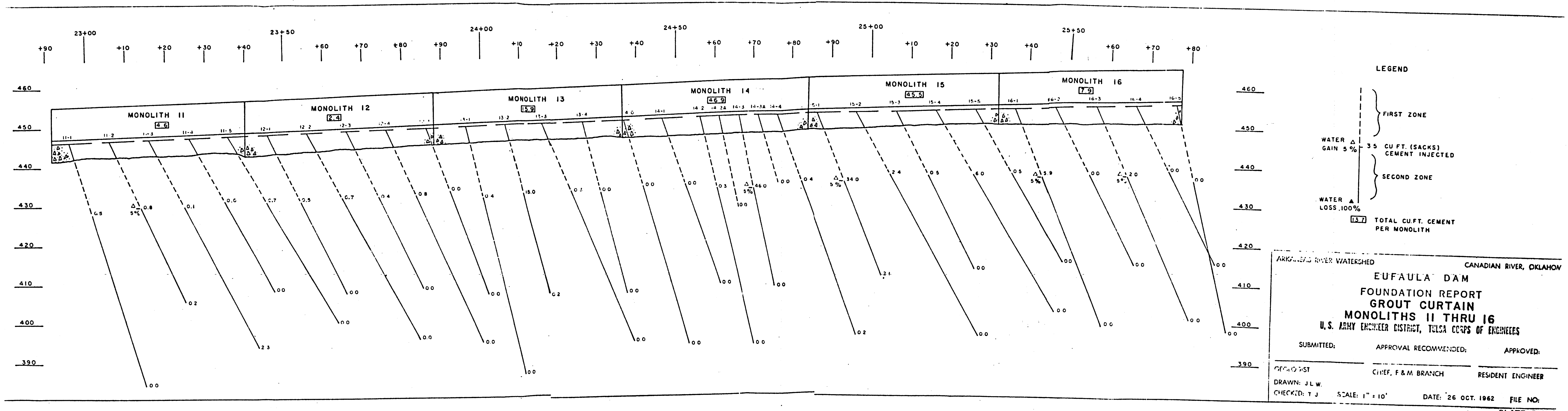
FOUNDATION REPORT
GROUT CURTAIN
MONOLITHS 6 THRU 10.

U.S. ARMY ENGINEER DISTRICT, TULSA CORPS OF ENGINEERS

SUBMITTED:	APPROVAL RECOMMENDED:	APPROVED:
GEOLOGIST	CHIEF, F & M BRANCH	RESIDENT ENGINEER

DRAWN T.J.
CHECKED H.W.M. SCALE: 1" = 10' DATE: 26 OCT. 1962 FILE NO:

PLATE I-H5



ARKANSAS RIVER WATERSHED — CANADIAN RIVER, OKLAHOMA

EUFAULA DAM

FOUNDATION REPORT

GROUT CURTAIN

MONOLITHS 11 THRU 16

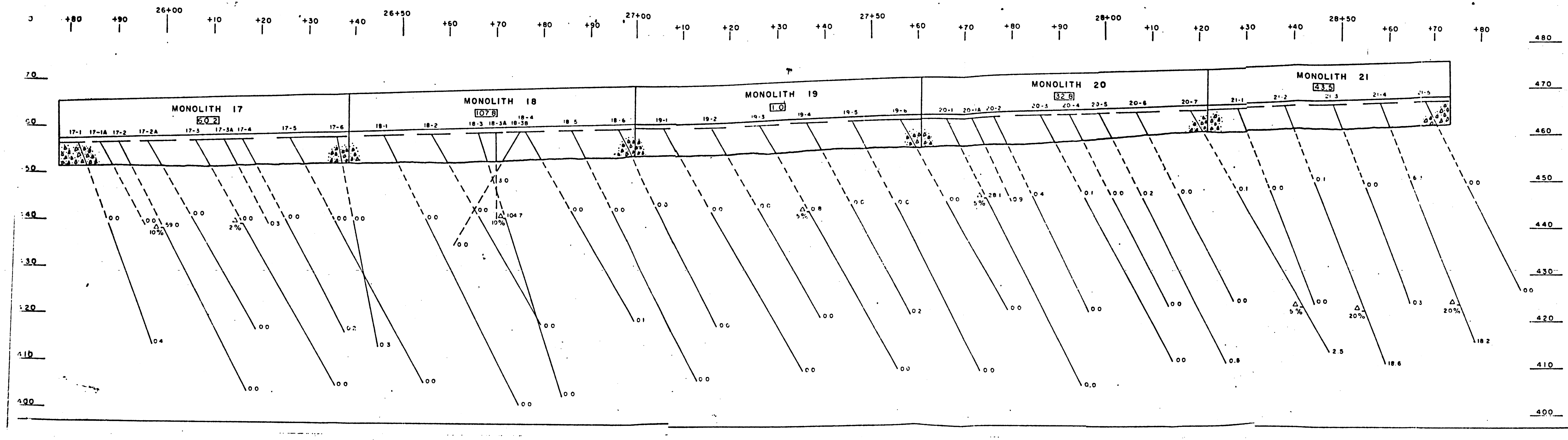
U.S. ARMY ENGINEER DISTRICT, TULSA CORPS OF ENGINEERS

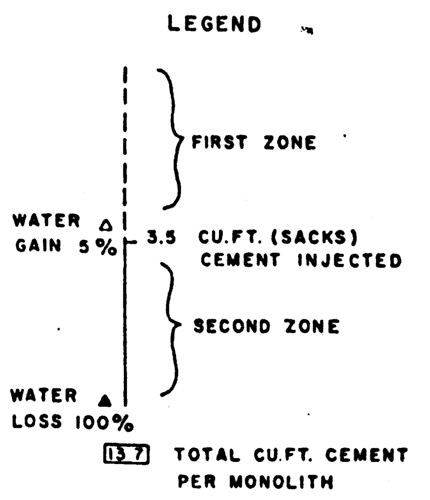
SUBMITTED:	APPROVAL RECOMMENDED:	APPROVED:
GEOLOGIST	CHIEF, F & M BRANCH	RESIDENT ENGINEER

DRAWN: J.L.W.

CHECKED: T.J. SCALE: 1" = 10' DATE: 26 OCT. 1962 FILE NO:

PLATE I-H6





ARKANSAS RIVER WATERSHED — CANADIAN RIVER, OKLAHOMA.

EUFAULA DAM

FOUNDATION REPORT
GROUT CURTAIN
MONOLITHS 17 THRU 21

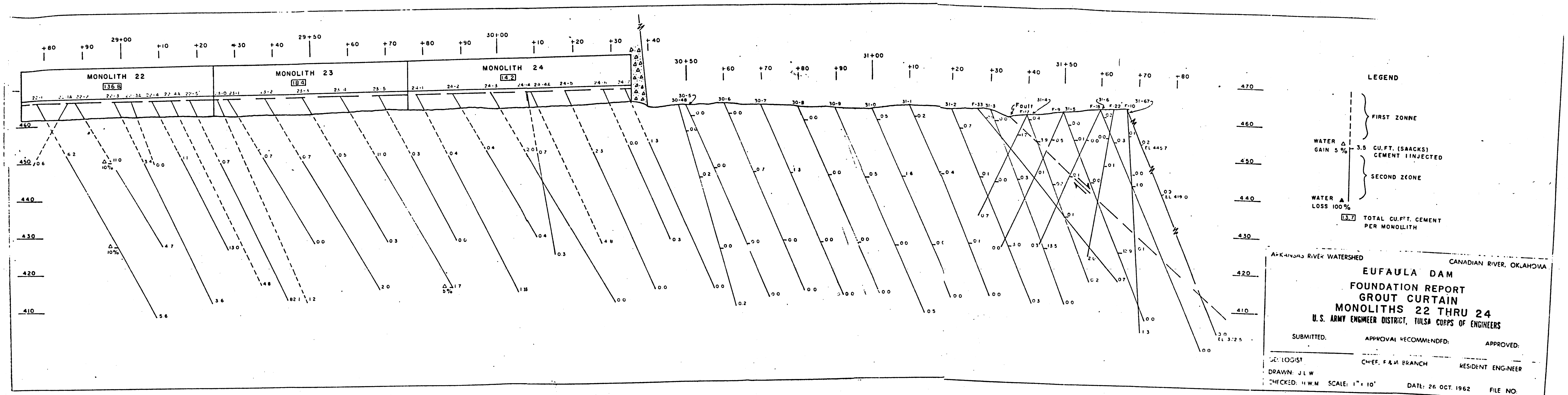
U.S. ARMY ENGINEER DISTRICT, TULSA CORPS OF ENGINEERS

SUBMITTED:	APPROVAL RECOMMENDED.	APPROVED:
GEOLOGIST	CHIEF, F & M BRANCH	RESIDENT ENGINEER

DRAWN T. J.

CHECKED J.L.W SCALE 1" = 10' DATE: 26 OCT. 1962 FILE NO:

PLATE I-H7



ARKANSAS RIVER WATERSHED — CANADIAN RIVER, OKLAHOMA

EUFAULA DAM

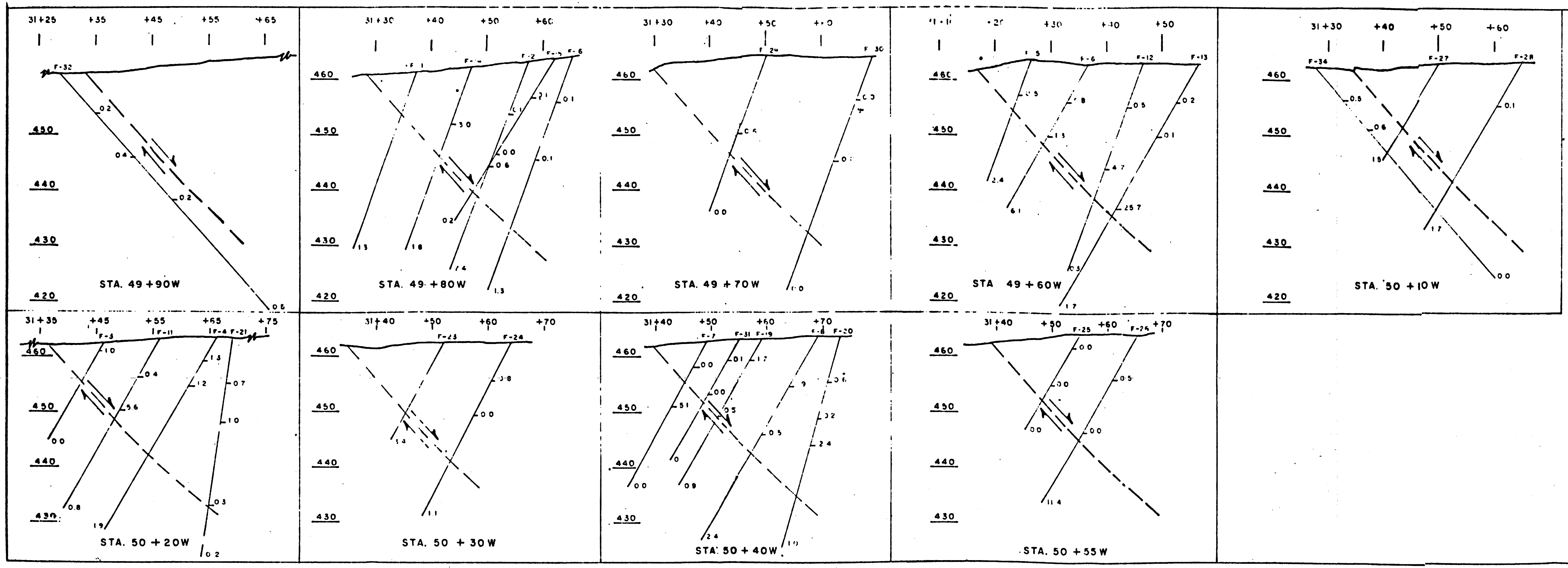
FOUNDATION REPORT
GROUT CURTAIN
MONOLITHS 22 THRU 24

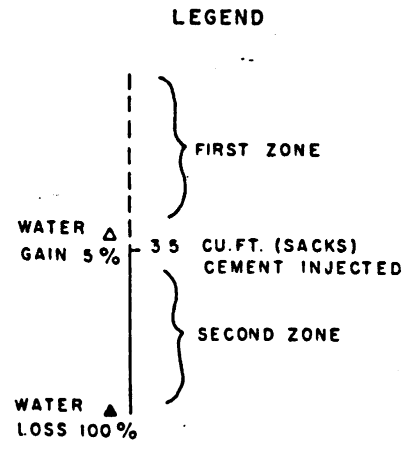
U.S. ARMY ENGINEER DISTRICT, TULSA CORPS OF ENGINEERS

SUBMITTED:	APPROVAL RECOMMENDED:	APPROVED:
GEOLOGIST	CHIEF, F&M BRANCH	RESIDENT ENGINEER

DRAWN: J.L.W.
CHECKED: H.W.M. SCALE: 1" = 10' DATE: 26 OCT. 1962 FILE NO:

PLATE I-H8





ARKANSAS RIVER WATERSHED — CANADIAN RIVER, OKLAHOMA

EUFAULA DAM

FOUNDATION REPORT

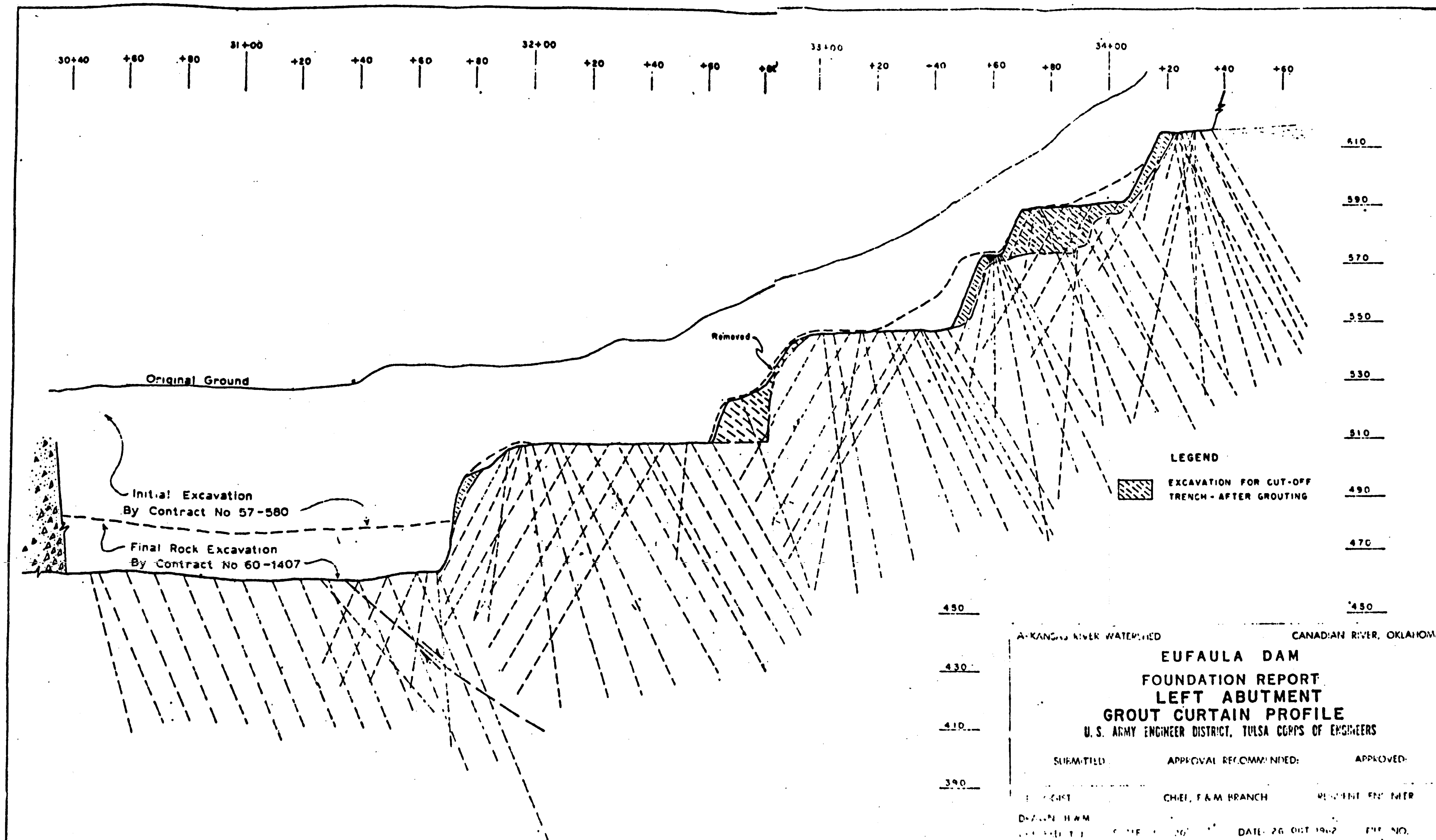
FAULT ZONE GROUTING

U. S. ARMY ENGINEER DISTRICT, TULSA CORPS OF ENGINEERS

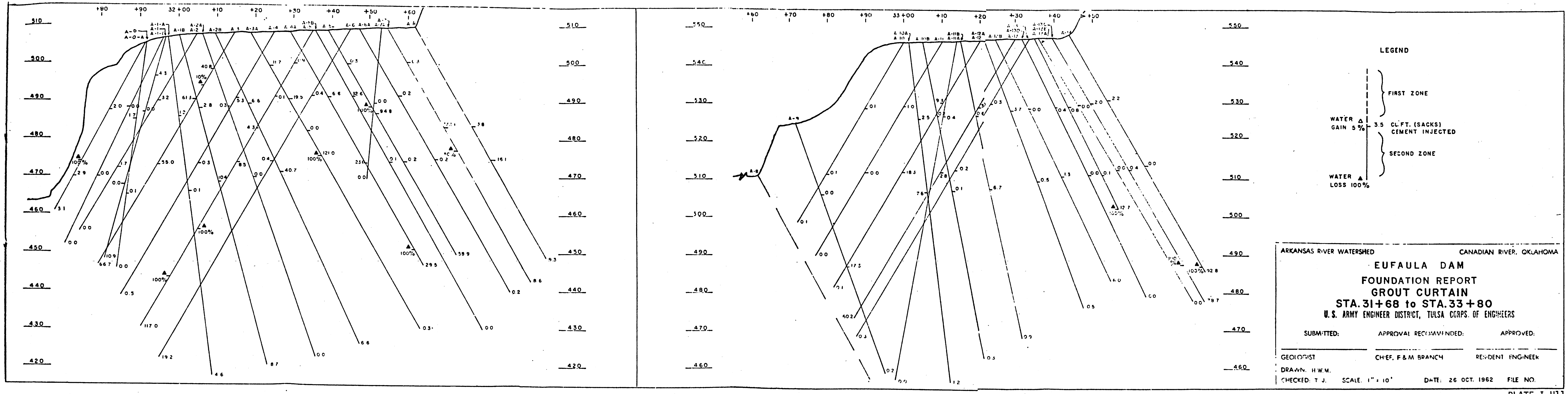
SUBMITTED:	APPROVAL RECOMMENDED:	APPROVED:
GEOLOGIST	CHIEF, F & M BRANCH	RESIDENT ENGINEER

DRAWN J.L.W.
CHECKED T.J. — SCALE: 1" = 10' — DATE: 26 OCT 1962 — FILE NO:

PLATE I-H9



30+40
+60
+80
31+00
+20
+40
+60
+80
32+00
+20
+40
+60
33+00
+20
+40
+60
+80
34+00
+20
+40
+60
610
590
570
550
530
510
490
470
450
430
410
390
Original Ground
Removed
Initial Excavation
By Contract No 57-580
Final Rock Excavation
By Contract No 60-1407
LEGEND
EXCAVATION FOR CUT-OFF
TRENCH - AFTER GROUTING
CANADIAN RIVER, OKLAHOMA
EUFAULA DAM
FOUNDATION REPORT
LEFT ABUTMENT
GROUT CURTAIN PROFILE
U.S. ARMY ENGINEER DISTRICT, TULSA CORPS OF ENGINEERS
SUBMITTED
APPROVAL RECOMMENDED:
APPROVED:
CHIEF, F&M BRANCH
DATE: 26 OCT 1962



ARKANSAS RIVER WATERSHED — CANADIAN RIVER, OKLAHOMA

EUFAULA DAM

FOUNDATION REPORT

GROUT CURTAIN

STA. 31+68 to STA. 33+80

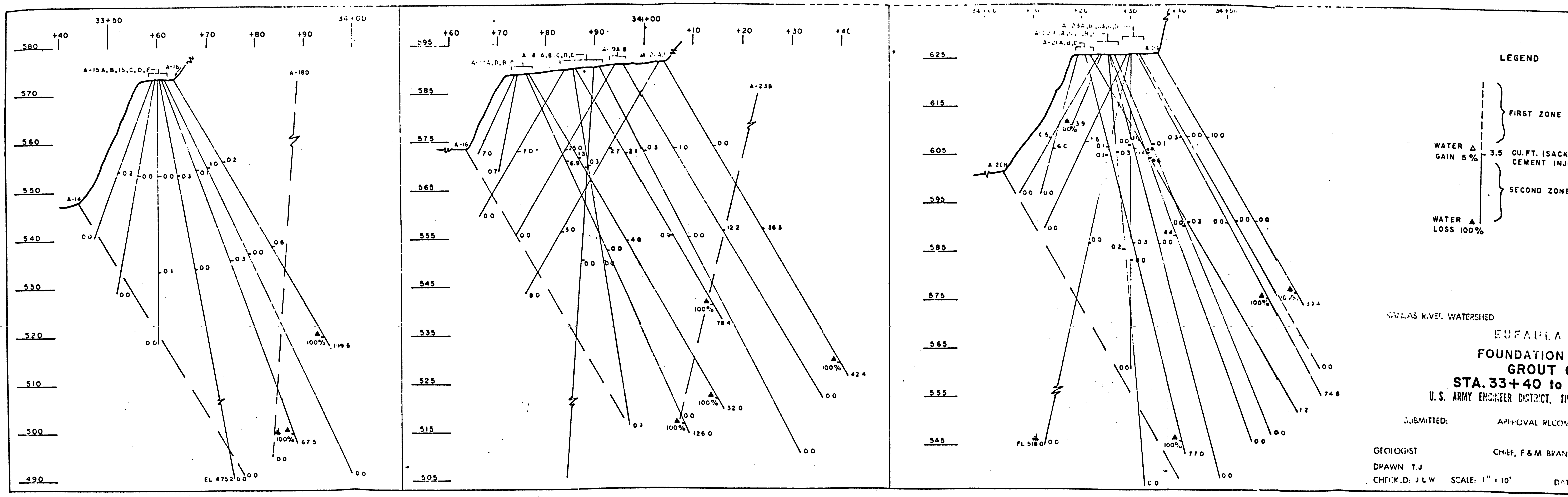
U. S. ARMY ENGINEER DISTRICT, TULSA CORPS. OF ENGINEERS

SUBMITTED:	APPROVAL RECOMMENDED:	APPROVED:
GEOLOGIST	CHIEF, F & M BRANCH	RESIDENT ENGINEER

DRAWN: H.W.M.

CHECKED: T. J. SCALE: 1" = 10' DATE: 26 OCT. 1962 FILE NO.

PLATE I-H11



ARKANSAS RIVER WATERSHED

CANADIAN RIVER, OKLAHOMA

EUFAULA DAM

FOUNDATION REPORT
GROUT CURTAIN
STA. 33+40 to STA. 34+70

U. S. ARMY ENGINEER DISTRICT, TULSA CORPS OF ENGINEERS

SUBMITTED:	APPROVAL RECOMMENDED:	APPROVED:
GEOLOGIST	CHIEF, F & M BRANCH	RESIDENT ENGINEER

DRAWN T.J

CHECKED: J L W SCALE: 1" = 10' DATE: 26 OCT. 1962 FILE NO

PROJECT I: DWORSHAK DAM

(This case history was developed with the assistance of Tilden McDowell, Walla Walla District)

Location and Description of Project

I1. The Dworkshak Dam is a concrete gravity dam located on the North Fork, Clearwater River approximately 42 miles east of Lewiston, Idaho. The dam is 3,277 ft long at the crest and has a maximum height of 717 ft. Construction took place from August 1966 until October 1973 under the direction of the Walla Walla District.

Geology

I2. The dam is founded on rocks of the Orofino metamorphic units consisting of regionally metamophosed gneisses and amphibolites. Rock types at the damsite are hornblende gneiss and biotite gneiss with minor lenses and stringers of marble. Grain size varies from fine to coarse, and the gneisses exhibit conspicuous banding.

Subsurface Investigations

I3. Although considerable effort was expended on subsurface exploration during design, details were not provided to the investigators for this study. It appears that most of the subsurface investigations were for determining geologic structural features such as shear zones and defining weathering conditions. It is doubtful that many borings were drilled and pressure tested to the full 250-ft depth of the grouting treatment design. Plate I-I1 is a plan showing additional exploratory drilling which was done during construction. These included core holes and air-trac probe holes which were used to establish the depth of weathering and/or depth of sliding material.

Grouting Design

I4. Dworshak Dam is provided with galleries from which drilling and grouting operations were conducted. Grout holes were drilled perpendicular to the base line on a slope of three vertical to one horizontal in an upstream direction. Drilling was done with either CP-65 or CP-55 air-powered screw feed drills using EX diamond plug bits. In a few cases EX coring bits were used for advancing holes but this was definitely the exception rather than the rule.

I5. Grout hole sequence was by the split-spacing method. Primary holes were drilled on 20-ft centers, secondary holes were on 20-ft centers midway between primary holes, and tertiary holes were on 10-ft centers midway between primary and secondary holes. This resulted in grout holes on 5-ft centers. Figure I-1 shows the layout of grout holes in a typical monolith. Primary holes were indicated by the letter A, secondary by the letter B, and tertiary by the letter C. Holes were coded by a combination number and letter designation. Thus, hole designation 21-1C represented the first hole in monolith 21 from the southern boundary of the monolith and the C indicated a tertiary hole.

I6. The grout curtain was also divided into zones. Zone 1 extended down 120 ft vertically from the rock-concrete contact while Zone 2 extended from 120 ft down to 200 ft below the concrete-rock contact. Zone 3 extended from 200 to 250 ft from the rock-concrete contact. Hole spacing was 5 ft in Zone 1, 10 ft in Zone 2, and 30 ft in Zone 3. Only Zone 1 was divided into two stages. The first stage was the rock-concrete contact plus 15 ft and the second stage was the remainder of Zone 1. Stage 1 was grouted only when the water take during pressure testing exceeded 1 cu ft per minute. Exceptions to this were the tertiary holes in monoliths 21, 22, and 23 which were only drilled to the limit of stage 1 of Zone 1.

I7. A further subdivision of the grout curtain was to divide the length of the curtain into sections. Each monolith constituted one section.

I8. A typical grouting sequence for a section was to drill the primary grout holes to the bottom of Zone 1, pressure test the holes and grout all holes that took more than 1 cu ft of water per minute. The grout was allowed to set to the consistency where it could be just washed out of the hole without redrilling. For grout with a 5.0 water-cement ratio, the setting time was 3 hr. The holes were then advanced to the bottom limit of Zone 1, washed, pressure tested, and grouted regardless of water take. Again the grout was allowed to set to the consistency where it could be just washed out of the hole without redrilling. Secondary holes were then drilled and grouted in the same manner to the bottom of Zone 1. This was followed by drilling and grouting of tertiary holes to the bottom of Zone 1 in the same manner as primary and secondary holes except that the grout was not washed from the holes but allowed to harden and remain permanently. Tertiary drilling and grouting was complete to the bottom of Zone 1.

I9. When drilling and grouting for Zone 1 in the adjacent monolith had been completed, then drilling commenced for Zone 2 primary holes. The primary holes were drilled to the full depth of Zone 2, washed, pressure tested, and grouted regardless of water take. For those holes that were to be advanced to the bottom of Zone 3, the grout was allowed to set to the consistency where it could be just washed out of the hole without redrilling. Grout was allowed to harden and permanently remain in the holes that were to full depth at the bottom of Zone 2.

I10. Secondary holes were then drilled and grouted to the full depth of Zone 2 and those holes that were to be continued to the bottom of Zone 3 were washed out after the grout had set initially. In the holes that were complete, the grout was allowed to harden and remain permanently. There were no tertiary holes in Zone 2.

I11. Zone 3 drilling and grouting proceeded in a manner similar to the Zone 2 operation except that no grout was washed from the holes. Zone 3 operations did not begin until Zone 2 holes in each monolith of the Valley Section extended down into Zone 3.

I12. The only change in the grout curtain from the contract to as built was the direction the holes were drilled. In the contract, grout hole directions were to be three vertical on one horizontal in the upstream direction and at right angles to the rock concrete contact parallel to the base line. To simplify drilling control at no decrease in grouting efficiency, all holes were drilled perpendicular to the base line at a slope of three vertical to one horizontal in the upstream direction, except as noted. Plates I-I2 through I-I21 show the plan and profile of the grout curtain as constructed. Included are depth of zones, water pressure test results, and grout takes.

Contractual Considerations

Contract

I13. The contract for Dworshak Dam was a firm fixed-price contract awarded to the lowest responsible bidder - Dworshak Dam Constructors. The subcontractor for drilling and grouting was Continental Drilling Company. Mr. Ray Nichols was the grouting superintendent for Continental. Messrs. Donald Basgen and Beniah Molle were resident engineers for the Corps during construction, and Mr. Douglas Hansen was project geologist.

Specification drilling
and grouting requirements

I14. The specifications (USACE 1966) required standard rotary drilling equipment. No core was required and the type of bit was optional with the contractor. Drilling and grouting were performed from the gallery of the concrete dam with the mixing plant located outside the dam as shown in Figure I-I2. Stage grouting, split-spacing methods were required. The program shown in the drawings was described as tentative, however, only minor adjustments were made and the completed grout curtain as shown in Plates I-I2 through I-I21 was generally a single line on 5-ft centers. Grouting mixtures, pressures, pumping rate, and sequence in which holes were drilled and grouted were determined in the field and as directed by the contracting officer's representative.

I15. The contractor elected to use CP-65 and CP-55 drills. A mixer capable of achieving mixing by constant rapid circulation of grout in a manner similar or equal to that of a "Colcrete" grout mixer was required. Double acting, duplex slush pumps or screw type pumps were required. A circulating header was specified as well as adequate valves, gages and stopcocks for accurate control of pressures. Pressure testing and washing equipment and suitable grouting and pressure testing accessory equipment were required.

I16. Nonshrink grout was specified composed of water, cement and fluidifier with shrinkage compensators. Type III cement was required.

I17. Estimated quantities for drilling and grouting are shown in Table I1 and final actual quantities in Table I2. Based on underruns of the items of bid, items 45, 46, 52, 53, 56, and 295 a claim was filed under the authority of GP-4, CHANGED CONDITIONS, and SP-30 VARIATIONS IN ESTIMATED QUANTITIES - SUBDIVIDED ITEMS. Items 45a and 295a are not shown in Tables I1 and I2. Item 45a was standby time for inspection: First 18 hr of which none was used; and item 295a was grouting plug: Contact grouting, first 30 hr of which 15 was the actual quantity. The claim was settled by negotiation.

Contract management

I18. No contract management or administration problems were revealed during this study. The claim for quantity underruns was justified and properly handled under GP-4. The GP-4 CHANGED CONDITIONS clause for this contract was the pre 1968 clause and only required cost/time adjustments for directly changed work, even though the claim modification was in 1974.

Drilling and Grouting Methods

Drilling

I19. Drilling of the EX grout holes was with air-powered, screw feed, postmounted drills, the Chicago Pneumatic models CP-65 and CP-55. Most drilling was with diamond plug bits, but coring bits were used in a few instances.

Pressure testing

I20. All holes were pressure tested prior to grouting. Plates I-I22 through I-I25 show the relationship between water take in cubic feet per minute and grout take in sacks of cement on a log plot. The wide scatter illustrated in these four plates shows the futility of trying to estimate total grout acceptance capacity from rate of water take. Likewise, the greatest benefit of pressure testing drain holes is that it gives an indication of whether or not the drain hole is capable of performing its intended purpose rather than the amount it may yield (USACE 1979).

Grouting mixtures

I21. Grout was mixed in a batch plant located outside the dam. After mixing, the grout was blown through a 1-1/2-in. line into the holding tank for the grout pump. This tank was capable of holding 17 cu ft of grout. From the holding tank in the gallery the grout was pumped with a double-acting, positive displacement pump into the hole. Hole pressure was measured and regulated by a gage and valve at the top of the hole. As soon as refusal was reached, the valve was closed holding the pressure in the hole until the grout had set. Grout consistencies varied from 5.0 water-cement ratio to 1.0 water-cement ratio. All holes were started with 5.0 water-cement ratio grout. Fluidifier was added to the grout only when the consistency was 2.0 water-cement ratio or thicker. Type III cement was used for all grouting.

Pressures

I22. Water pressure tests for all of Zone 1 were conducted with a pressure of 50 psi gage. Stage 1 of Zone 1 was grouted at a pressure of 50 psi gage while stage 2 of Zone 1 was grouted at a pressure of 80 psi gage. Zone 2 was pressure tested at 80 psi gage and grouted at a pressure of 100 psi gage. Zone 3 water pressures and grouting pressures were both 100 psi gage.

Field procedures

I23. Split spacing, stage grouting procedures were used. The curtain was divided into three zones of depth. Zone 1 extended from the concrete/rock contact to a vertical depth of 120 ft. Zone 2 extended to 200 ft and Zone 3 to 250 ft. Primary holes were on 20-ft spacing and were generally split in Zone 1 by secondary and tertiary holes to yield a grout curtain on 5-ft spacing in Zone 1. Tertiary holes did not extend below Zone 1. Zone 2 consisted of primary and secondary holes on 10-ft spacing, and Zone 3 spacing was generally 30 ft. Grouting procedures, mixes, hole depths and angles, and order of drilling were as directed in the field. The Corps provided direct control and supervision of the grouting program. Up to three geologists were assigned to the project during grouting operations.

Grout take

I24. Grout takes were significantly less than anticipated although a few holes took over 100 sacks. Approximately 161,000 lin ft of grout holes were drilled which accepted approximately 9,262 sacks of cement, or slightly less than 0.6 sacks per linear foot. The total estimated grout take was 62,000 sacks or over six times the amount actually injected.

Refusal criteria

I25. All holes were grouted to refusal which was defined by the contract to be a rate of take of less than 1 cu ft of solids (cement) per 1 hr at whatever grout mixture was used. During the curtain grouting operations at Dworshak, refusal was determined by use of the following criteria:

Refusal Criteria

Water-Cement Ratio	Volume Grout/15 Min
5.0	1.4 cu ft
4.0	1.1 cu ft
3.5	1.0 cu ft
3.0	0.9 cu ft
2.5	0.7 cu ft
2.0	0.6 cu ft
1.5	0.5 cu ft
1.0	0.4 cu ft
0.75	0.3 cu ft
0.5	0.2 cu ft

When grout take is equal to or less than the above listed quantities, the stage is considered to be grouted.

Records

I26. The contractor was required to prepare records covering the log of the drilling of the grout hole, results of washing and pressure washing operations, time of each change of grouting operation, pressure, rate of pumping, amount of cement for each change in water-cement ratio, and other data as deemed necessary by the contracting officer. In addition, the contractor was required to furnish all necessary assistance and cooperation to the contracting officer for development of records kept by the Government.

Unexpected Geological Conditions Encountered During Construction

I27. No major unexpected geological conditions which affected curtain grouting were encountered during construction. Smaller grout takes than expected were experienced, and adjustments were made for cost and time for the directly changed work under GP-4 CHANGED CONDITIONS.

Evaluations of Grouting

I28. The grouting program for Dworshak apparently produced satisfactory results. The program may be considered conservative considering the small takes.

Costs of Drilling and Grouting

Government Estimate:	$1,024,500
Contract Bid Price:	$1,002,372
Actual:	$ 835,522.87

I29. This includes $116,144.87 negotiated price adjustment under GP-4 because of the quantity underrun.

Performance

I30. Grout curtain performance is apparently satisfactory, however, no seepage data were available during the study.

References

US Army Corps of Engineers. 1966. Specifications for Dworshak Dam, Section 4 of Technical Provisions, Walla Walla District, Serial No. CIVENG-45-164-66-45.

___________. 1979. Dworshak Dam and Reservoir, North Fork Clearwater River, Idaho, Foundation Report, Chapter 3, Dam and Powerhouse, Walla Walla District.

Table I1

Unit Price Schedule No. DACW68-67-C-0005

Item No.	Description	Estimated Quantity	Unit	Unit Price	Estimated Amount
FOUNDATION DRILLING, GROUTING, AND DRAINAGE					
50	Drilling EX grout hole				
	a. First 100,000 lin ft	100,000	lin ft	4.00	$400,000.00
	b. Over 100,000 lin ft	55,000	lin ft	4.00	220,000.00
51	Portland Cement, Type III for grout				
	a. First 40,000 sacks	40,000	Sack	1.80	72,000.00
	b. Over 40,000 sacks	22,000	Sack	1.80	39,600.00
52	Fluidifier in grout				
	a. First 10,000 lb	10,000	Lb	1.10	11,000.00
	b. Over 10,000 lb	5,500	Lb	1.10	6,050.00
53	Placing grout				
	a. First 40,000 cu ft	40,000	cu ft	3.40	136,000.00
	b. Over 40,000 cu ft	22,000	cu ft	3.30	72,600.00
54	Grout hookup				
	a. First 1,500 connections	1,500	Each	10.00	15,000.00
	b. Over 1,500 connections	700	Each	10.00	7,000.00
55	Drilling NX drain hole				
	a. First 70,000 lin ft	70,000	lin ft	8.40	588,000.00
	b. Over 70,000 lin ft	40,000	lin ft	8.30	332,000.00
56	Drilling grout holes through overburden				
	a. First 500 lin ft	500	lin ft	22.00	11,000.00
	b. Over 500 lin ft	500	lin ft	22.00	11,000.00

Table I2

Contract No. DACW68-67-C-0005

Foundation Drilling, Grouting, and Drainage

Bid Item	Description	Contract Quantity	Contract Unit	Contract Unit Price	Contract Amount	Current Quantity	Current Amount	To-Date Quantity	To-Date Amount
50.00	Drilling EX grout hole								
	a. First 100,000 lin ft	100,000.00	lin ft	4.00	400,000.00			100,000.00	400,000.00
	b. Over 100,000 lin ft	55,000.00	lin ft	4.00	220,000.00			61,306.50	245,526.00
51.00	Portland Cement, Type III for grout								
	a. First 40,000 sacks	40,000.00	Sack	1.80	72,000.00			11,521.75	20,739.00
	b. Over 40,000 sacks	22,589.00	Sack	1.80	40,660.20			0.0	0.0
52.00	Fluidifier in grout								
	a. First 10,000 lb	10,000.00	lb	1.10	11,000.00			2,436.50	2,680.00
	b. Over 10,000 lb	5,556.00	lb	1.10	6,111.60			0.0	0.0
53.00	Placing grout								
	a. First 40,000 cu ft	40,000.00	cu ft	3.40	136,000.00			9,262.12	31,491.00
	b. Over 40,000 cu ft	22,000.00	cu ft	3.30	72,600.00			0.0	0.0
54.00	Grout hookup								
	a. First 1,500 connections	1,500.00	ea	10.00	15,000.00			1,500.00	15,000.00
	b. Over 1,500 connections	700.00	ea	10.00	7,000.00			4.00	40.00
55.00	Drilling NX drain hole								
	b. Over 70,000 lin ft	40,000.00	lin ft	8.30	333,000.00			36,677.40	30,442.00
56.00	Drilling grout holes through overburden								
	a. First 500 lin ft	500.00	lin ft	22.00	11,000.00			191.00	4,202.00
	b. Over 500 lin ft	500.00	lin ft	22.00	11,000.00			0.0	0.0

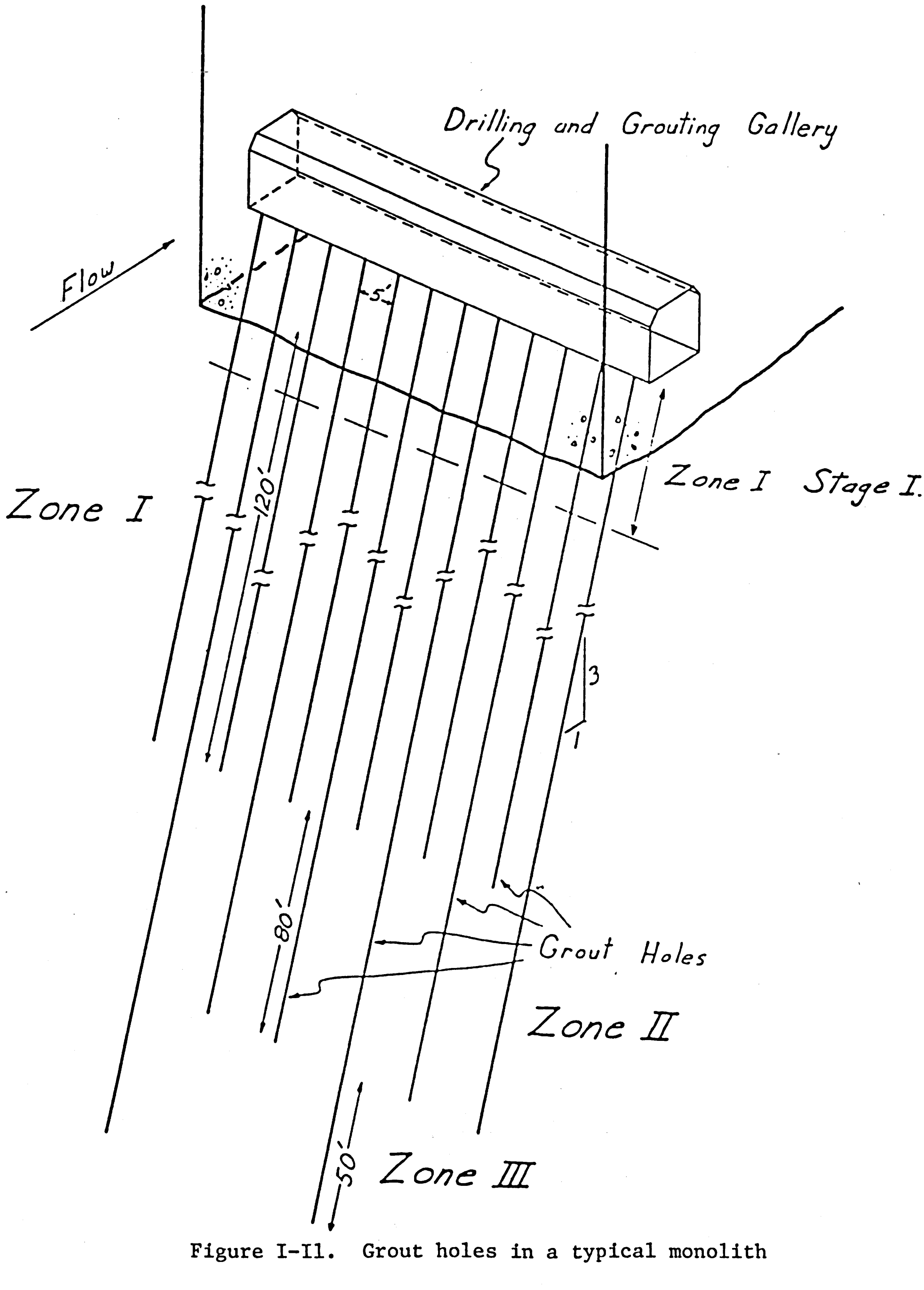


Figure I-I1. Grout holes in a typical monolith

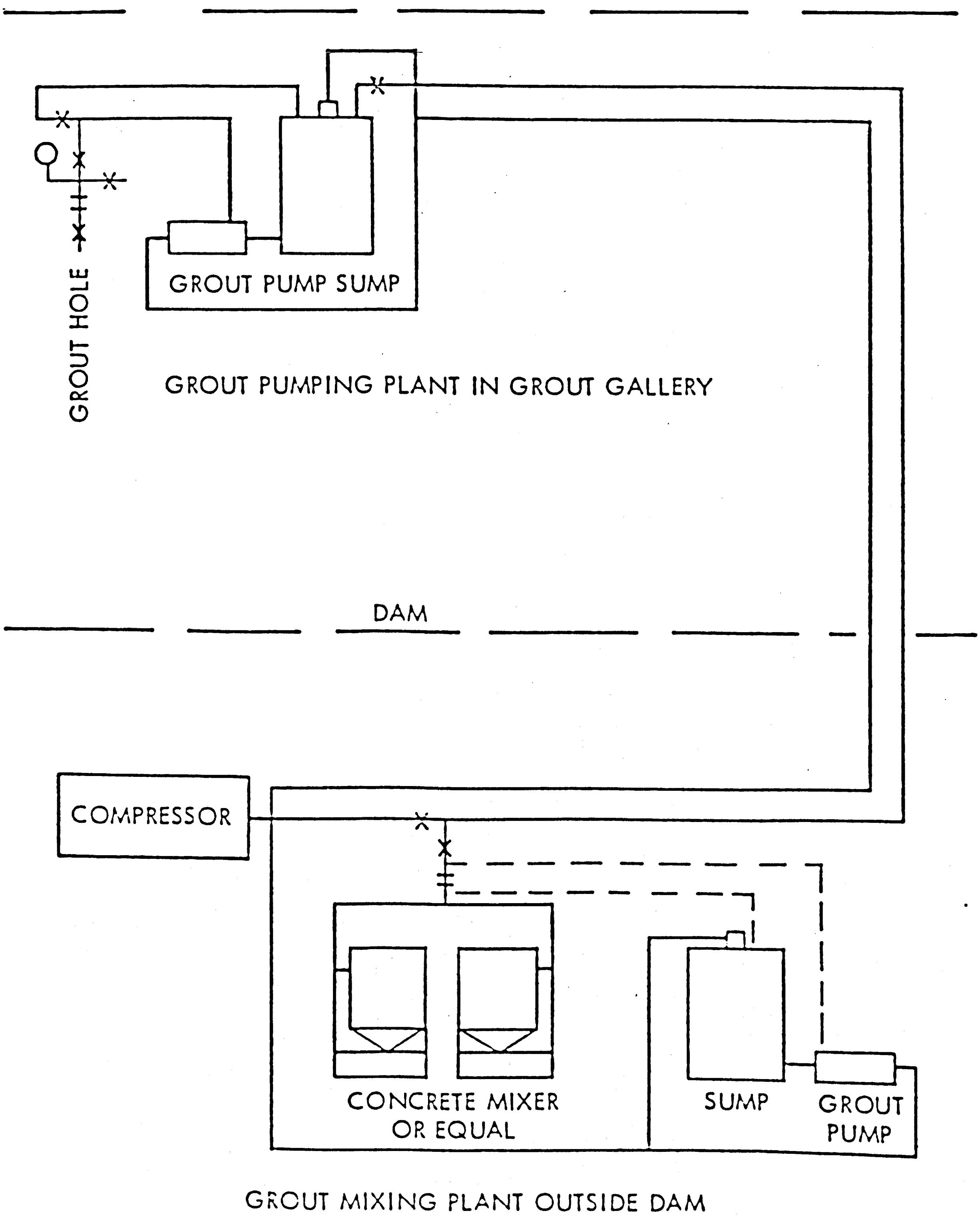


Figure I-I2. Schematic layout, grout mixing, and pumping plant

CORPS OF ENGINEERS U.S. ARMY

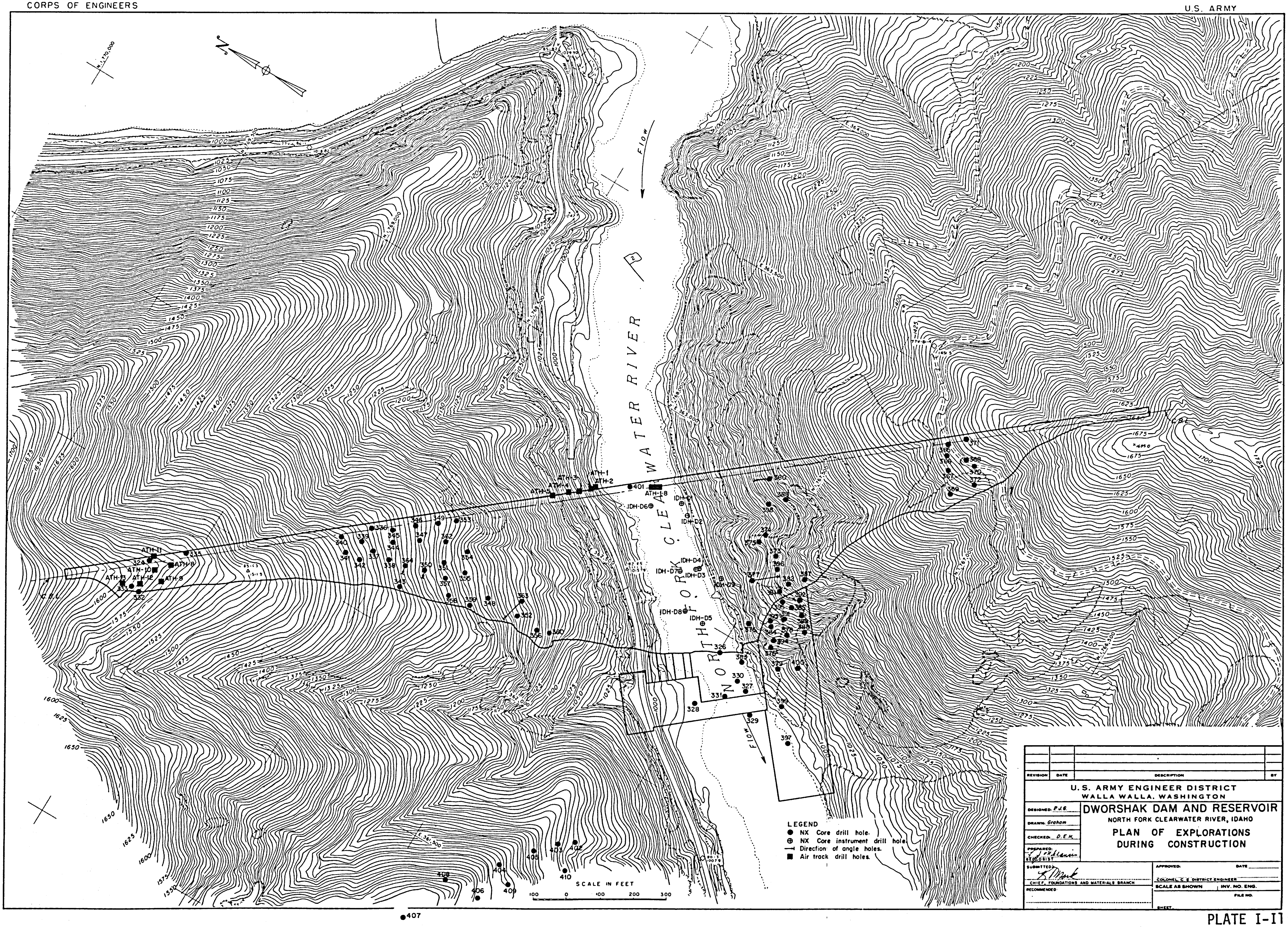
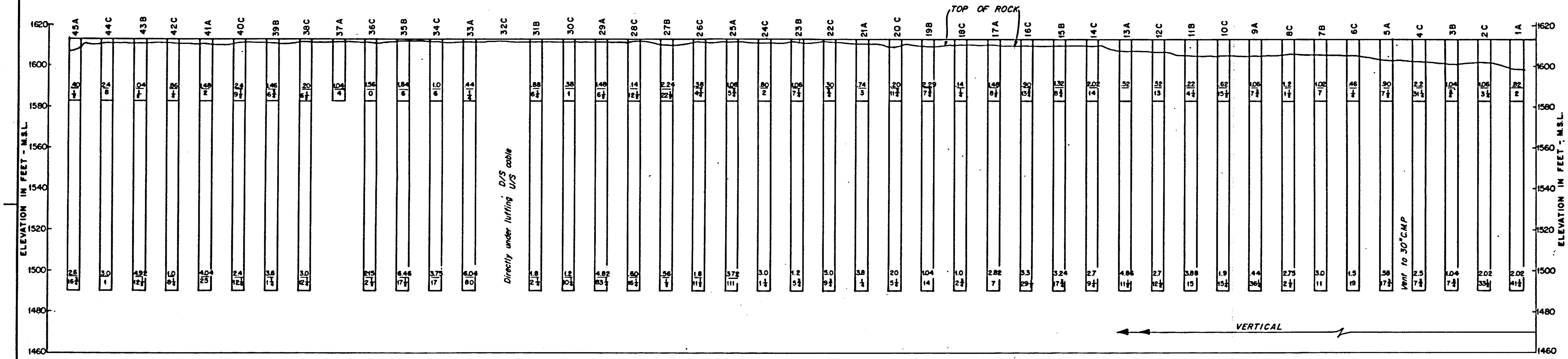
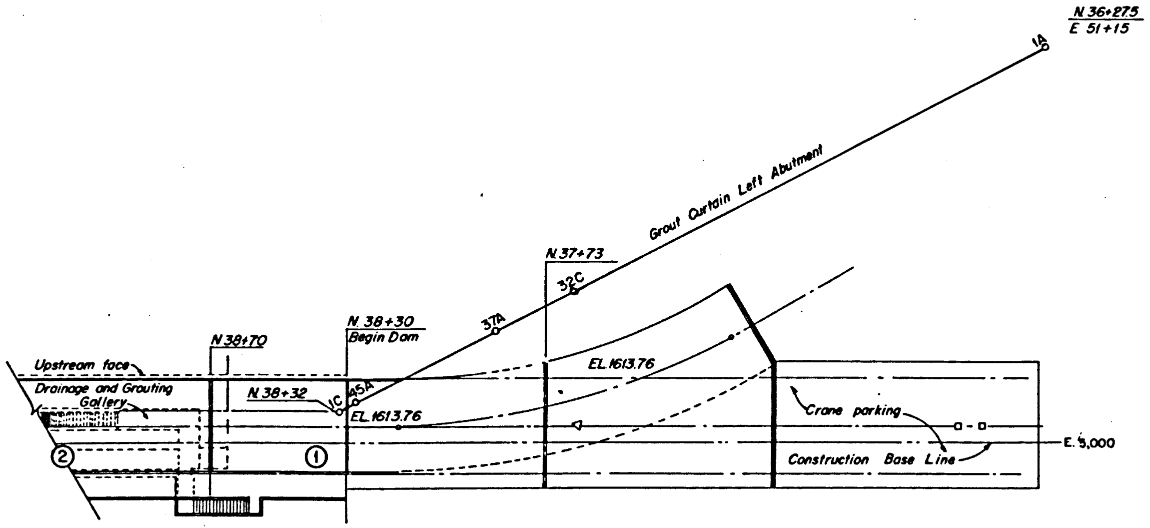


PLATE I-11



LEFT ABUTMENT

NOT TO SCALE HORIZONTALLY



PLAN OF LEFT ABUTMENT GROUT CURTAIN

SCALE IN FEET

20 0 20 40 60

LEGEND

— STAGE OR ZONE

.10 / 6 WATER TAKE, CFM / CEMENT TAKE, SACKS

.02 / ? WATER TAKE, CFM / DENOTES NO HOOKUP

REVISION	DATE	DESCRIPTION	BY

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA, WASHINGTON

DESIGNED: Joscelyn
DRAWN: Graham
CHECKED: Joscelyn

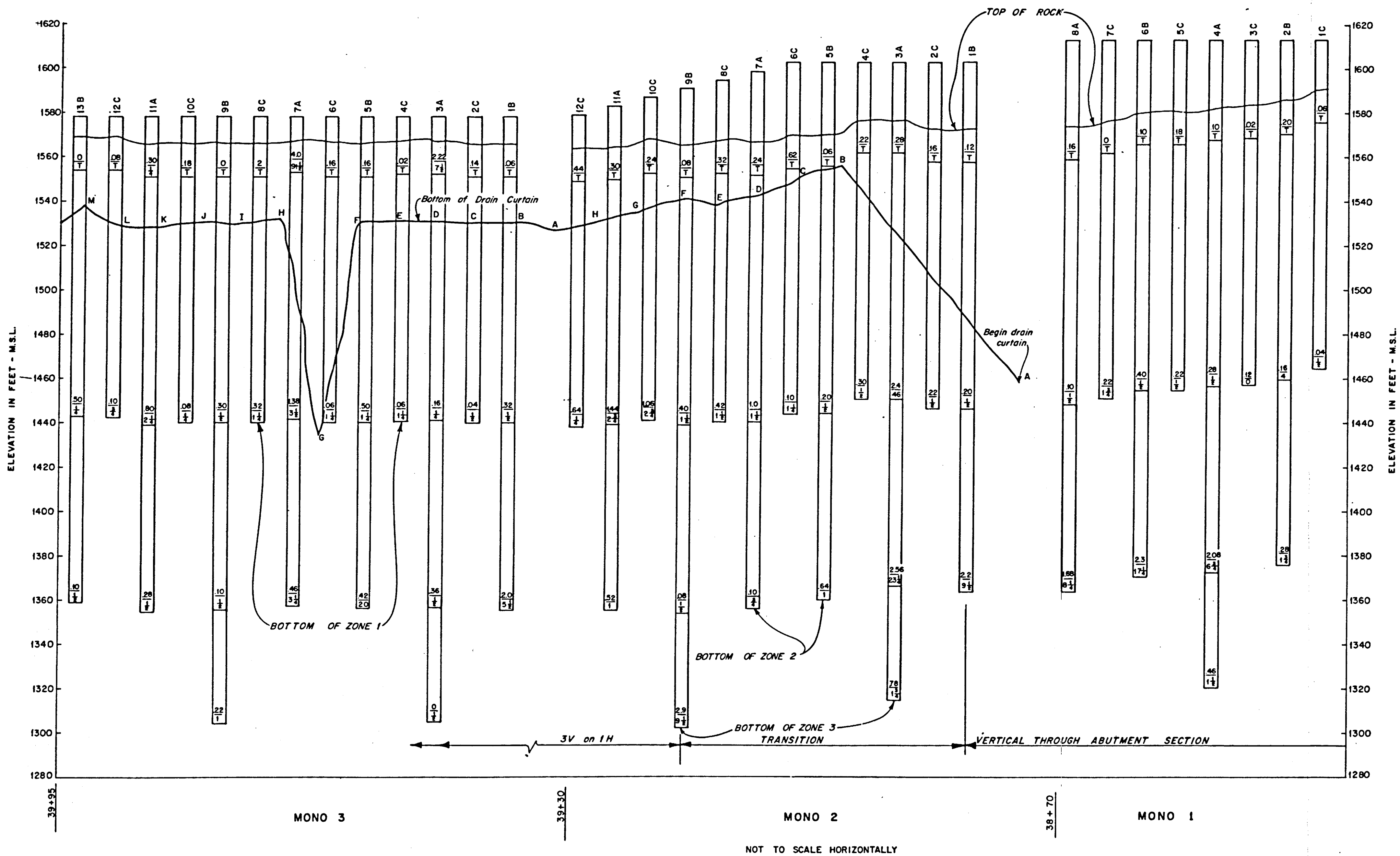
DWORSHAK DAM AND RESERVOIR
NORTH FORK CLEARWATER RIVER, IDAHO

FOUNDATION REPORT

GROUT AND DRAIN CURTAINS

SUPERVISED:
SUBMITTED:
CHIEF, FOUNDATIONS AND MATERIALS BRANCH

DATE
SCALE AS SHOWN
INV. NO.
FILE NO.
SHEET



LEGEND

— STAGE OR ZONE

.10 / 6 — WATER TAKE, CFM / CEMENT TAKE, SACKS

.02 / T — WATER TAKE, CFM / DENOTES NO HOOKUP

REVISION	DATE	DESCRIPTION	BY

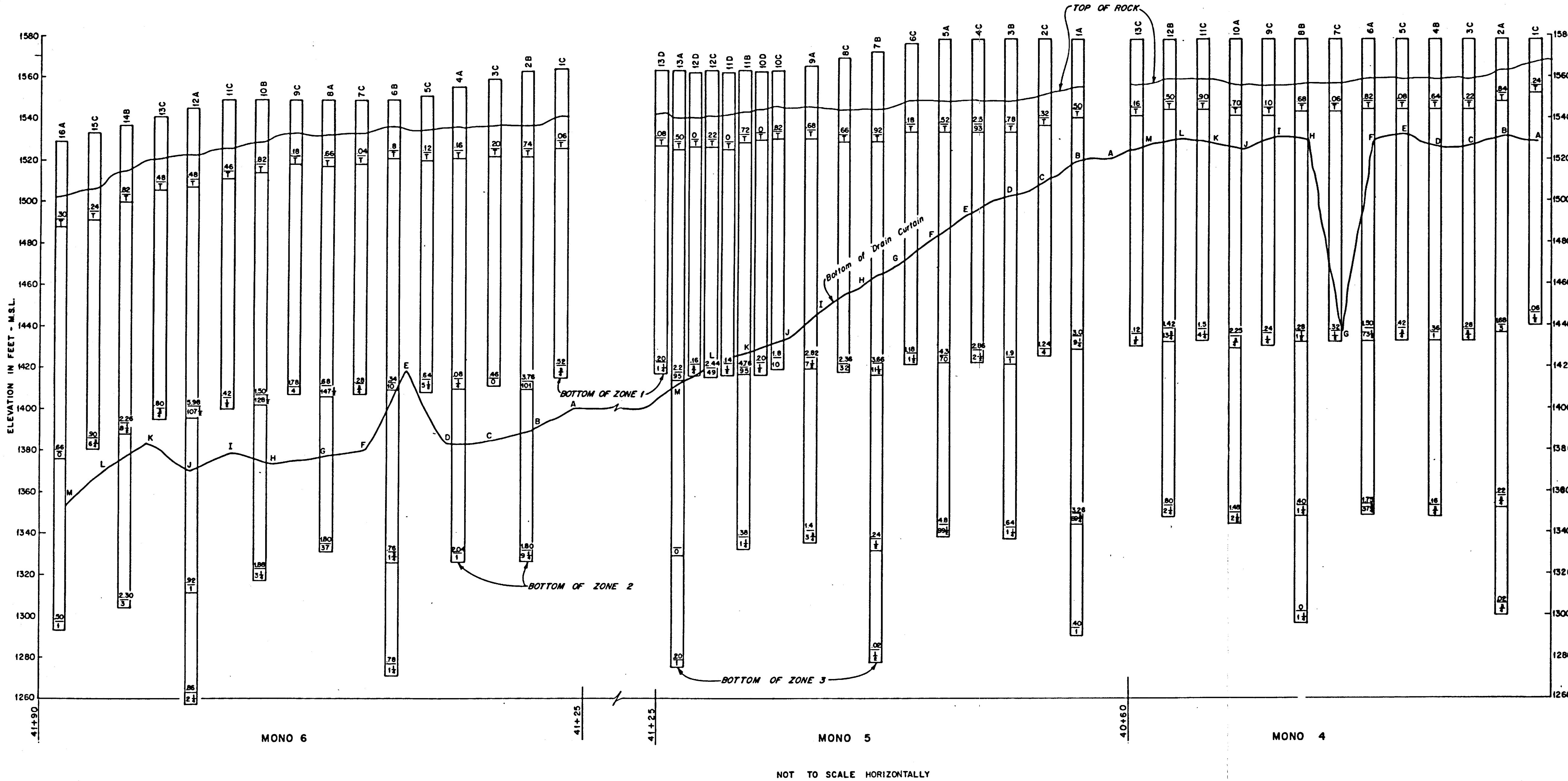
U. S. ARMY ENGINEER DISTRICT
WALLA WALLA, WASHINGTON

DESIGNED: Joscelyn
DRAWN: Graham
CHECKED: Joscelyn
SUPERVISED: CHIEF, GEOLOGY SECTION
SUBMITTED: CHIEF, FOUNDATIONS AND MATERIALS BRANCH

DWORSHAK DAM AND RESERVOIR
NORTH FORK CLEARWATER RIVER, IDAHO

FOUNDATION REPORT
GROUT AND DRAIN CURTAINS

DATE
SCALE AS SHOWN | INV. NO.
FILE NO.
SHEET



LEGEND

— STAGE OR ZONE

$\frac{.10}{6}$ WATER TAKE, CFM / CEMENT TAKE, SACKS

$\frac{.02}{T}$ WATER TAKE, CFM / DENOTES NO HOOKUP

REVISION	DATE	DESCRIPTION	BY

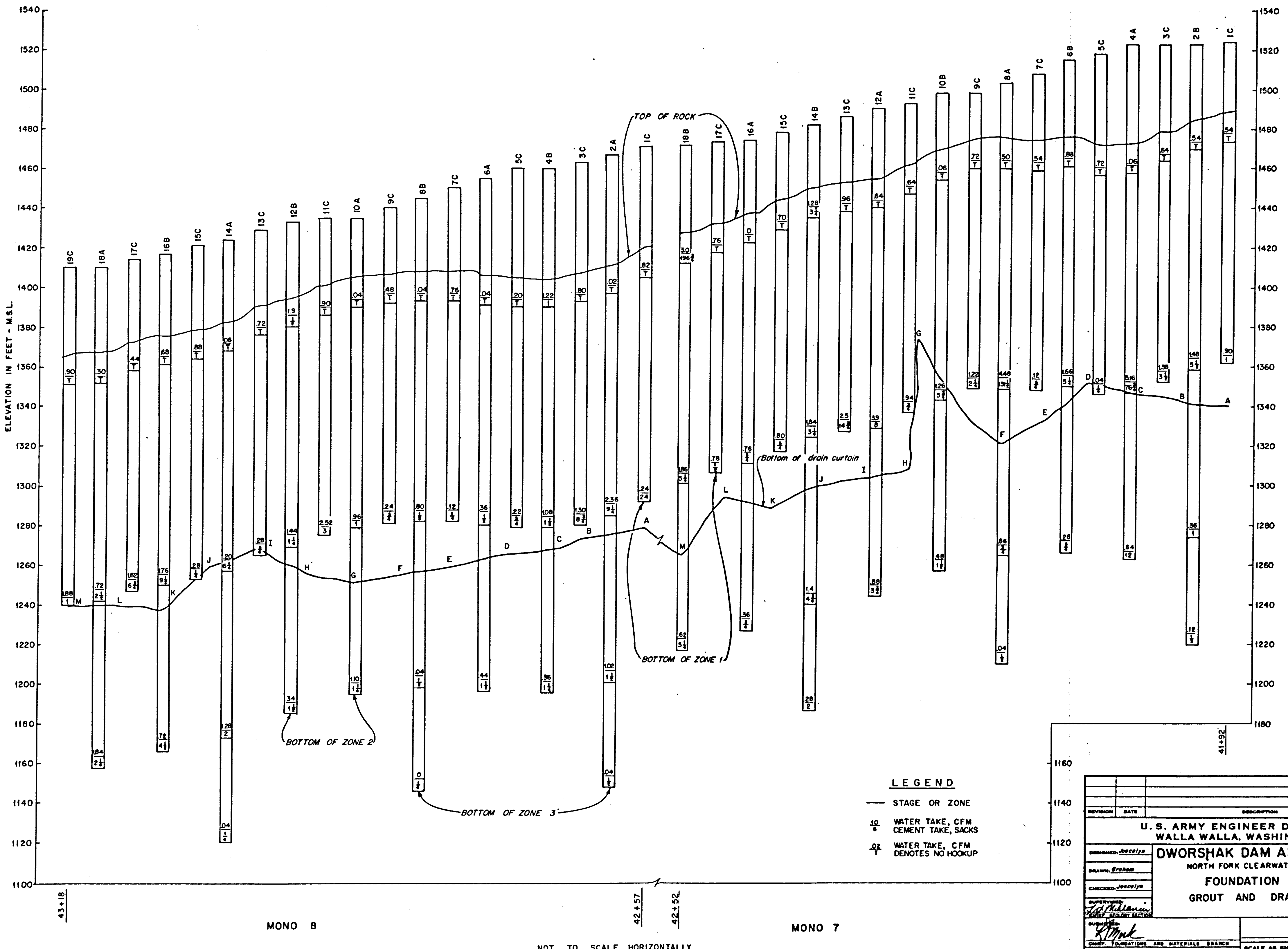
U. S. ARMY ENGINEER DISTRICT
WALLA WALLA, WASHINGTON

DESIGNED: Joscelyn
DRAWN: Graham
CHECKED: Joscelyn
SUPERVISED: CHIEF, GEOLOGY SECTION
SUBMITTED: CHIEF, FOUNDATIONS AND MATERIALS BRANCH

DWORSHAK DAM AND RESERVOIR
NORTH FORK CLEARWATER RIVER, IDAHO

FOUNDATION REPORT
GROUT AND DRAIN CURTAINS

DATE
SCALE AS SHOWN | INV. NO.
FILE NO.
SHEET



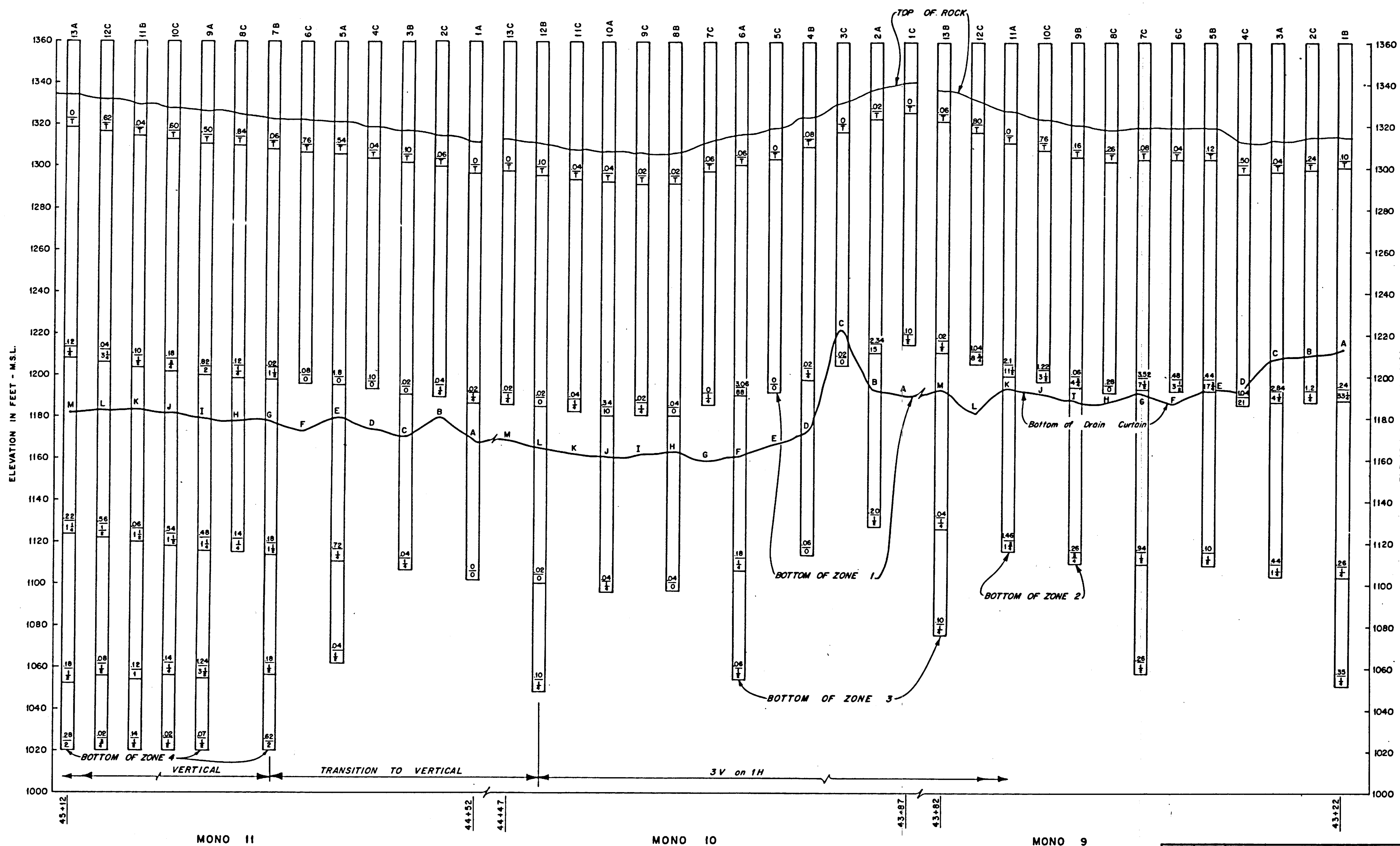
U. S. ARMY ENGINEER DISTRICT
WALLA WALLA, WASHINGTON

DWORSHAK DAM AND RESERVOIR
NORTH FORK CLEARWATER RIVER, IDAHO

FOUNDATION REPORT

GROUT AND DRAIN CURTAINS

DESIGNED: Jocelyn
DRAWN: Graham
CHECKED: Jocelyn
CHIEF, FOUNDATIONS AND MATERIALS BRANCH
SCALE AS SHOWN | INV. NO.



NOT TO SCALE HORIZONTALLY

NOTE:
Tunnel plug section 3rd. and 4th zone holes not to scale vertically.

LEGEND

— STAGE OR ZONE

10/6 WATER TAKE, CFM; CEMENT TAKE, SACKS

.02/T WATER TAKE, CFM; DENOTES NO HOOKUP

REVISION	DATE	DESCRIPTION	BY

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA, WASHINGTON

DESIGNED: Joscelyn
DRAWN: Graham
CHECKED: Joscelyn
SUBMITTED: CHIEF, GEOLOGY SECTION
RECOMMENDED: CHIEF, FOUNDATIONS AND MATERIALS BRANCH

DWORSHAK DAM AND RESERVOIR
NORTH FORK CLEARWATER RIVER, IDAHO

FOUNDATION REPORT
GROUT AND DRAIN CURTAINS

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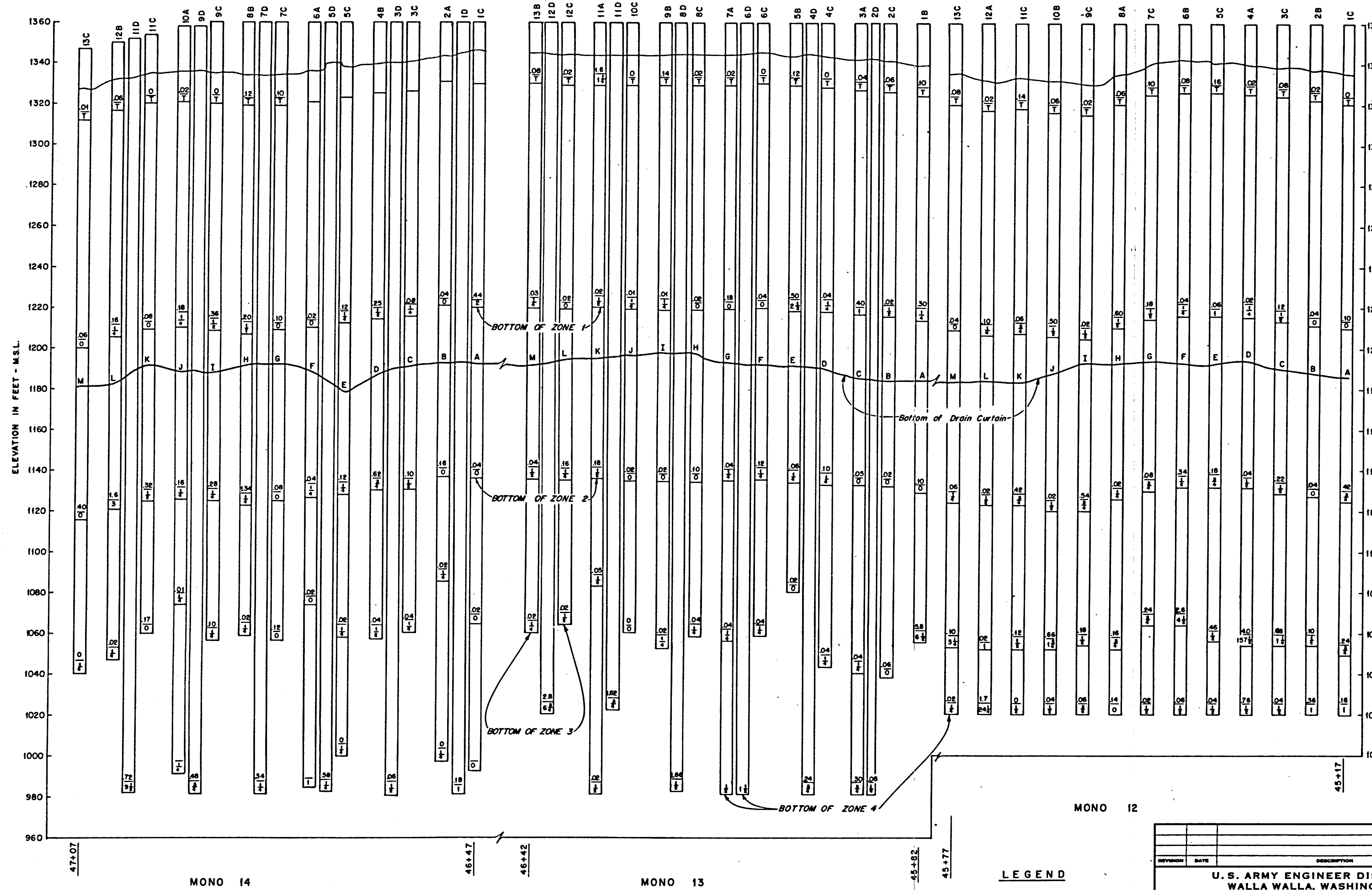


NOTE:
Tunnel plug section 3rd and 4th zone holes not to scale vertically. All holes this Plate vertical.

LEGEND

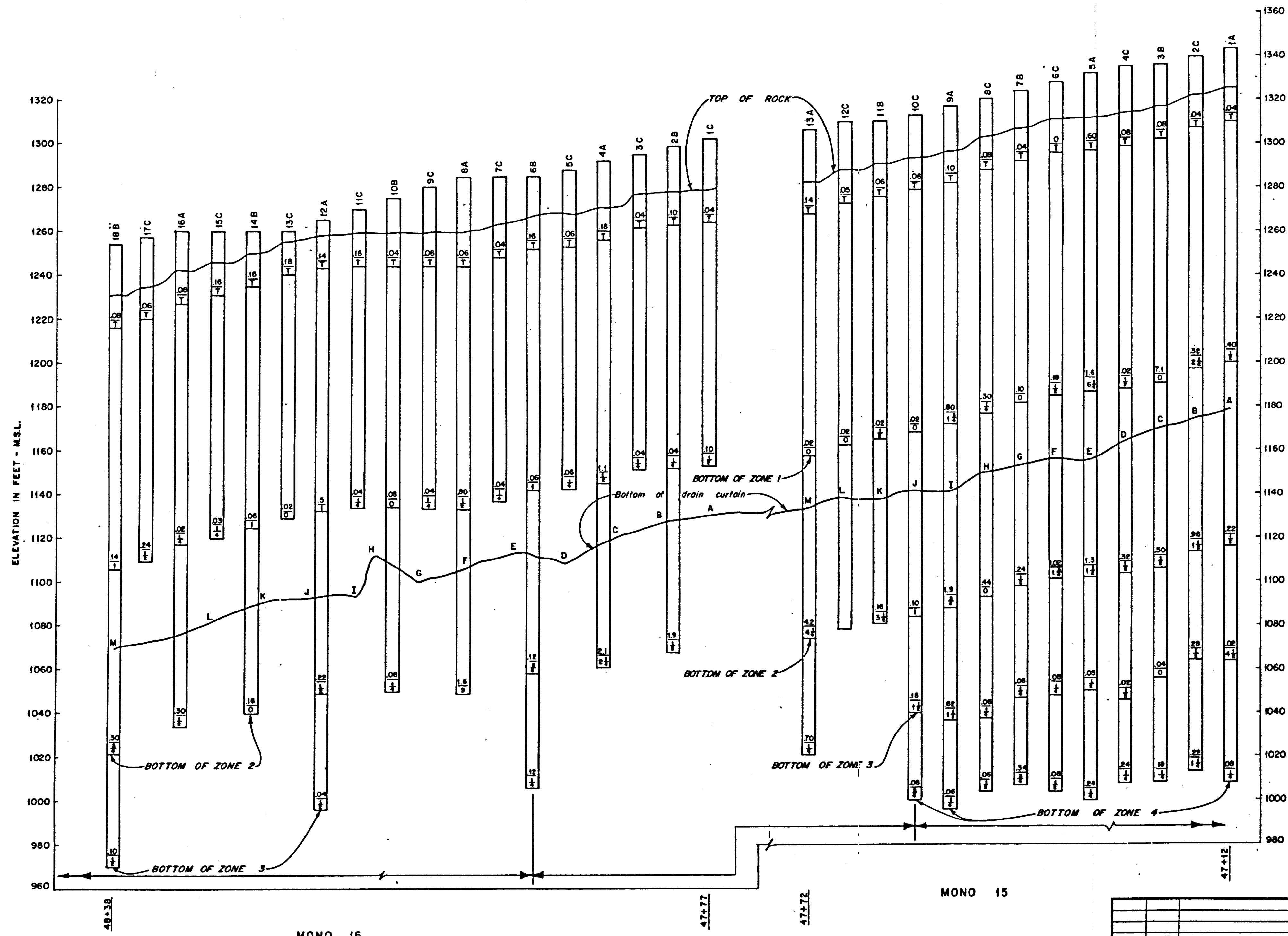
- STAGE OR ZONE
- 10/6 — WATER TAKE, CFM / CEMENT TAKE, SACKS
- .02/T — WATER TAKE, CFM / DENOTES NO HOOKUP

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA, WASHINGTON

DWORSHAK DAM AND RESERVOIR
NORTH FORK CLEARWATER RIVER, IDAHO

FOUNDATION REPORT
GROUT AND DRAIN CURTAINS

DESIGNED: Joscelyn
DRAWN: Graham
CHECKED: Joscelyn
SUPERVISED: [signature] CHIEF, GEOLOGY SECTION
SUBMITTED: [signature] CHIEF, FOUNDATIONS AND MATERIALS BRANCH
SCALE AS SHOWN | INV. NO. | FILE NO. | DATE | SHEET
REVISION | DATE | DESCRIPTION | BY



NOT TO SCALE HORIZONTALLY

NOTE:
Tunnel plug section 3rd and 4th zone holes not to scale vertically.

LEGEND

— STAGE OR ZONE

WATER TAKE, CFM / CEMENT TAKE, SACKS

WATER TAKE, CFM / T DENOTES NO HOOKUP

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA, WASHINGTON

DWORSHAK DAM AND RESERVOIR
NORTH FORK CLEARWATER RIVER, IDAHO

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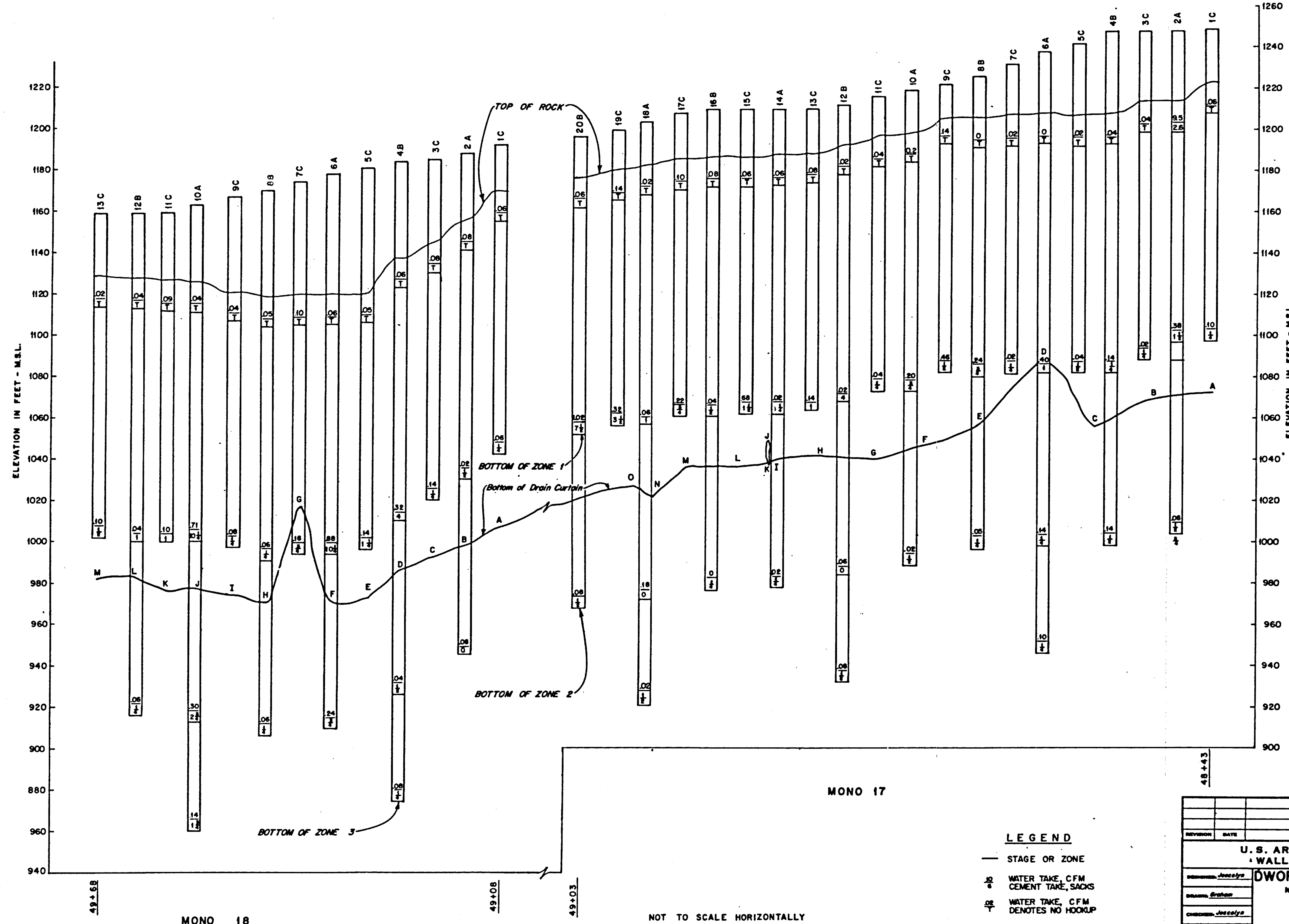
CHIEF, FOUNDATIONS AND MATERIALS BRANCH

SCALE AS SHOWN



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WALLA WALLA, WASHINGTON

DWORSHAK DAM AND RESERVOIR
NORTH FORK CLEARWATER RIVER, IDAHO

FOUNDATION REPORT
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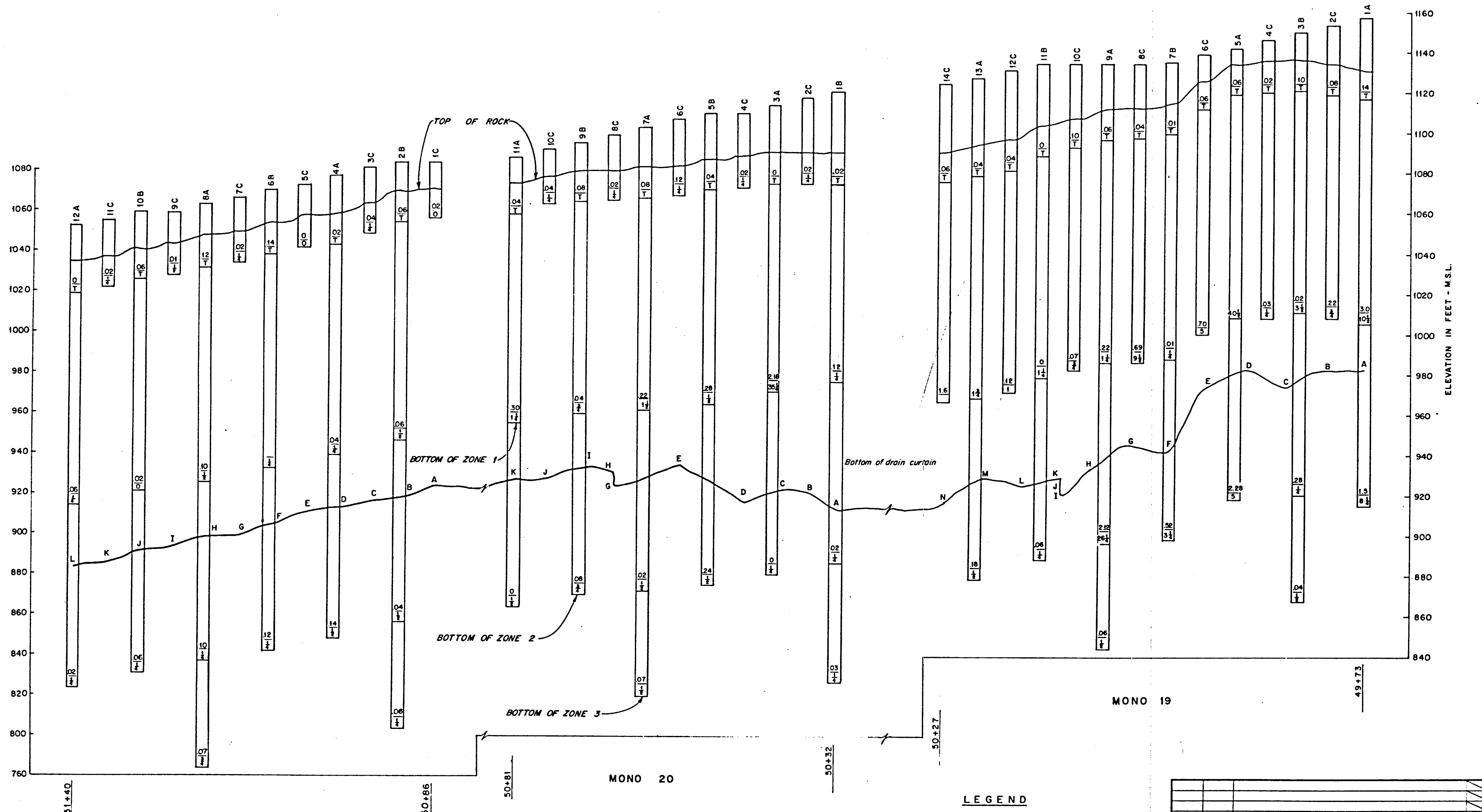
SCALE AS SHOWN



LEGEND

- STAGE OR ZONE
- 10/6 WATER TAKE, CFM / CEMENT TAKE, SACKS
- .02/T WATER TAKE, CFM / DENOTES NO HOOKUP

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA, WASHINGTON

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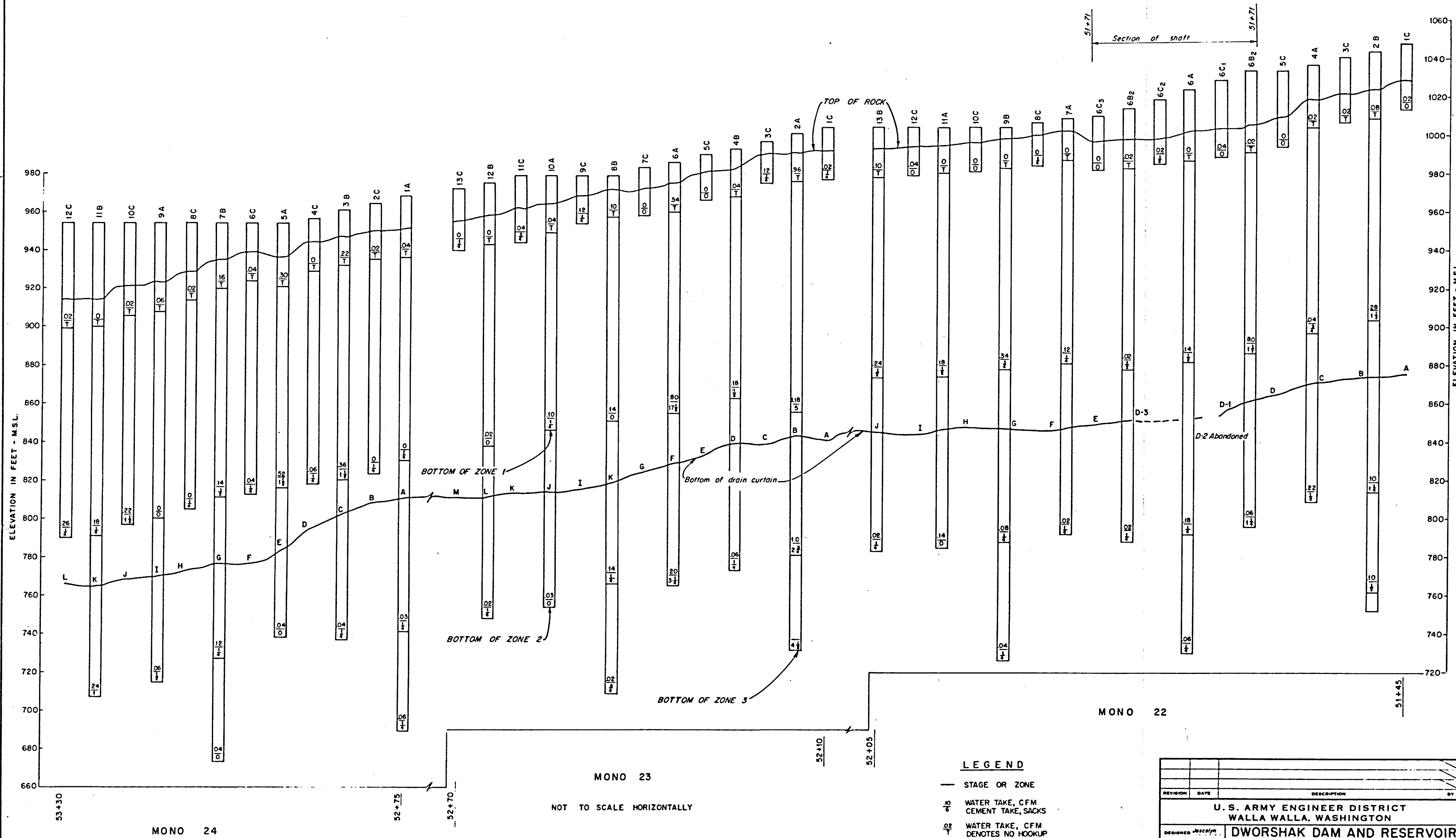

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA, WASHINGTON

DWORSHAK DAM AND RESERVOIR
NORTH FORK CLEARWATER RIVER, IDAHO

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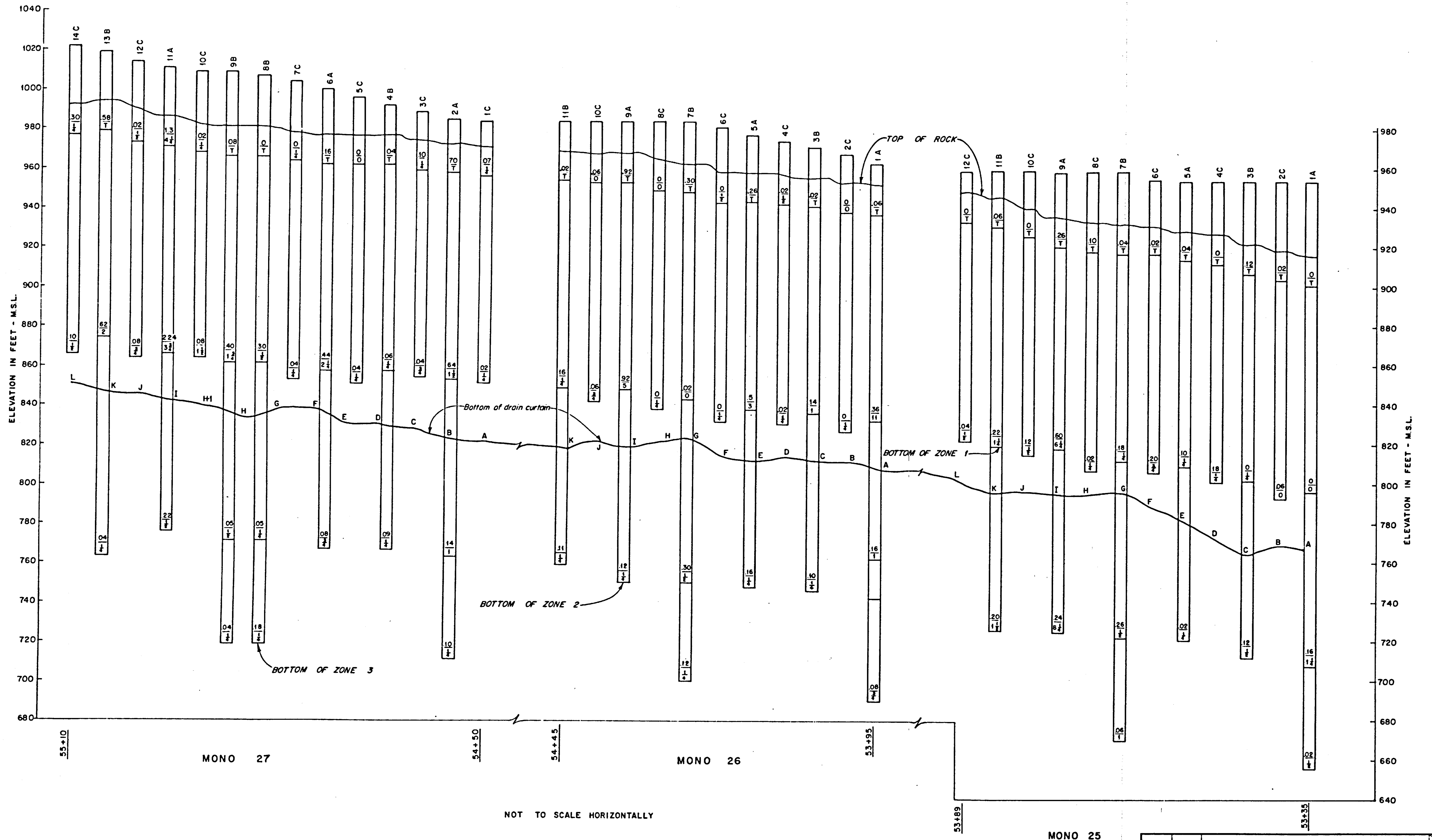
DESIGNED Joscelyn
DRAWN Graham
CHECKED Joscelyn
SUPERVISED: CHIEF GEOLOGY SECTION
SUBMITTED: CHIEF FOUNDATIONS AND MATERIALS BRANCH

REVISION | DATE | DESCRIPTION | BY

DATE
SCALE AS SHOWN | INV. NO.
FILE NO.
SHEET



LEGEND

— STAGE OR ZONE

WATER TAKE, CFM / CEMENT TAKE, SACKS

.02/T WATER TAKE, CFM / DENOTES NO HOOKUP

U. S. ARMY ENGINEER DISTRICT
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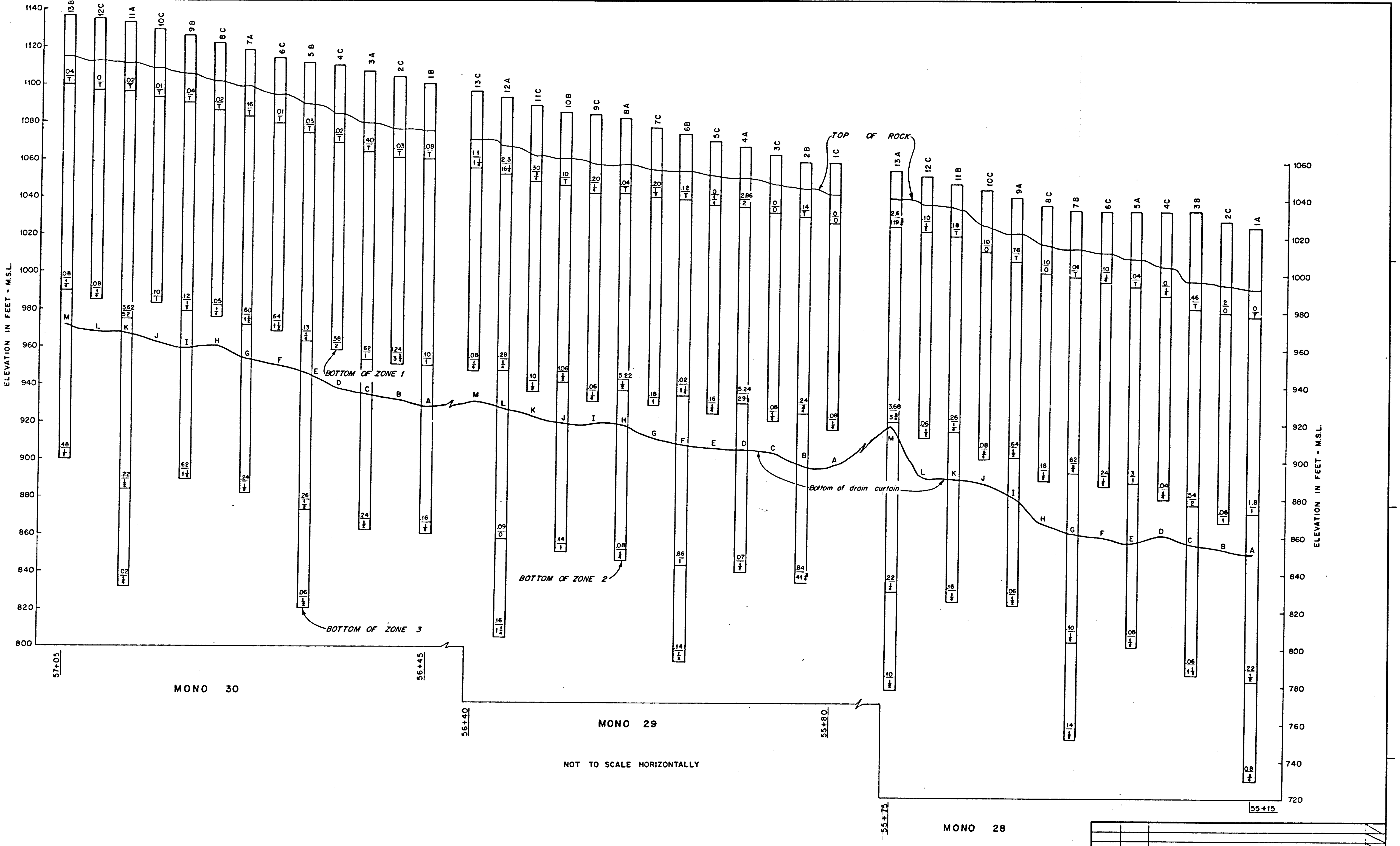

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DWORSHAK DAM AND RESERVOIR
NORTH FORK CLEARWATER RIVER, IDAHO
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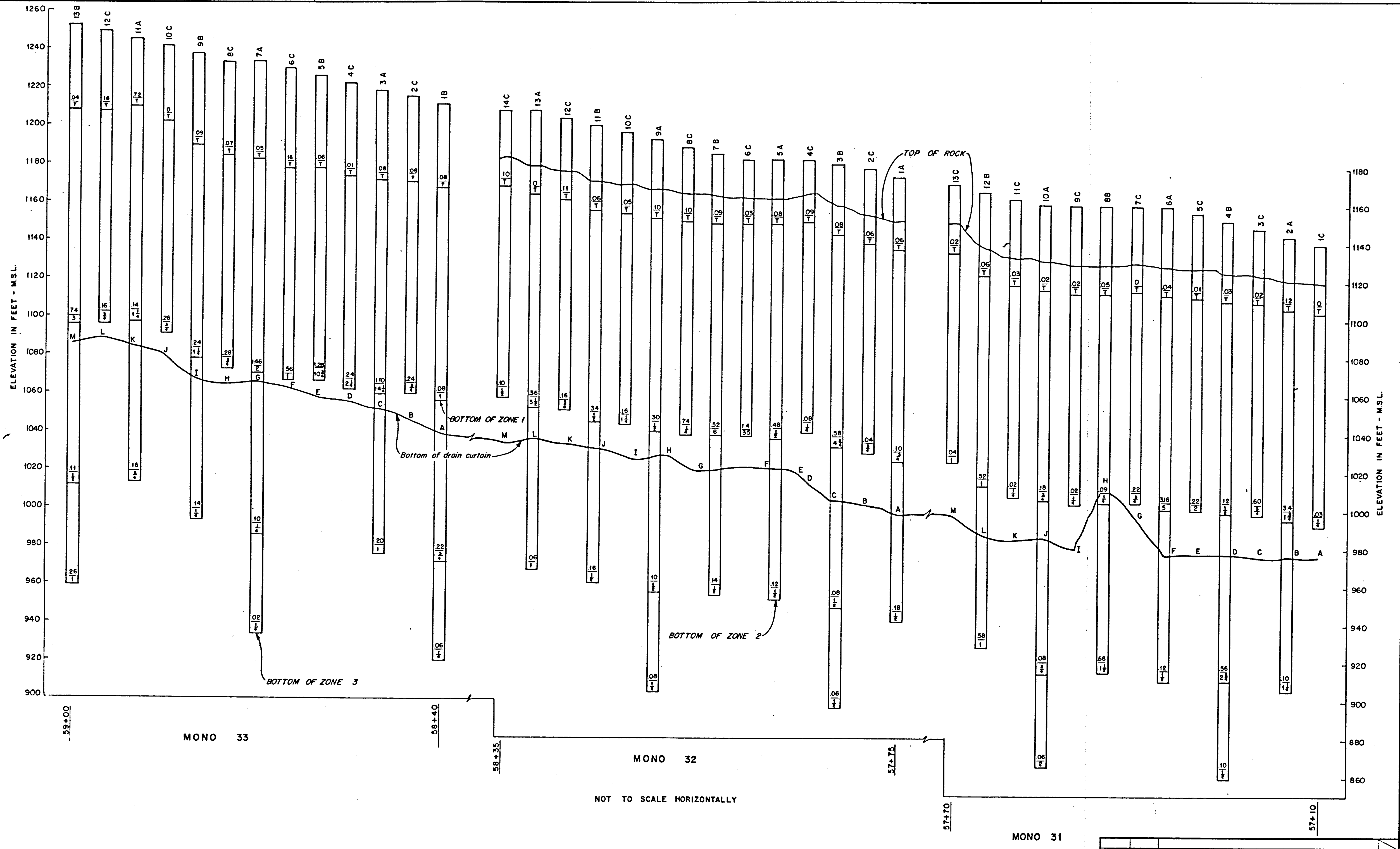

LEGEND

— STAGE OR ZONE

$\frac{.10}{6}$ WATER TAKE, CFM / CEMENT TAKE, SACKS

$\frac{.02}{T}$ WATER TAKE, CFM / T DENOTES NO HOOKUP

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DWORSHAK DAM AND RESERVOIR
NORTH FORK CLEARWATER RIVER, IDAHO
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GROUT AND DRAIN CURTAINS

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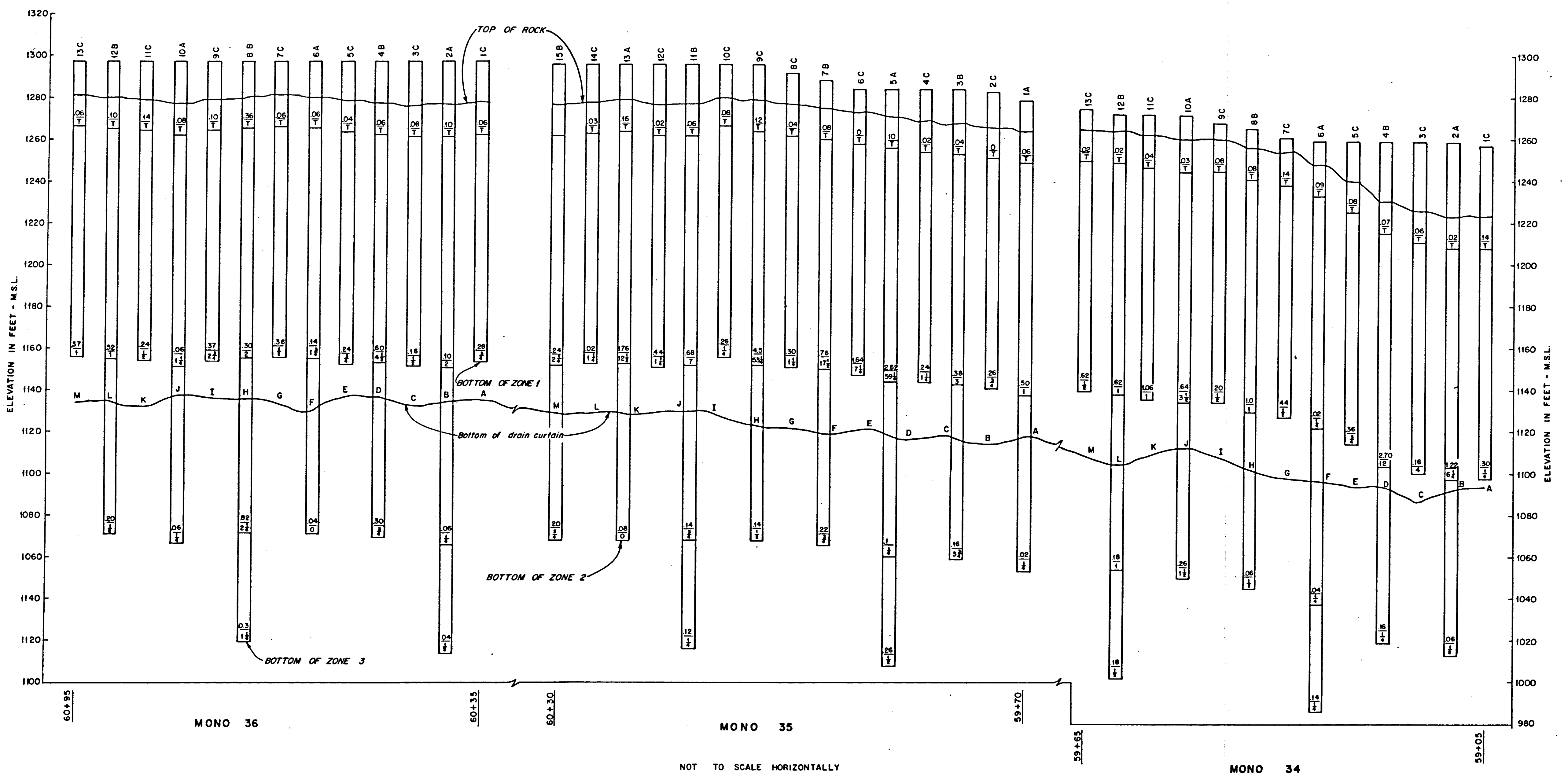

LEGEND

- — STAGE OR ZONE
- .10/6 WATER TAKE, CFM; CEMENT TAKE, SACKS
- .02/T WATER TAKE, CFM; DENOTES NO HOOKUP

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CHECKED: Joscelyn
SUPERVISED: CHIEF, GEOLOGY SECTION
SUBMITTED: CHIEF, FOUNDATIONS AND MATERIALS BRANCH

DWORSHAK DAM AND RESERVOIR

NORTH FORK CLEARWATER RIVER, IDAHO

FOUNDATION REPORT
GROUT AND DRAIN CURTAINS

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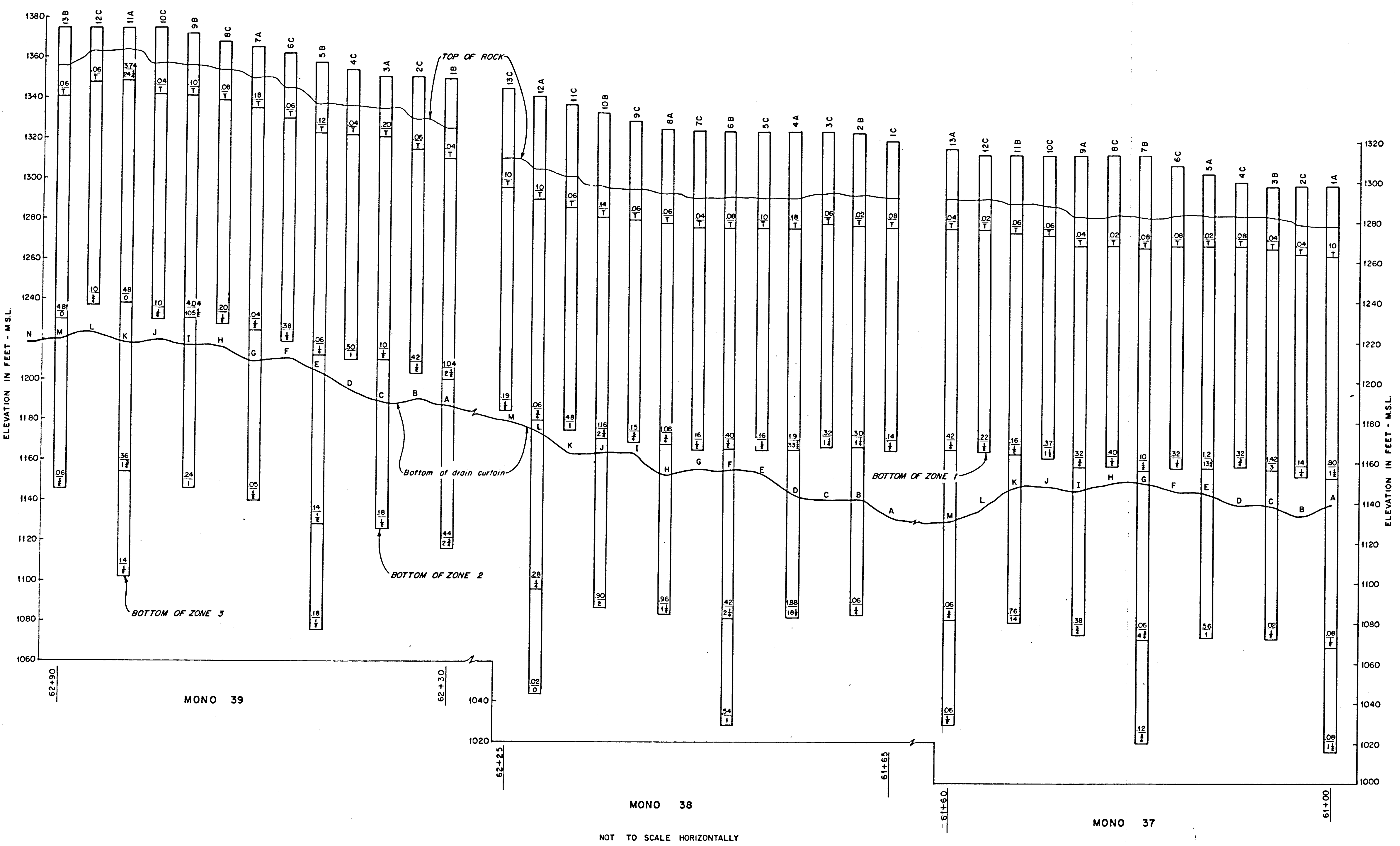

LEGEND

— STAGE OR ZONE

$\frac{.10}{6}$ WATER TAKE, CFM
CEMENT TAKE, SACKS

$\frac{.02}{T}$ WATER TAKE, CFM
DENOTES NO HOOKUP

REVISION	DATE	DESCRIPTION	BY

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA, WASHINGTON

DESIGNED: Joscelyn
DRAWN: Graham
CHECKED: Joscelyn
SUPERVISED: [signature] CHIEF GEOLOGY SECTION
SUBMITTED: [signature] CHIEF, FOUNDATIONS AND MATERIALS BRANCH

DWORSHAK DAM AND RESERVOIR
NORTH FORK CLEARWATER RIVER, IDAHO

FOUNDATION REPORT

GROUT AND DRAIN CURTAINS

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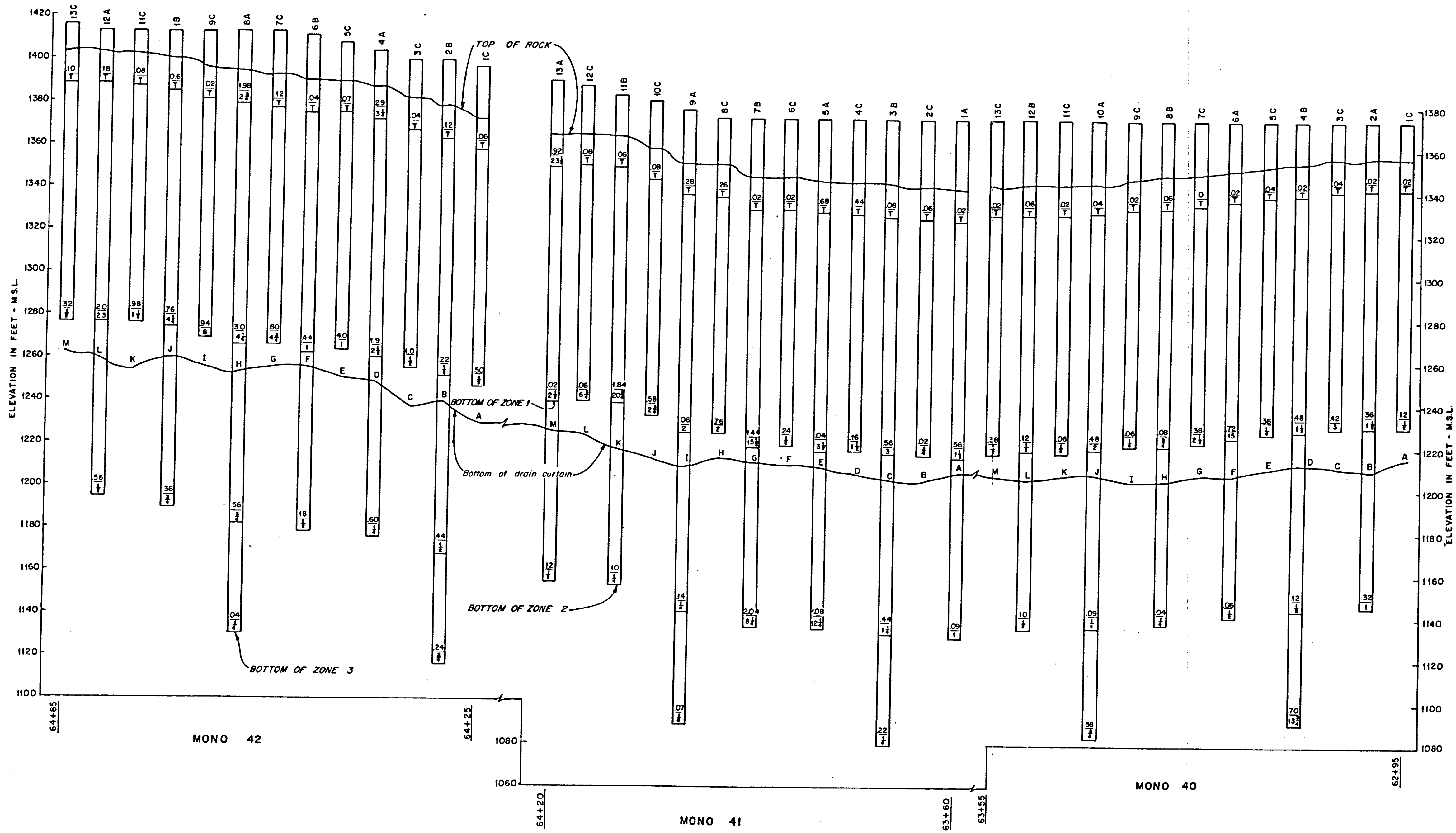

NOT TO SCALE HORIZONTALLY

LEGEND

— STAGE OR ZONE

10/6 WATER TAKE, CFM / CEMENT TAKE, SACKS

.02/T WATER TAKE, CFM / DENOTES NO HOOKUP

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DRAWN: Graham
CHECKED: Joscelyn
SUPERVISED: CHIEF GEOLOGY SECTION
SUBMITTED: CHIEF, FOUNDATIONS AND MATERIALS BRANCH

DWORSHAK DAM AND RESERVOIR
NORTH FORK CLEARWATER RIVER, IDAHO

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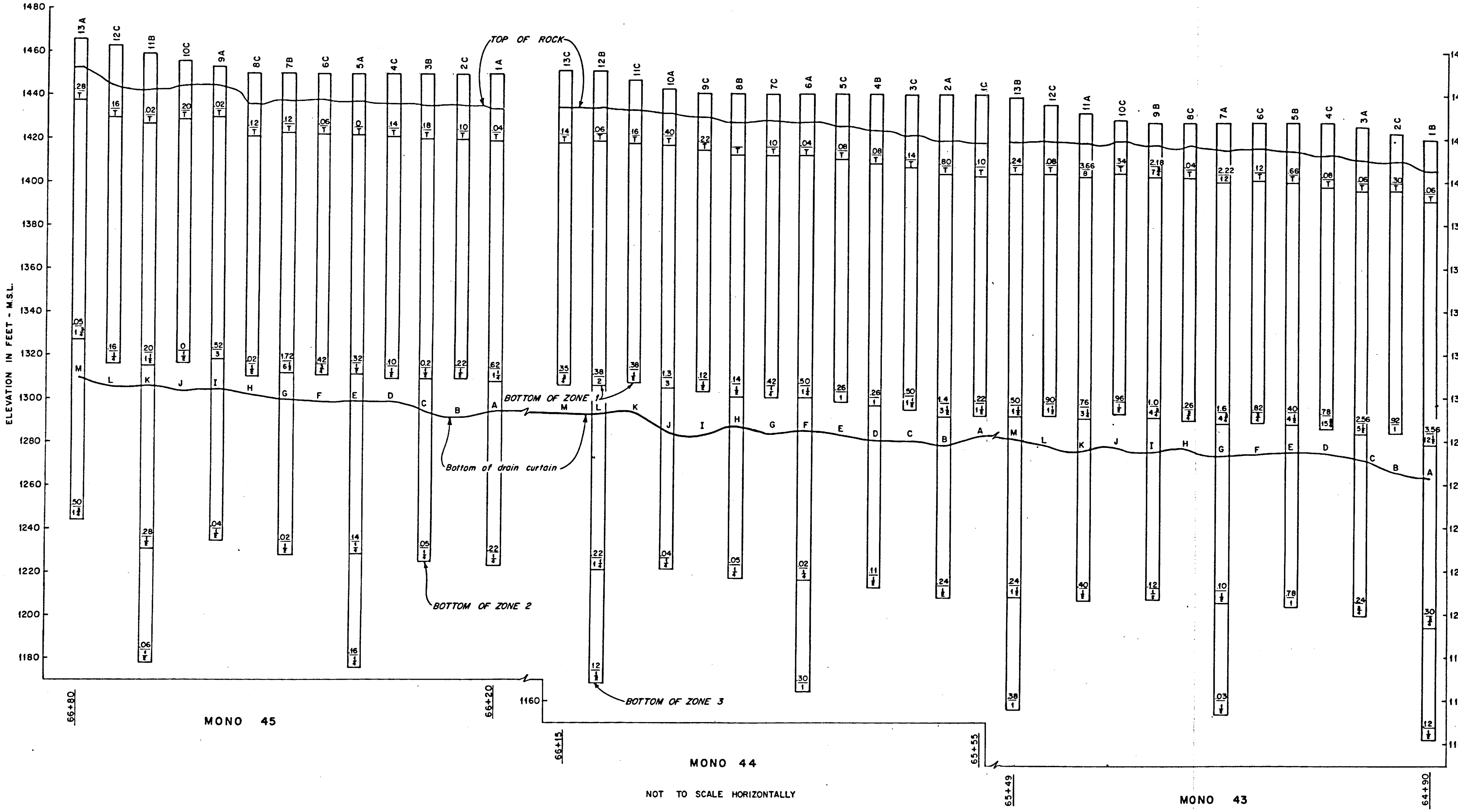

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U. S. ARMY ENGINEER DISTRICT
WALLA WALLA, WASHINGTON

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CHECKED: Joscelyn
SUPERVISED: CHIEF GEOLOGY SECTION
SUBMITTED: CHIEF, FOUNDATIONS AND MATERIALS BRANCH

DWORSHAK DAM AND RESERVOIR
NORTH FORK CLEARWATER RIVER, IDAHO

FOUNDATION REPORT
GROUT AND DRAIN CURTAINS

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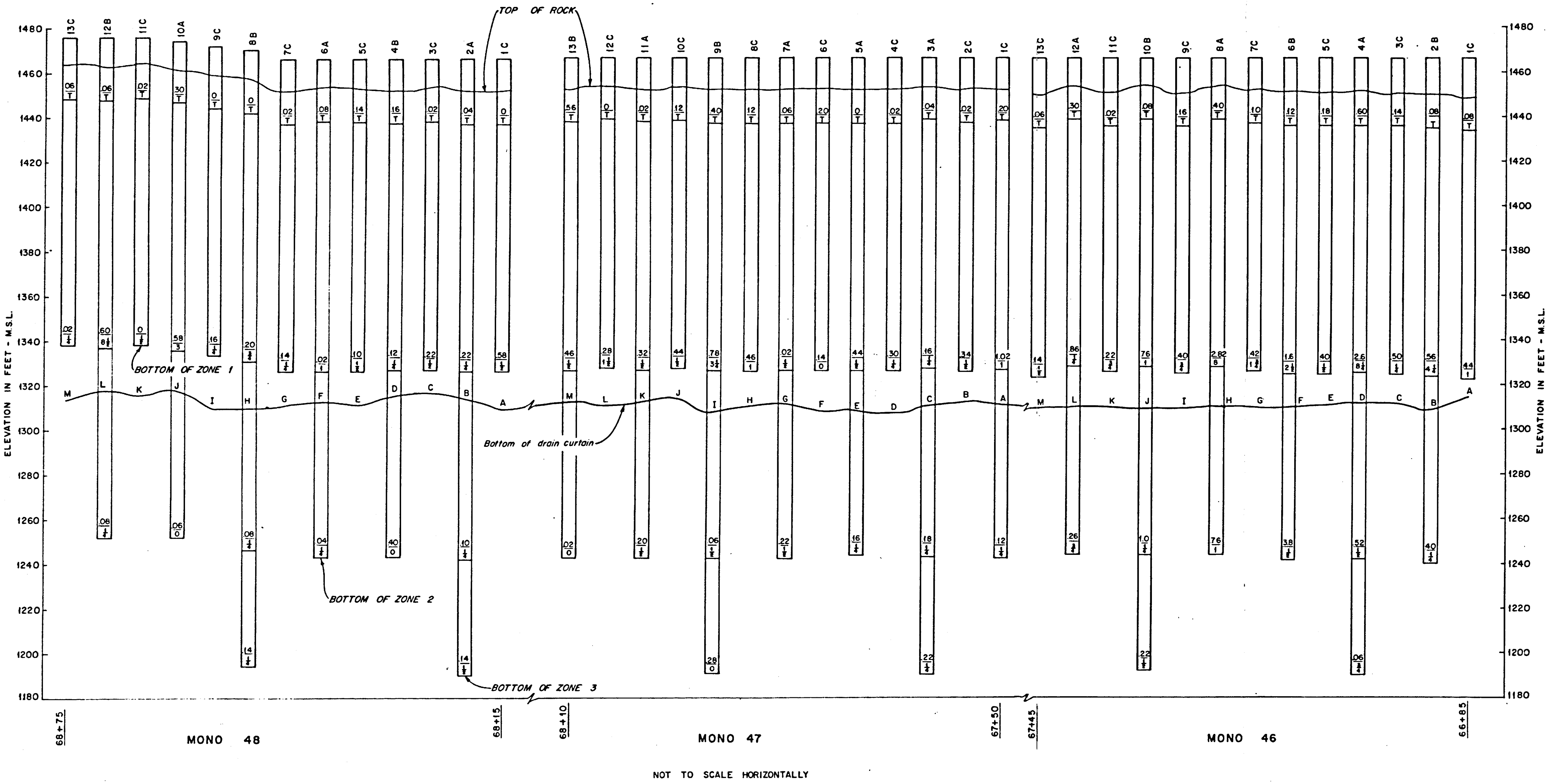

LEGEND

— STAGE OR ZONE

$\frac{10}{8}$ WATER TAKE, CFM / CEMENT TAKE, SACKS

$\frac{.02}{T}$ WATER TAKE, CFM / DENOTES NO HOOKUP

REVISION	DATE	DESCRIPTION	BY

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA, WASHINGTON

DESIGNED: Joscelyn
DRAWN: Graham
CHECKED: Joscelyn
SUPERVISED: CHIEF, GEOLOGY SECTION
SUBMITTED: CHIEF, FOUNDATIONS AND MATERIALS BRANCH

DWORSHAK DAM AND RESERVOIR
NORTH FORK CLEARWATER RIVER, IDAHO
FOUNDATION REPORT
GROUT AND DRAIN CURTAINS

DATE
SCALE AS SHOWN
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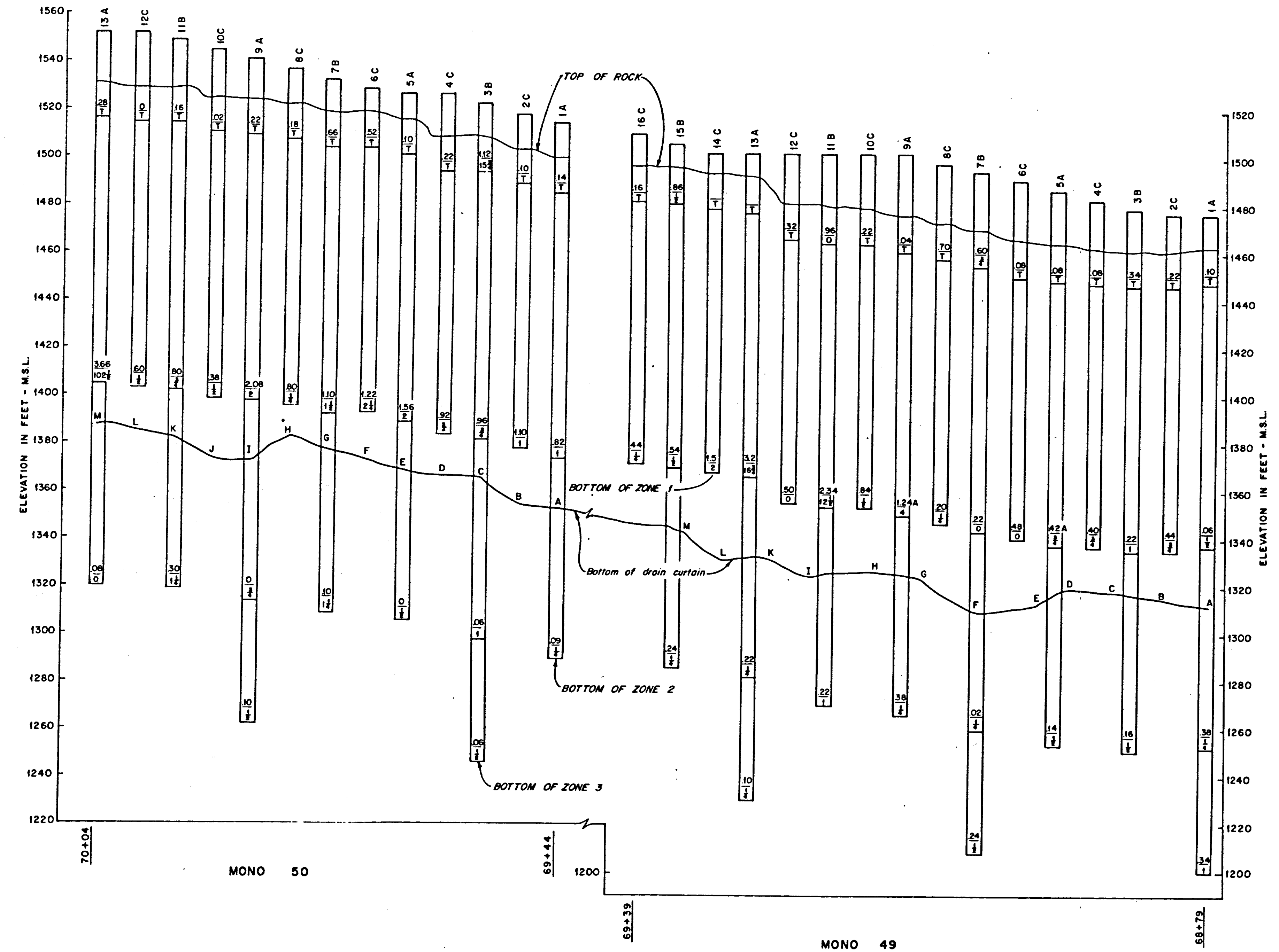

NOT TO SCALE HORIZONTLY

LEGEND

— STAGE OR ZONE

$\frac{.10}{6}$ WATER TAKE, CFM / CEMENT TAKE, SACKS

$\frac{.02}{T}$ WATER TAKE, CFM / DENOTES NO HOOKUP

REVISION	DATE	DESCRIPTION	BY

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA, WASHINGTON

DESIGNED: Joscelyn
DRAWN: Graham
CHECKED: Joscelyn
SUPERVISED: Chief, Geology Section
SUBMITTED: Chief, Foundations and Materials Branch

DWORSHAK DAM AND RESERVOIR
NORTH FORK CLEARWATER RIVER, IDAHO

FOUNDATION REPORT
GROUT AND DRAIN CURTAINS

DATE
SCALE AS SHOWN
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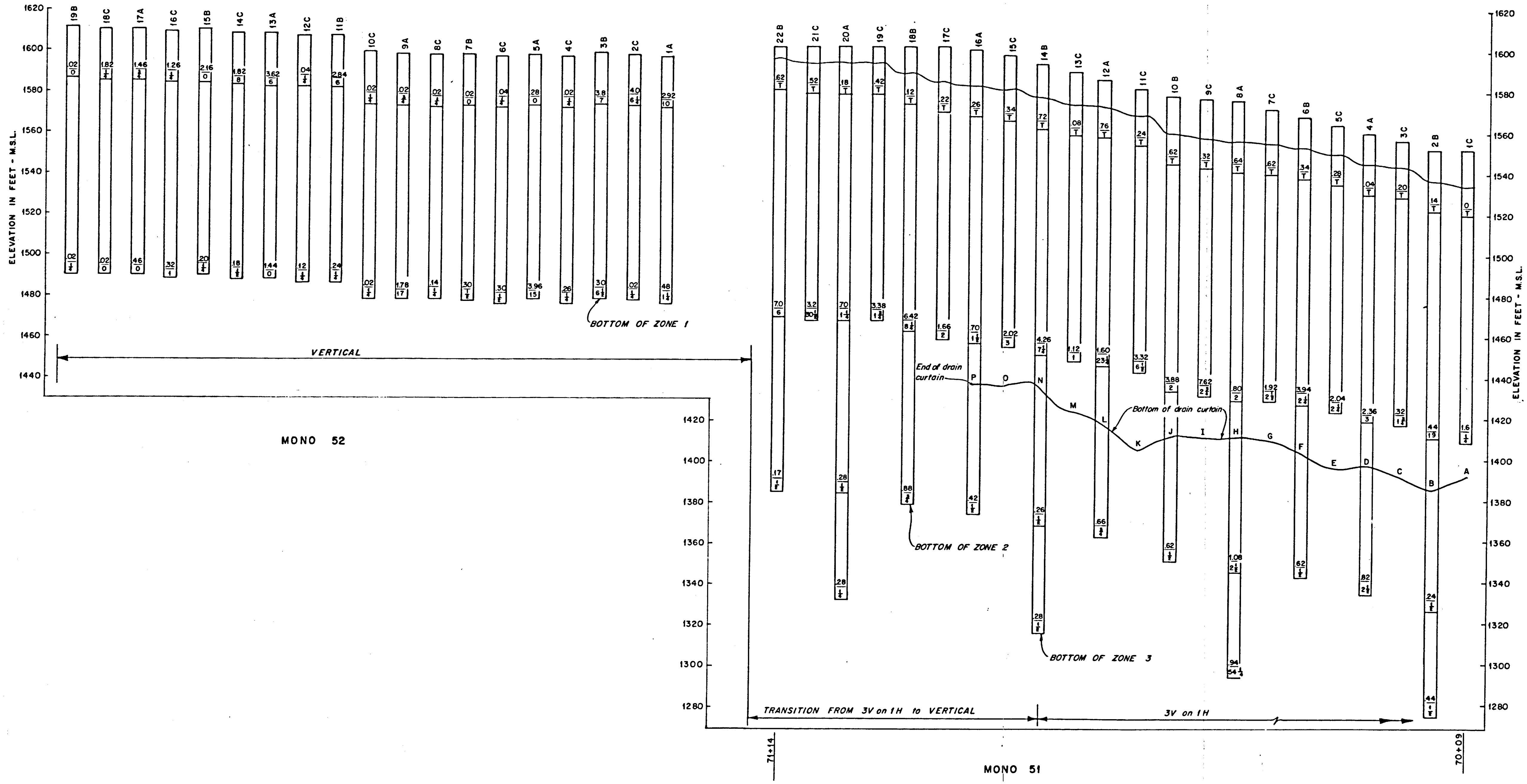

NOT TO SCALE HORIZONTALLY

LEGEND

— STAGE OR ZONE

.10/6 WATER TAKE, CFM / CEMENT TAKE, SACKS

.02/T WATER TAKE, CFM / DENOTES NO HOOKUP

REVISION	DATE	DESCRIPTION	BY

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA, WASHINGTON

DWORSHAK DAM AND RESERVOIR
NORTH FORK CLEARWATER RIVER, IDAHO

FOUNDATION REPORT
GROUT AND DRAIN CURTAINS

DESIGNED: Joscelyn
DRAWN: Graham
CHECKED: Joscelyn
SUPERVISED: CHIEF, GEOLOGY SECTION
SUBMITTED: CHIEF, FOUNDATIONS AND MATERIALS BRANCH
DATE
SCALE AS SHOWN
INV. NO.
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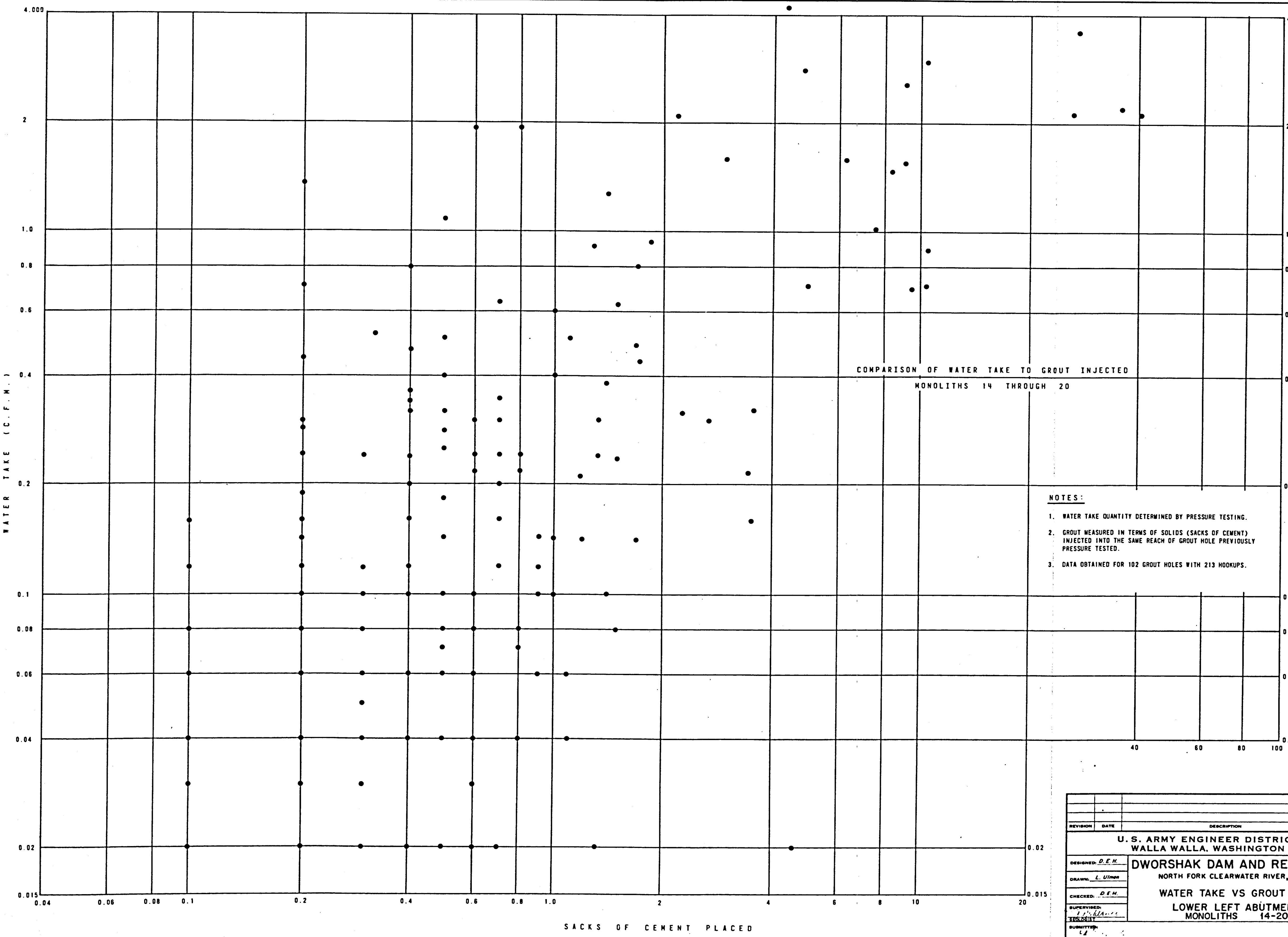


REVISION	DATE	DESCRIPTION	BY

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA, WASHINGTON

DESIGNED: D.E.H.
DRAWN: L. Ulmen
CHECKED: D.E.H.
SUPERVISED:
GEOLOGIST
SUBMITTED:

DWORSHAK DAM AND RESERVOIR

NORTH FORK CLEARWATER RIVER, IDAHO

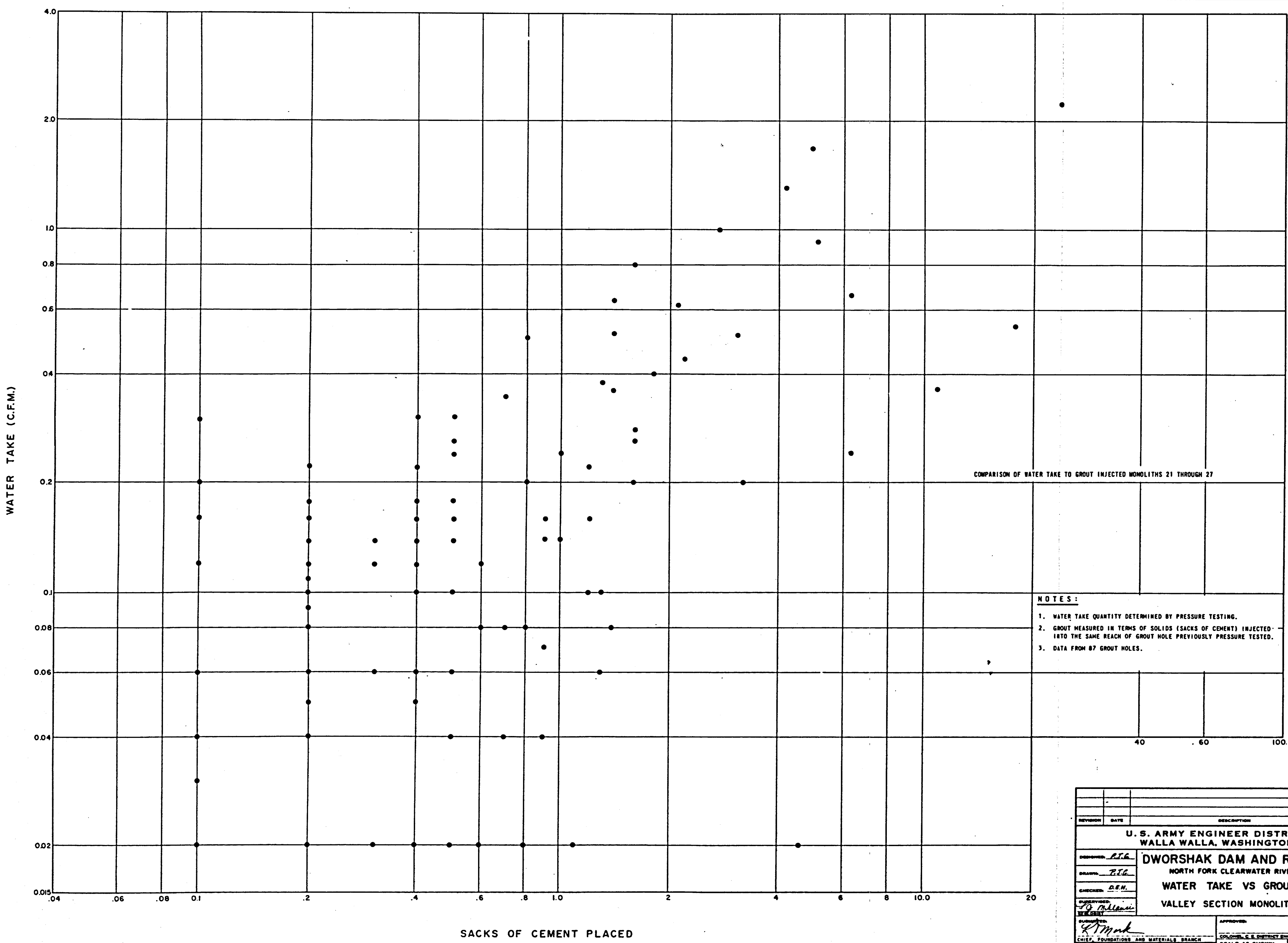
WATER TAKE VS GROUT TAKE

LOWER LEFT ABUTMENT
MONOLITHS 14-20

DATE

CHIEF, FOUNDATIONS AND MATERIALS BRANCH
RECOMMENDED:

SCALE AS SHOWN | INV. NO.
FILE NO.
SHEET

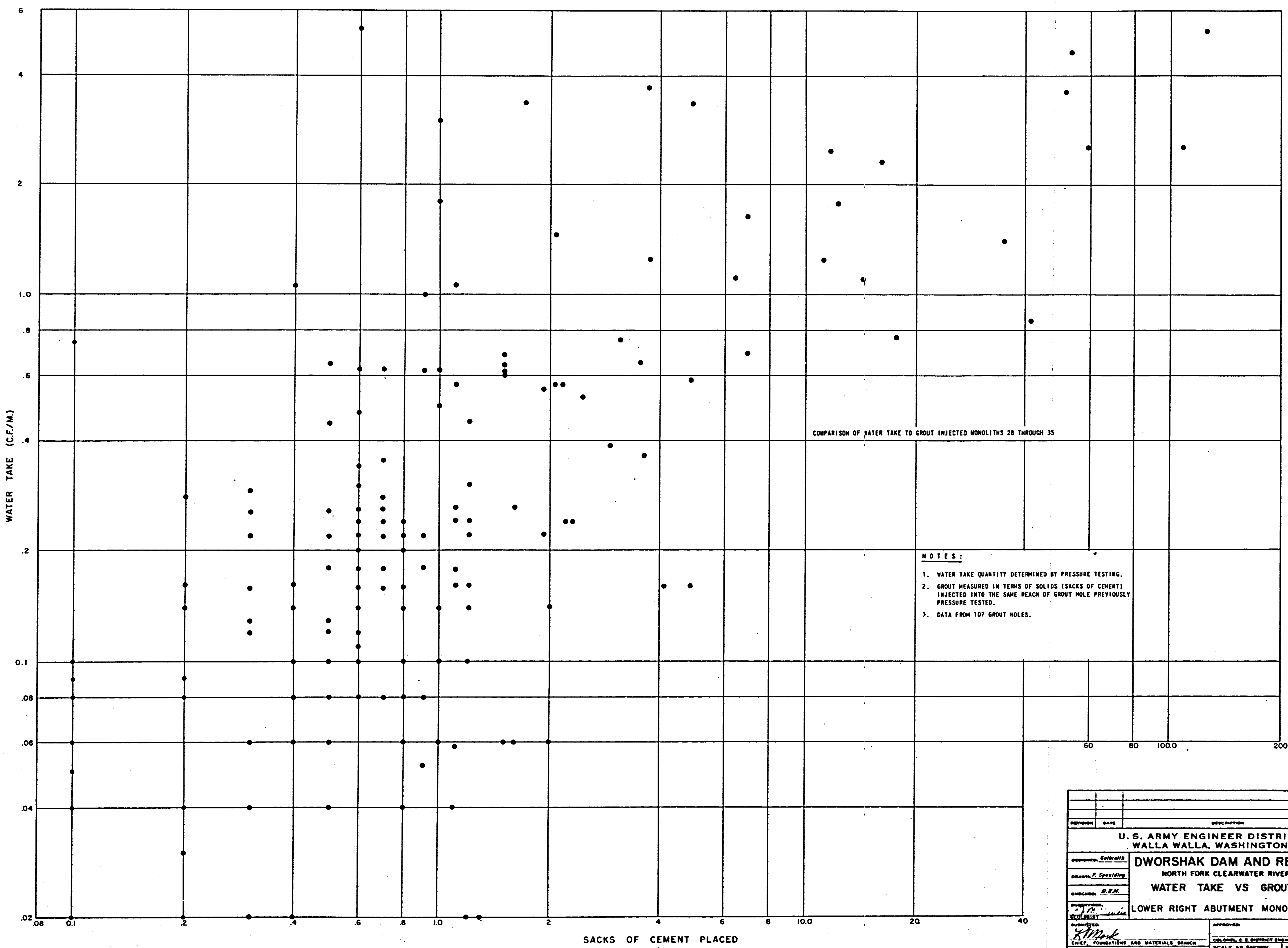


U. S. ARMY ENGINEER DISTRICT
WALLA WALLA, WASHINGTON

DESIGNED: P.T.G.
DRAWN: P.T.G.
CHECKED: D.E.H.

DWORSHAK DAM AND RESERVOIR
NORTH FORK CLEARWATER RIVER, IDAHO
WATER TAKE VS GROUT TAKE
VALLEY SECTION MONOLITHS 21-27

CHIEF, FOUNDATIONS AND MATERIALS BRANCH
SCALE AS SHOWN



REVISION	DATE	DESCRIPTION	BY

U.S. ARMY ENGINEER DISTRICT
WALLA WALLA, WASHINGTON

DWORSHAK DAM AND RESERVOIR

NORTH FORK CLEARWATER RIVER, IDAHO

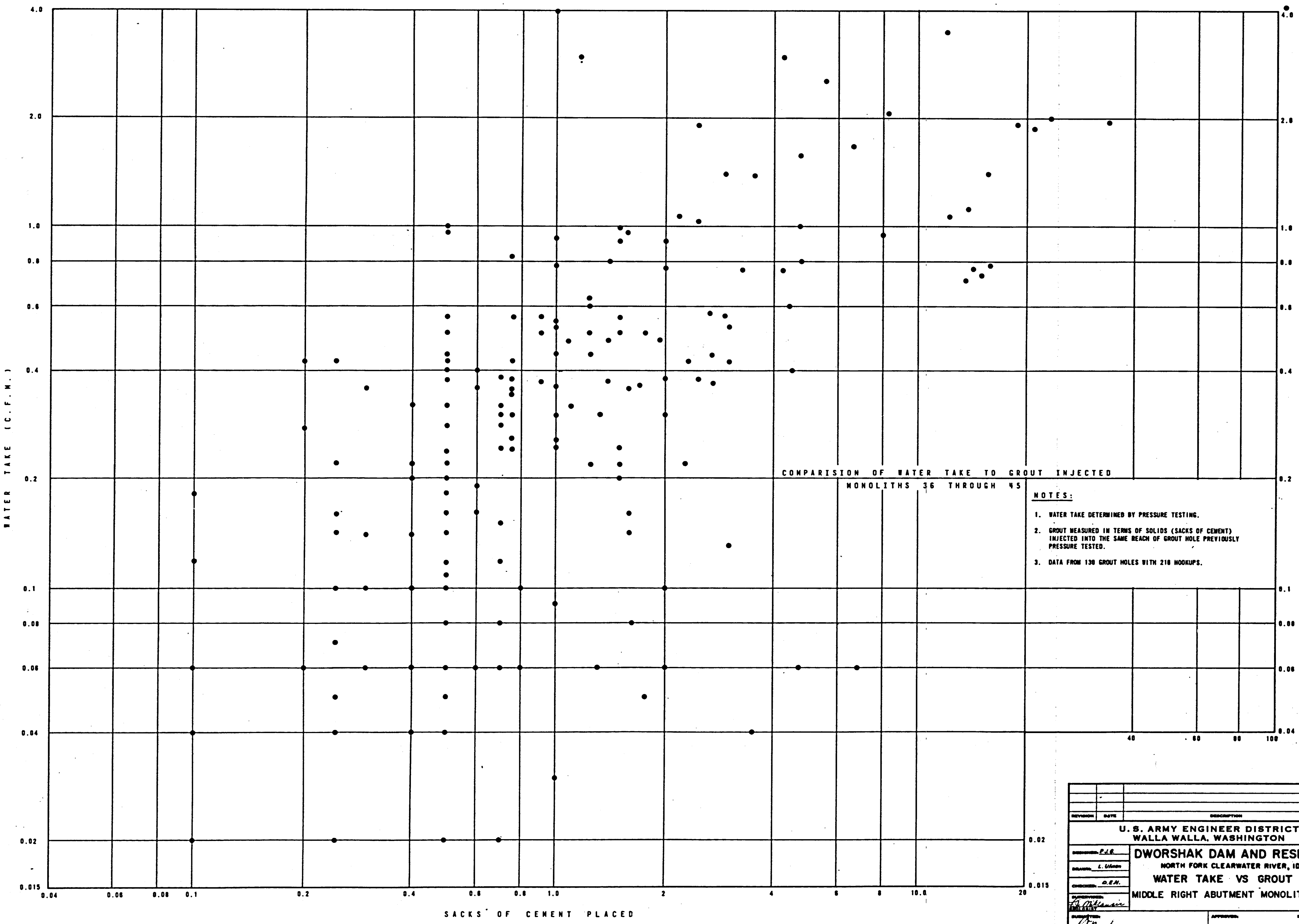
WATER TAKE VS GROUT TAKE

LOWER RIGHT ABUTMENT MONOLITHS 28-35

DESIGNED: Galbraith
DRAWN: F. Spaulding
CHECKED: D.E.M.
SUPERVISED:
GEOLOGIST

SUBMITTED:
CHIEF, FOUNDATIONS AND MATERIALS BRANCH
RECOMMENDED:

APPROVED: DATE
COLONEL, C. E. DISTRICT ENGINEER
SCALE AS SHOWN | INV. NO.
FILE NO.
SHEET



NOTES:

1. WATER TAKE DETERMINED BY PRESSURE TESTING.
2. GROUT MEASURED IN TERMS OF SOLIDS (SACKS OF CEMENT) INJECTED INTO THE SAME REACH OF GROUT HOLE PREVIOUSLY PRESSURE TESTED.
3. DATA FROM 130 GROUT HOLES WITH 218 HOOKUPS.

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA, WASHINGTON

DWORSHAK DAM AND RESERVOIR
NORTH FORK CLEARWATER RIVER, IDAHO
WATER TAKE VS GROUT TAKE
MIDDLE RIGHT ABUTMENT MONOLITHS 36-45

CHIEF, FOUNDATIONS AND MATERIALS BRANCH
SCALE AS SHOWN

PROJECT J: LIBBY DAM

(This case history was developed with the assistance of Richard Galster and E. T. Bailey, Seattle District)

Location and Description of Project

J1. Libby Dam is on the Kootenai River in northwestern Montana 221.9 river miles upstream from the confluence of the Kootenai River with the Columbia River and 17 miles upstream from the town of Libby, Montana (Plate I-J1). The project consists of a multipurpose concrete gravity dam 420 ft high (maximum pool elevation 2459 msl), which impounds a reservoir 90 miles long, backing water 42 miles north into Canada. An onsite powerhouse having an eight unit potential is provided. In conjunction with the main dam and powerhouse construction, it was necessary to relocate 59 miles of Burlington Northern transcontinental railroad, including construction of a 7-mile tunnel (Flathead Tunnel), 52 miles of Montana State Highway 37, and 52 miles of high-grade forest development and county roads. A high vehicular bridge was constructed across the reservoir at its midpoint and the town of Rexford, Mont., was relocated. The project was constructed by the Seattle District.

J2. The Libby Dam Project was proposed in House Document 531 and authorized by Public Law 516, 81st Congress, 2nd session, as a part of the Flood Control Act of 17 May 1950. Preliminary siting investigations began in 1951 and terminated in 1954. Upon signing of the Columbia River Treaty between the United States and Canada in January 1961, siting investigations were reactivated. Final siting was made in 1963 and detailed foundation investigation completed in 1966 (USACE 1979).

Geology

J3. The project is in northwestern Montana within the northern Rocky Mountains. The region is characterized by both high, rugged, and more subdued mountain ranges which trend north to north-northwest, separated by relatively narrow, linear valleys, all controlled by bedrock structure. General relief in the region is 5,000 ft. The region is underlain by a thick series of Precambrian metasediments known as the Belt Series (or Supergroup) which consists of argillite, quartzite, metasandstone, and limestone of variable purity. These rocks have been folded and faulted, generally in northwestward trends during their long history and are characterized by a well-developed joint system. Locally, igneous intrusions have invaded the rocks, causing changes by contact metamorphism and hydrothermal alteration together with superposition of additional joint patterns. Bedrock at the dam represents the transition zone between the Ravalli and overlying Piegan Groups which are subdivisions of the Belt Supergroup. High on the east (left) abutment are the moderately hard to hard siliceous, greenish gray argillites of the uppermost Ravalli (Koocanusa Formation), locally displaying thin stringers of quartzite or metasandstone. Much of the lower part of the left abutment and part of the rock beneath original valley alluvium consists of buff calcareous and noncalcareous, moderately hard argillite with two prominent limestone beds characteristic of the lower Piegan. The west (right) abutment consists largely of calcareous argillite of the Piegan Group. All the bedrock is sound, competent, and thin to medium bedded.

J4. A well-developed fracture system is present which is consistent with regional joint patterns. The principal joint sets are tectonic in origin while others have resulted from rebound or other near-surface phenomena. The fracture system is divided into the following sets:

a. Bedding joints which strike N30W and dip 40 to 45 deg west toward the valley from the left abutment and form moderate downstream facing slopes on the left side of the valley.

b. A conjugate set of generally east-west striking shear joints which has strong individuals striking due east-west and N70E. Dips are always high angle (60 to 80 deg) to the north or south. These joints form strong upstream facing scarps and, with bedding joints, form a multitude of small and large wedges, some of which daylight on the left valley side.

c. North-south striking "relaxation" joints may strike from N10W to N20E but generally dip 50 to 80 deg east (into the left abutment). These joints truncate the rock ribs on the left valley side commonly forming overhanging scarps.

d. Transverse tension joints which strike northeast and dip at moderate to high angles to the southeast, often forming overhanging scarps on the left abutment.

_e_. Tension joints which strike nearly the same as bedding and dip nearly at right angles to the bedding. These may be analogous to fracture cleavage developed during folding.

_f_. Low angle rebound joints which have random strikes.

_g_. Miscellaneous local fractures which are produced during rebound by adjustment of blocks bounded by the principal joints (USACE 1979).

Subsurface Investigations

Investigations prior to construction

J5. Initial exploration for the location of the dam axis was started in 1961. Exploration was accomplished by both contract and hired labor. Two hundred twenty-five exploration holes were drilled in the vicinity of the preliminary and the final design axes.

J6. Three test pits were excavated in the extensive overburden section near the right abutment, permitting better sampling of the thick overburden section in this area and more realistic design assumptions for overburden cut slopes in the vicinity of the right abutment.

J7. Four adits were excavated in the abutment areas. One adit was excavated into the rock adjacent to the right abutment. The adit is 208.3 ft in length, at elevation 2,261.7 ft, and the portal is a short distance downstream from the toe of the dam. The following table gives data on the three adits excavated into the left abutment.

Adit No.	Length ft	Portal Elevation ft	Crosscut	Length ft
2	201.0	2,239.6	A	86.2
3	86.5	2,187.4		
4	85.5	2,247.3		

J8. Adit 1 was left open to provide inspection for possible water seepage on the right abutment. Adit 4 was incorporated in the dam as a portion of the downstream drainage gallery. The remaining two adits and the crosscut were backfilled with concrete during the construction of the dam to assure positive water cutoff as crosscut "A" of Adit 2, and Adit 3 penetrated the foundation under the dam proper.

J9. Seismic surveys were conducted in the preliminary stages of exploration for axis siting. Basically the surveys were used to determine bedrock configuration in areas where there was no exploration and to tie down the bedrock configuration between drill holes. Seismic (longitudinal) velocities for the various materials at the site ranged as follows:

Material	Velocity, ft/sec
Overbank deposits (silty sand)	1,400
Glacial deposits on right bank (silty sand, gravel, cobbles, and boulders)	2,500-3,500
Alluvium (sandy gravel, silty sand with cobbles and boulders, saturated)	6,700
Bedrock (argillite)	16,500-17,500

(See Plate I-J2 for a plan of preconstruction investigations)

Investigations during construction

J10. To confirm the design evaluation of the foundation during construction, the contract specifications required foundation exploration. This consisted of a minimum of one NX core hole drilled 40 ft into the foundation rock for each abutment monolith found above elevation 2,300 ft and 60 ft into the foundation rock for each abutment monolith that is found below elevation 2,300 ft. In addition, eight air trac probe holes were drilled to establish the extent of a bedrock low at the downstream toe of the dam in the vicinity of monoliths 17 and 18. Drill action and cuttings were observed to establish top of rock.

Grouting Design

J11. A tentative program of curtain grouting was included in the main dam contract for bidding purposes. Primary holes were required on 20-ft centers with splits to 5-ft centers. The grout curtain was angled upstream at 25 deg and 2-vertical drain curtains were required from the galleries. A three zone grout curtain was specified with the upper zone 40 ft into rock, the middle zone from 40 to 90 ft into rock and the deepest zone from 90 to 160 ft into rock. Only primary holes on 20-ft spacing were required in the deepest zone. Primary and secondary holes (10-ft spacing) were required in the middle zone; and the upper zone was drilled on 5-ft spacing requiring primary, secondary and tertiary split-spaced grout holes. Due to increasing quantities of seepage and piping of foundation materials, the original grout curtain was repaired in 1975 and 1977 (see paragraphs 20-30).

J12. The 1975 grouting program consisted of filling cracks in concrete in monoliths 29, 33 and 39 with chemical grout and cement grouting of foundation rock in monoliths 18 through 21, 31 through 34, and 37 through 41. The chemical grout specified was AM-9 as manufactured by American Cyanamid Company. Cement grouting for this program specified aluminous cement in addition to Portland cement.

J13. The 1977 program consisted of grouting foundation rock in monoliths 7, 19, 20 and 29 with cement grout. Both aluminous and Portland cement were specified.

J14. Tables J1, J2 and J3 show the estimated quantities and contract unit prices for all three contracts. Plates I-J3 through I-J11 show the curtain as constructed and actual quantities of grout injected during the three contracts.

Contractual Considerations

Contracts

J15. The contract for the main dam was awarded to a joint venture, Libby Dam Builders. All drilling and grouting was performed by Continental Drilling Company, the grouting subcontractor. Continental was also the prime contractor for the 1977 grouting program. W. G. Jaques Company was the contractor for the 1975 program. The contracts were all firm-fixed price contracts awarded to the lowest responsible bidder. Bid items for drilling and grouting in each contract were subdivided with all subdivisions except mobilization and demobilization exempt from the variations in estimated quantities provisions. There were no modifications or claims on any of the three contracts and no delays or time extensions.

Specification drilling and grouting requirements

J16. Specification requirements for foundation drilling and grouting were similar in all three contracts (USACE 1967, 1975, 1977). Rotary drills were required for drilling the minimum 1-3/8-in.-diam grout holes. The holes were washed and/or pressure tested prior to grouting. Grouting pressures and mixtures were to be as directed in the field by the contracting officer. The specified range of water-cement ratios was 5:1 to 0.5:1. The 1975 and 1977 contracts specified aluminous cement in addition to Portland cement for grout. The ratio of Portland to aluminous cement specified ranged from 10 to 4. Maximum grouting pressures for the remedial grouting were specified as the pressure head at the time of grouting plus 20 psi. For the original grouting during construction, the contract indicated the anticipated gage pressure would vary from 10 to 250 psi, but in no event would pressures in excess of 300 psi be required. According to the foundation report, actual pressures used for upper zone grouting were 85 psi. Actual pressures used for lower zones are not clear. The specifications required 50 ft of mass concrete above the gallery before grouting was permitted. It is interested to note, however, that the 25 deg upstream angle of the grout holes extended the holes upstream of the heel of the dam thus reducing the surcharge effect of the mass concrete. Pressures of 300 psi are considered excessive for this situation, especially where low angle joints exist. (See Typical Section Through Dam, Plate I-J3.) The type of grout mixer was optional with the contractor--either a paddle mixer, or centrifugal high speed mixer (colloidal). Two pumps were required (one for standby). They were specified as double acting duplex slush pumps or progressing cavity type pumps. Suitable gages, valves, hoses, water meter, auxiliary equipment and supplies, and water supply lines for batching the grout, pressure testing, and washing of the grout system were specified. A circulating grouting header was required. Gravity flow was specified from the mixer to the agitator sump. Estimated quantities for drilling and grouting are shown in Tables J1, J2 and J3. Actual quantities are shown on Plates I-J3 through I-J11.

Contract management

J17. Direct information on contract management or administration was not available for this study. No indications of problems relative to grouting were present in the records. Contractual arrangements and relations which existed between the prime and grouting subcontractor are not known.

Drilling and Grouting Methods and Drainage

Drilling

J18. Jackhammer holes were drilled 8 to 12 in. into the drainage gutter at the required spacing and altitude. A 3/4-in. I.D. pipe nipple was then grouted into each hole. Air-driven, screw-fed drills were mounted on the previously grouted nipples. These nipples not only provided mounting posts but also acted as a drilling guide. Grout holes were EX and were drilled through the mounting posts.

Washing and pressure testing

J19. Washing and pressure testing prior to grouting was required by the specifications.

Grouting methods and drainage

J20. The original (main dam contract) foundation grouting and drainage problem is described in the following paragraphs (USACE 1979).

J21. Grouting. All drilling and grouting was performed by Continental Drilling Company, a subcontractor to Libby Dam Builders. Grouting began in late 1969 and was completed in early 1972.

J22. The grout curtain was composed of three zones: an upper zone 40 ft into rock, a secondary zone 90 ft into rock, and a lower zone 160 ft into rock. Due to the geologic structure, grout hole alignment varied between left abutment, valley floor, and right abutment sections. Grout holes drilled in the abutments were aligned normal to the excavated rock surface and inclined 25 deg upstream, measured from the vertical. In the valley section, monoliths 18 through 27, the grout holes were inclined 25 deg upstream and 15 deg towards the left abutment as measured from the vertical. Drilling footages through both rock and concrete are listed in Table J4.

J23. Grout holes were initially drilled on 20-ft centers with split spacing providing a hole every 5 ft. Grouting sections were limited to a maximum of 300 lin ft or five monoliths. Grouting was confined to that portion of the dam where a minimum of 50 ft of mass concrete had been placed above the grouting gallery.

J24. Difficulties were encountered when primary and secondary holes refilled with grout from adjacent holes after final washing. Several trials were conducted to establish a more appropriate wash time to prevent this refilling. The wash time varied between 6 to 10 hr after grouting depending on the water-cement ratio. Grout remaining in the primary and secondary holes after 10 hr was not readily removed with water and, in most cases, the holes had to be redrilled. Regardless of wash time, the refill problem persisted. This problem was resolved by modification of drilling and grouting operations, whereby drilling of secondary holes for a particular zone was done after grouting the primary holes for that zone, and tertiary holes were drilled after the secondary holes were grouted for the zone.

J25. Grouting operations were controlled from the grouting gallery. The grout plant located outside the dam proper consisted of a storage shed containing a 1-day supply of cement, a mixing tank, and two agitating holding tanks. Grout was delivered through pipes to an agitating tank and pump in the gallery mounted on a small dolly. A return line was provided for recirculation. Grout takes are summarized in Table J5.

J26. Repair of the original grout curtain was required in 1974, 1975, and 1977 in areas principally under monoliths 18 through 21, 31 through 34, and to a lesser extent under monoliths 29, 30, 37, 38, 40, and 7.

J27. Drainage. Due to the 290-ft base width of the dam, two drain curtains were used to relieve hydrostatic pressures downstream from the grout curtain. The upstream drain curtain is 5 ft downstream from the line of grout curtain collars, and the downstream drain curtain is located 105 ft downstream from the axis in the downstream drainage gallery. To provide additional drainage in the left abutment, the existing exploration adit was lengthened and incorporated with the downstream drainage gallery.

J28. During pool raise and lowering in 1972, seepage measurements were made on each drain hole in the drainage and grouting gallery and the drainage gallery of the dam when the pool reached the approximate elevations of 2,300, 2,355, and 2,405 ft. Measurements of the foundation drains when the pool was at an elevation of 2,405 ft indicated a total flow of 57 gpm from all drain holes. Negligible to minor seepage occurred in most of the foundation drains. Maximum flows ranged between 2 to 5 gpm in the drainage and grouting gallery in monolith 39, the drainage gallery in monolith 40, and the drainage adit.

J29. At beginning of drawdown of the 1972 pool, two drain holes in the upstream gallery in monolith 20 increased in flow. These drain holes were carefully observed during drawdown and refilling of the pool. The foundation drains ran clear during drawdown and minimum pool with a flow of 5 gpm to 10 gpm. A general increase in flow from drains in monolith 20 occurred with the raising of the pool in 1973. With the pool at elevation 2,357.5 ft, two drain holes started carrying sands and silts. The amount and size of material being discharged increased as the pool continued to rise, reaching a maximum particle size of 1-1/2 in. Not only did the amount of water from the drains increase with the pool, but discharge migrated to adjacent drain holes until all drains were flowing in monolith 20. Both quantity and size of material abruptly decreased just prior to maximum pool. By November 1973, material discharge was negligible. Total measured drain hole flow at maximum pool for 1973 was 183 gpm of which 102.6 gpm was from monolith 20.

J30. During subsequent pool rises it became evident that additional grouting and drainage in several areas would be required. Successive attempts to regrout the bedding fault beneath monoliths 19 and 20, through which piping had reoccurred, were finally successful by mixing aluminous cement with Portland cement grout. Similar procedures were followed beneath monoliths 7, 29 and 30, 31 through 35, 37, 40, and 41 during the 1975 and 1977 grouting contracts. Additional drains were drilled beneath monoliths 20 and 34 to relieve uplift pressures. During the 1978 maximum pool, total leakage from foundation drains was about 120 gpm (USACE 1979).

Records

J31. According to the specifications, it was the responsibility of the contracting officer to keep records of all grouting operations, results of washing and pressure testing operations, time of each change of grouting operation, pressure, rate of pumping, amount of cement for each change in water cement ratio, and other data considered necessary by the contracting officer. The contractor was required to furnish all necessary assistance and cooperation to this end. The contractor was also required to furnish an accurate driller's log and records of drilling operations at the completion of each boring or such other time as directed.

Unexpected Geological Conditions Encountered During Construction

J32. Area grouting was undertaken in monoliths 28 through 33 to fill open joints and assist in controlling water. Various sanded and neat cement grout mixtures were used to reduce inflows to where they could be handled by sandbagging and pumping. Grouting was also attempted in the stilling basin but was not as successful and was stopped after a short experimental period. The inflows were handled by controlled drainage. Other adverse geological conditions consisted of faults and fractured zones which were handled by excavation. The grouting, excavation, and drainage procedures used were all within the framework of the specifications and no modifications were necessary.

Evaluation of Grouting

J33. Repair of portions of the original grout curtain was necessary at two different times indicating the original curtain was not as effective as desired. Reasons for the necessity for making the repairs are conjectural as there was insufficient information available during this study to evaluate the program. Whether or not high grouting pressures contributed to the problem is not known. The experience of washing grout from holes for drilling to the next deeper stage and then having grout from the previously grouted area flow into the holes appears to indicate that either the holes were washed too soon or the grout did not set up as anticipated. At any rate, the washing operation in some instances removed previously placed grout which may have contributed to later problems.

Costs, Drilling and Grouting

Bid price

1967 Contract*	$625,125 ($19.23/cu ft)
1975 Contract**	$120,380 ($120.4/cu ft)
1977 Contract†	$ 45,325 ($477.1/cu ft)

Government estimate

Not available.

Actual

Not available.

Performance

J34. Performance of the grout curtain was apparently considered satisfactory in 1979 at the time the foundation report was published. No later data were available during this study.

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* Does not include drilling NX core boring, drilling 14-in. instrumentation boring, drilling 2-1/2-in. instrumentation boring, or drilling drain holes.

** Excludes exploratory drilling, grout hole drilling for crack grouting, drain hole drilling, chemical grout (Table J2).

† Excludes exploratory drilling (Table J3).

References

US Army Corps of Engineers. 1967. Libby Dam Contract Technical Provisions for Drilling and Grouting, Seattle District, Contract No. DACW-67-67-C-0056.

___________. 1975. Libby Dam Contract Technical Provisions for Drilling and Grouting, Seattle District, Contract No. DACW-67-75-C-0074.

___________. 1977. Libby Dam Contract Technical Provisions for Drilling and Grouting, Seattle District, Contract No. DACW-67-77-C-0030.

___________. 1979. Libby Dam Foundation Report, Seattle District.

Table J1

Unit Price Schedule

Item No.	Description	Estimated Quantities	Unit	Unit Price	Estimated Amount
166	Sump pumps, deep well turbine	1	job	$ Lump Sum	$ 17,100.00
167	Piezometer piping	1	job	Lump Sum	34,500.00
168	Piezometers in cofferdams	1	job	Lump Sum	17,700.00
169	Miscellaneous drain pipe within the structure	1	job	Lump Sum	232,000.00
170	Drilling and grouting				
	a. Mobilization and demobilization	1	job	Lump Sum	16,000.00
	b. Drilling NX core boring	3,000	lin ft	19.50	58,500.00
	c. Reserved				
	d. Drilling 14-in. instrumentation boring	188	lin ft	120.00	22,560.00
	e. Drilling 2-1/2-in. instrumentation boring	412	lin ft	18.00	7,416.00
	f. Drilling grout holes	65,000	lin ft	5.10	331,500.00
	g. Drilling drain holes	53,000	lin ft	9.20	487,600.00
	h. Portland cement in grout	32,500	bag	2.50	81,250.00
	i. Fluidifier in grout	8,125	lb	1.40	11,375.00
	j. Placing grout	32,500	cu ft	5.00	162,500.00
	k. Connection to grout holes	1,500	ea	15.00	22,500.00
170.1	Drains in stilling basin slab	1	job	Lump Sum	38,270.00
	Dam Instrumentation (Items 171 thru 181)				
171	Install foundation deformation meters	1	job	Lump Sum	2,800.00

Table J2

Contract Schedule "A"

Contract No. DACW67-75-C-0074

Item No.	Description	Estimated Quantities	Unit	Unit Price	Estimated Amount
1	Drilling and grouting				
1a	Mobilization and demobilization	1	job	Lump Sum	$ 25,000.00
1b	Exploratory drilling - NX core boring	350	lin ft	20.00	7,000.00
1c	Exploratory drilling - EX core boring	200	lin ft	12.00	2,400.00
1d	Grout hole drilling for crack grouting 1-3/8-in. size	500	lin ft	8.00	4,000.00
1e	Grout hole drilling (Y holes)	5,200	lin ft	8.00	41,600.00
1f	Redrilling existing grout holes (X holes)	1,100	lin ft	5.00	5,500.00
1g	Drain hole drilling - 2-7/8-in. size	2,000	lin ft	14.00	28,000.00
1h	Drain hole drilling - 1-3/8-in. size	2,000	lin ft	8.00	16,000.00
1i	Clearing grout from drain holes	3,000	lin ft	5.00	15,000.00
1j	Chemical grout	850	gal	15.00	12,750.00
1k	Portland cement in grout	1,000	bags	4.00	4,000.00
1l	Aluminous cement in grout	300	bags	6.00	1,800.00
1m	Fluidifier in grout	250	lb	2.00	500.00
1n	Placing neat portland and aluminous cement grout	900	cu ft	12.00	10,800.00
1o	Placing sanded neat cement grout	100	cu ft	20.00	2,000.00
1p	Dry pack grout holes	52	ea	40.00	2,080.00
1q	Connection to grout holes	52	ea	50.00	2,600.00
1r	Pressure testing	150	hr	50.00	7,500.00
1s	Standby time	20	hr	100.00	2,000.00
2	Covering crack with steel	1	job	Lump Sum	4,500.00
3	Relief drilling				

(Continued)

Table J2 (Concluded)

Item No.	Description	Estimated Quantities	Unit	Unit Price	Estimated Amount
3a	Relief drilling equipment standby time				
	a. First 60 days	60	day	100.00	6,000.00
	b. Over 60 days	60	day	25.00	1,500.00
3b	Relief drilling crew mobilization and demobilization	1	job	Lump Sum	5,000.00
3c	Relief drain hole drilling 1-3/8-in. size	2,000	lin ft	8.00	16,000.00
3d	Relief drilling demobilization	1	job	Lump Sum	3,000.00
				TOTAL	$226,530.00

Table J3

Contract Schedule "A"

Contract No. DACW67-77-C-0030

Item No.	Description	Estimated Quantities	Unit	Unit Price	Estimated Amount
1	Drilling and grouting				
1a	Mobilization and demobilization	1	Job	Lump Sum	$25,000.00
1b	Exploratory drilling - NX core boring	350	lin ft	25.00	8,750.00
1c	Grout hole drilling (Z holes)	660	lin ft	15.00	9,900.00
1d	Redrilling existing grout holes (Y holes)	50	lin ft	20.00	1,000.00
1e	Cleaning drain holes	200	lin ft	12.00	2,400.00
1f	Portland cement in grout	75	bag	7.00	525.00
1g	Aluminous cement in grout	15	bag	20.00	300.00
1h	Placing neat portland and aluminous cement grout	75	cu ft	10.00	750.00
1i	Placing sand neat cement grout	20	cu ft	20.00	400.00
1j	Dry pack grout holes	15	ea	50.00	750.00
1k	Connection to grout holes	15	ea	40.00	600.00
1l	Pressure testing	25	hr	100.00	2,500.00
1m	Standby time	16	hr	75.00	1,200.00
	Total Contract Schedule "A"				$54,075.00

Table J4

Footage of Rock and Concrete Drilled Per Monolith

Mono	Tertiary Rock Concrete	Secondary Rock Concrete	Primary Rock Concrete	Total Rock Concrete
0	160 (41)	360 (57)	*	520 (98)
1	520 (146)	980 (172)	*	1500 (318)
2	360 (91)	800 (83)	*	1160 (174)
3	405 (88)	800 (77)	*	1205 (165)
4	450 (99)	1000 (98)	*	1450 (197)
5	180 (42)	500 (49)	*	680 (91)
6	270 (62)	600 (66)	*	870 (128)
7	270 (56)	600 (58)	*	870 (114)
8	270 (77)	600 (78)	*	870 (155)
9	185 (66)	125 (38)	225 (30)	535 (134)
10	240 (52)	360 (39)	504 (25)	1104 (116)
11	240 (59)	270 (36)	504 (32)	1014 (127)
12	280 (91)	270 (41)	504 (39)	1054 (171)
13	240 (55)	270 (26)	672 (39)	1182 (120)
14	280 (80)	270 (26)	504 (29)	1054 (135)
15	240 (162)	270 (76)	504 (80)	1014 (318)
16	280 (159)	360 (97)	672 (96)	1312 (352)
17	240 (175)	460 (143)	845 (139)	1545 (457)
18	**	990 (326)	1885 (320)	2875 (646)
19	240 (138)	360 (97)	504 (75)	1104 (310)
20	240 (118)	270 (55)	504 (58)	1014 (231)
21	240 (108)	360 (70)	336 (36)	936 (214)
22	240 (108)	270 (52)	504 (54)	1014 (214)
23	289 (105)	285 (44)	504 (42)	1078 (191)
24	255 (82)	380 (58)	504 (43)	1139 (183)
25	264 (81)	285 (45)	504 (44)	1053 (170)
26	301 (80)	285 (32)	504 (36)	1090 (148)
27	258 (55)	285 (26)	504 (27)	1047 (108)
28	280 (40)	285 (16)	672 (22)	1237 (78)

(Continued)

Table J4 (Concluded)

Mono	Tertiary Rock Concrete	Secondary Rock Concrete	Primary Rock Concrete	Total Rock Concrete
29	240 (30)	285 (17)	504 (16)	1029 (63)
30	240 (58)	380 (39)	504 (31)	1124 (128)
31	240 (66)	285 (33)	504 (34)	1029 (133)
32	240 (81)	285 (48)	504 (47)	1029 (176)
33	240 (59)	270 (30)	504 (33)	1014 (122)
34	240 (63)	270 (29)	504 (27)	1014 (119)
35	240 (54)	270 (27)	504 (23)	1014 (104)
36	240 (52)	270 (23)	504 (24)	1014 (99)
37	240 (62)	270 (35)	504 (40)	1014 (137)
38	280 (126)	270 (60)	504 (57)	1054 (243)
39	240 (94)	270 (47)	672 (71)	1182 (212)
40	280 (129)	270 (60)	504 (56)	1054 (245)
41	240 (109)	360 (76)	504 (54)	1104 (239)
42	280 (152)	270 (67)	504 (89)	1054 (308)
43	415 (128)	735 (79)	660 (42)	1810 (249)
44	241 (60)	270 (30)	495 (33)	1006 (123)
45	240 (52)	270 (29)	497 (40)	1007 (121)
46	160 (30)	550 (86)	504 (29)	1214 (145)
	12,253 (3,921)	18,800 (2,896)	21,239 (2,012)	52,292 (8,829)

* No primary zone

** No tertiary zone

Table J5

Grout Take in Sacks of Cement Per Monolith

Mono	Tertiary	Secondary	Primary	Total
0	47	13	*	60
1	76	65	*	141
2	74	62	*	136
3	17	124	*	141
4	176	23	*	9
5	0	36	*	36
6	14	24	*	38
7	668	396	*	1064
8	34	296	*	330
9	22	1	*	23
10	361	82	211	654
11	1683	259	238	2180
12	331	44	130	505
13	383	130	0	513
14	432	39	303	774
15	217	303	70	590
16	180	0	0	180
17	140	121	215	476
18	0	124	194	318
19	303	286	138	727
20	218	6	1	225
21	436	1007	15	1458
22	4	1742	418	2164
23	25	573	3	601
24	3	11	757	771
25	3	4	18	25
26	6	8	98	112
27	7	49	774	830
28	0	9	71	80
29	0	6	38	44
30	2	12	207	221
31	4	5	109	118
32	1	13	313	327
33	357	310	5	672
34	0	1	6	7
35	1	2	13	16
36	4	0	2	6
37	5	4	2	11
38	10	2	179	191
39	111	6	17	134
40	199	39	318	556
41	2	33	40	75
42	20	19	141	180
43	213	32	55	300
44	40	6	7	53
45	9	105	9	123
46	55	69	51	175
TOTAL	6893	6501	5166	18560

* No primary zone.

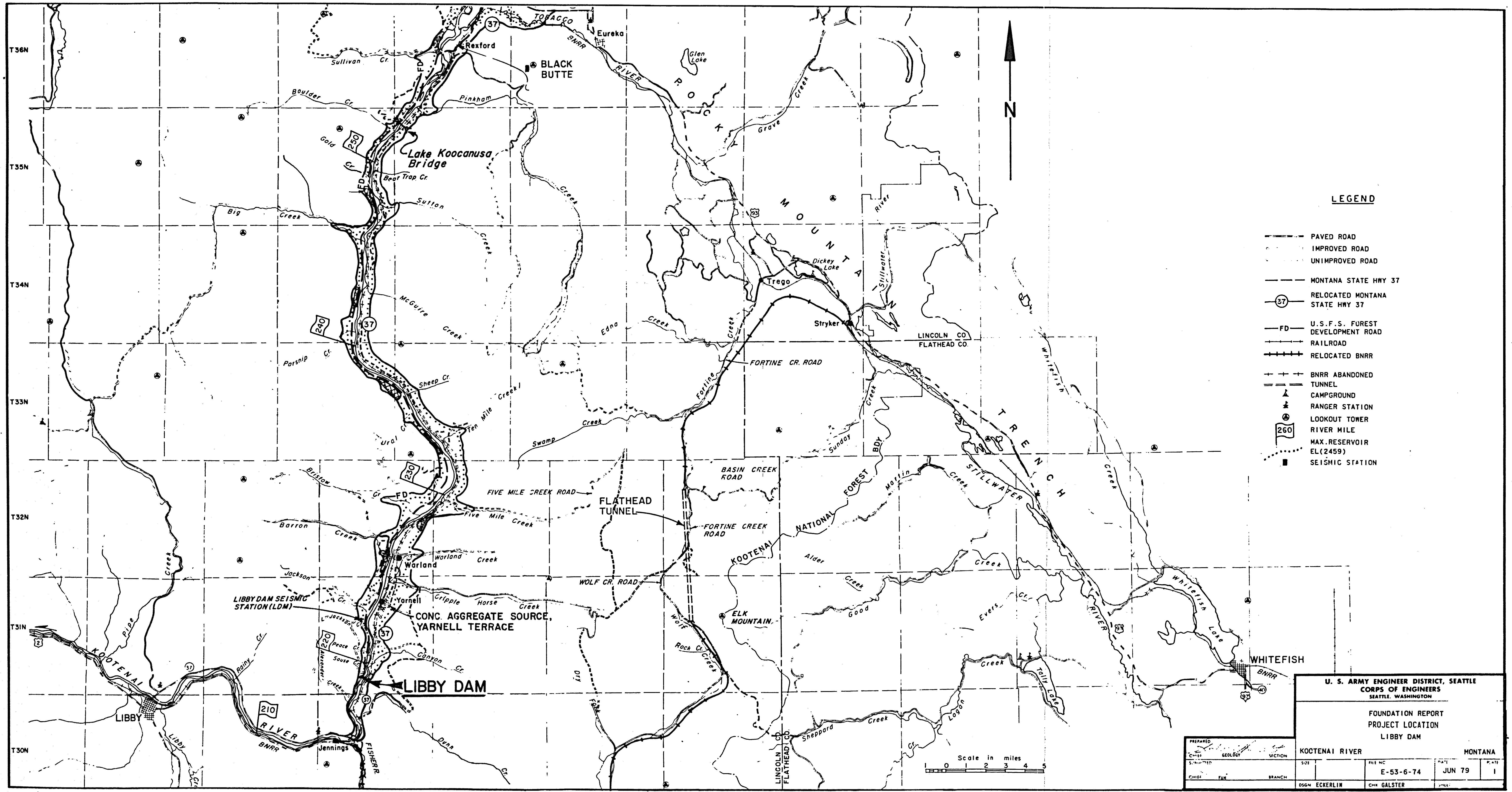

U. S. ARMY ENGINEER DISTRICT, SEATTLE
CORPS OF ENGINEERS
SEATTLE, WASHINGTON
FOUNDATION REPORT
PROJECT LOCATION
LIBBY DAM
KOOTENAI RIVER
MONTANA
E-53-6-74
JUN 79
1
DSGN ECKERLIN
CHK GALSTER
LEGEND
PAVED ROAD
IMPROVED ROAD
UNIMPROVED ROAD
MONTANA STATE HWY 37
RELOCATED MONTANA STATE HWY 37
U.S.F.S. FOREST DEVELOPMENT ROAD
RAILROAD
RELOCATED BNRR
BNRR ABANDONED
TUNNEL
CAMPGROUND
RANGER STATION
LOOKOUT TOWER
RIVER MILE
MAX. RESERVOIR EL(2459)
SEISMIC STATION
N
Scale in miles
T36N
T35N
T34N
T33N
T32N
T31N
T30N
LIBBY DAM
LIBBY
WHITEFISH
Eureka
Rexford
BLACK BUTTE
Lake Koocanusa Bridge
Trego
Stryker
Warland
Yarnell
Jennings
FLATHEAD TUNNEL
LIBBY DAM SEISMIC STATION (LDM)
CONC. AGGREGATE SOURCE, YARNELL TERRACE
ROCKY MOUNTAIN TRENCH
KOOTENAI NATIONAL FOREST BDY
KOOTENAI RIVER
TOBACCO RIVER
STILLWATER RIVER
FISHER R.
ELK MOUNTAIN
FORTINE CR. ROAD
FIVE MILE CREEK ROAD
FORTINE CREEK ROAD
BASIN CREEK ROAD
WOLF CR. ROAD
LINCOLN CO.
FLATHEAD CO.
BNRR
Dickey Lake
Glen Lake
Whitefish Lake
Tally Lake
250
240
230
220
210

PLATE I-J1

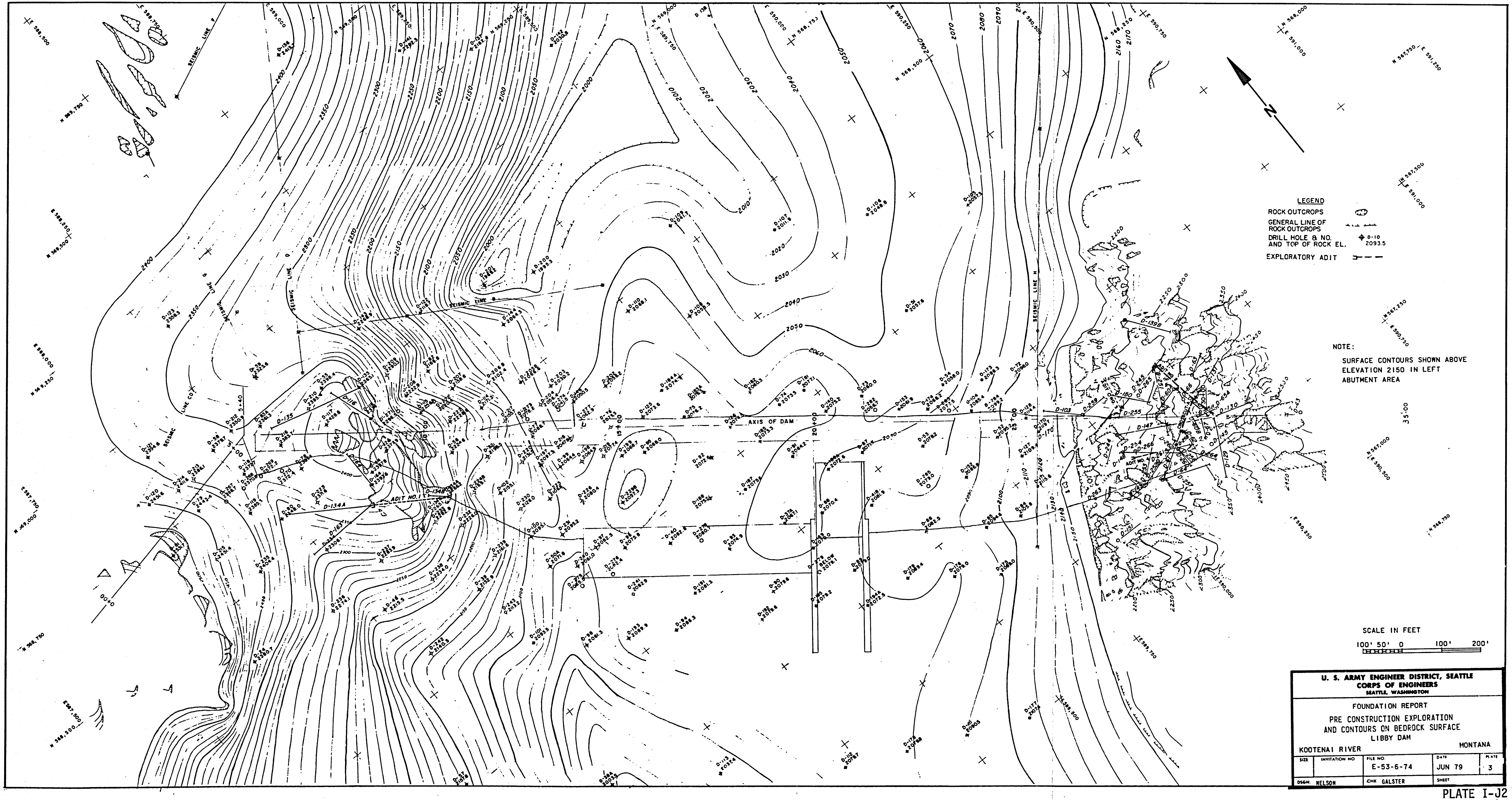
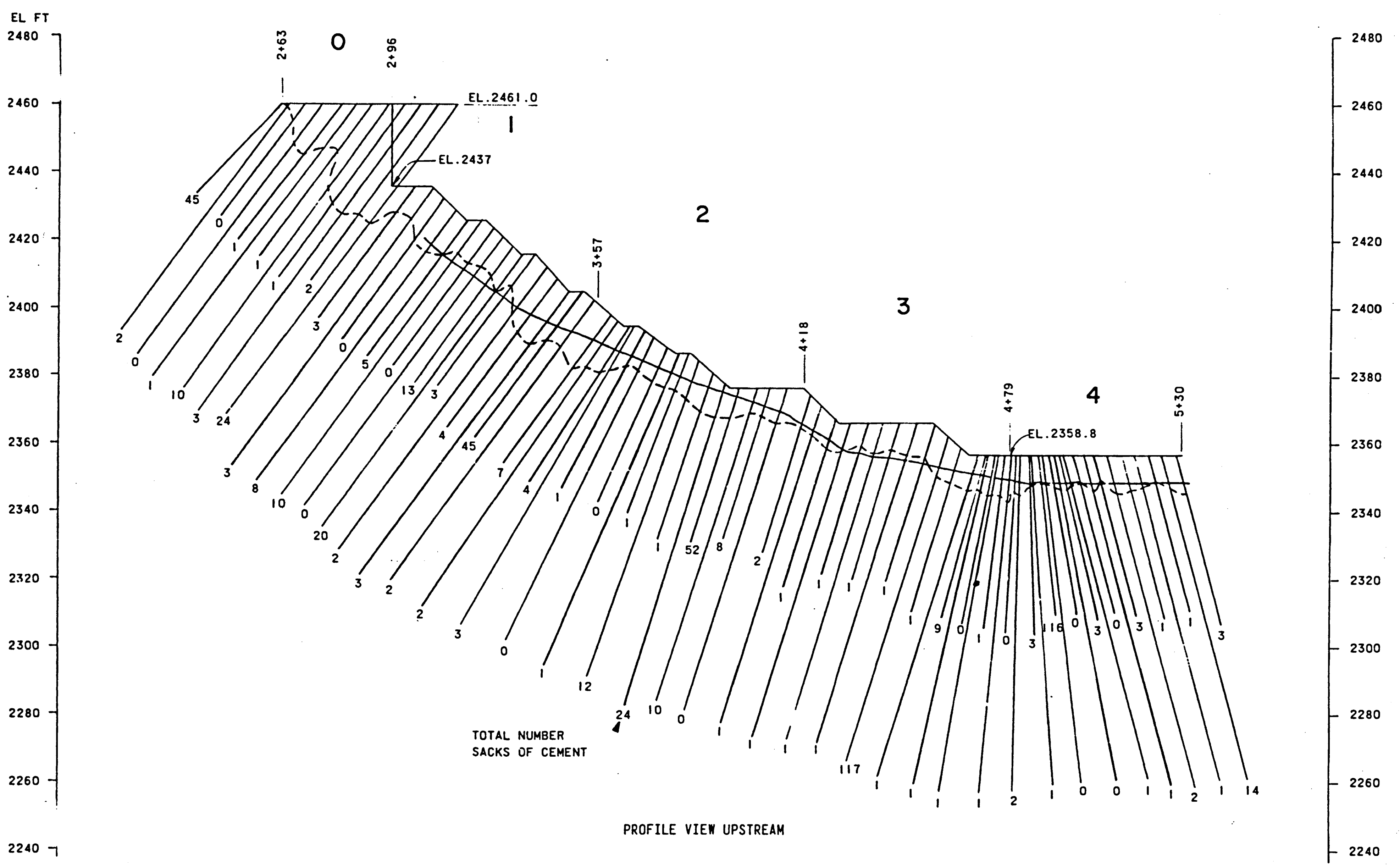
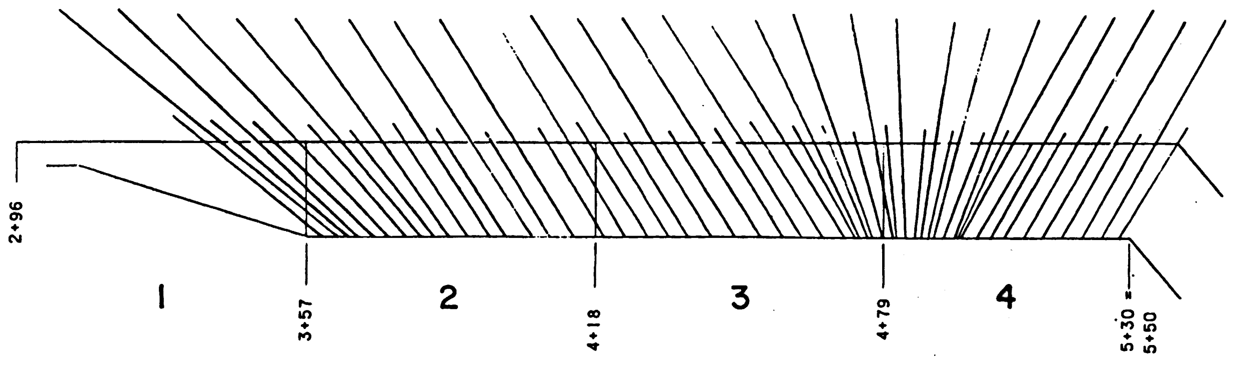

LEGEND
ROCK OUTCROPS
GENERAL LINE OF ROCK OUTCROPS
DRILL HOLE & NO. AND TOP OF ROCK EL.
D-10 2093.5
EXPLORATORY ADIT
NOTE:
SURFACE CONTOURS SHOWN ABOVE ELEVATION 2150 IN LEFT ABUTMENT AREA
SCALE IN FEET
100' 50' 0 100' 200'
AXIS OF DAM
ADIT NO. 1
SEISMIC LINE E
SEISMIC LINE B
SEISMIC LINE H
U. S. ARMY ENGINEER DISTRICT, SEATTLE
CORPS OF ENGINEERS
SEATTLE, WASHINGTON
FOUNDATION REPORT
PRE CONSTRUCTION EXPLORATION
AND CONTOURS ON BEDROCK SURFACE
LIBBY DAM
KOOTENAI RIVER
MONTANA
SIZE
INVITATION NO
FILE NO.
E-53-6-74
DATE
JUN 79
PLATE
3
DSGN. NELSON
CHK GALSTER
SHEET

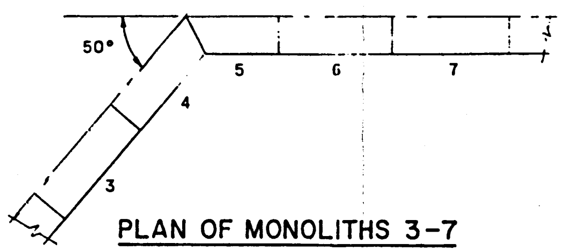
PLATE I-J2



PROFILE VIEW UPSTREAM

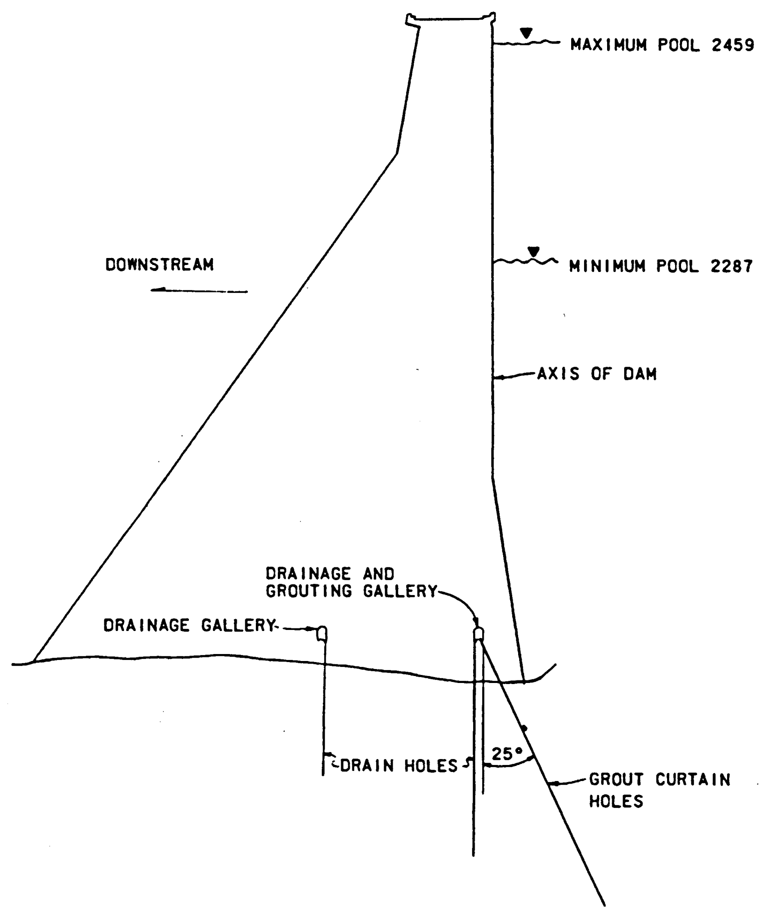


PLAN



PLAN OF MONOLITHS 3-7

SCALE IN FEET



TYPICAL SECTION THROUGH DAM

SCALE IN FEET

LEGEND

—— ROCKLINE DETERMINED BY FOUNDATION MAPPING

– – – ROCKLINE DETERMINED BY GROUT HOLE DRILLING

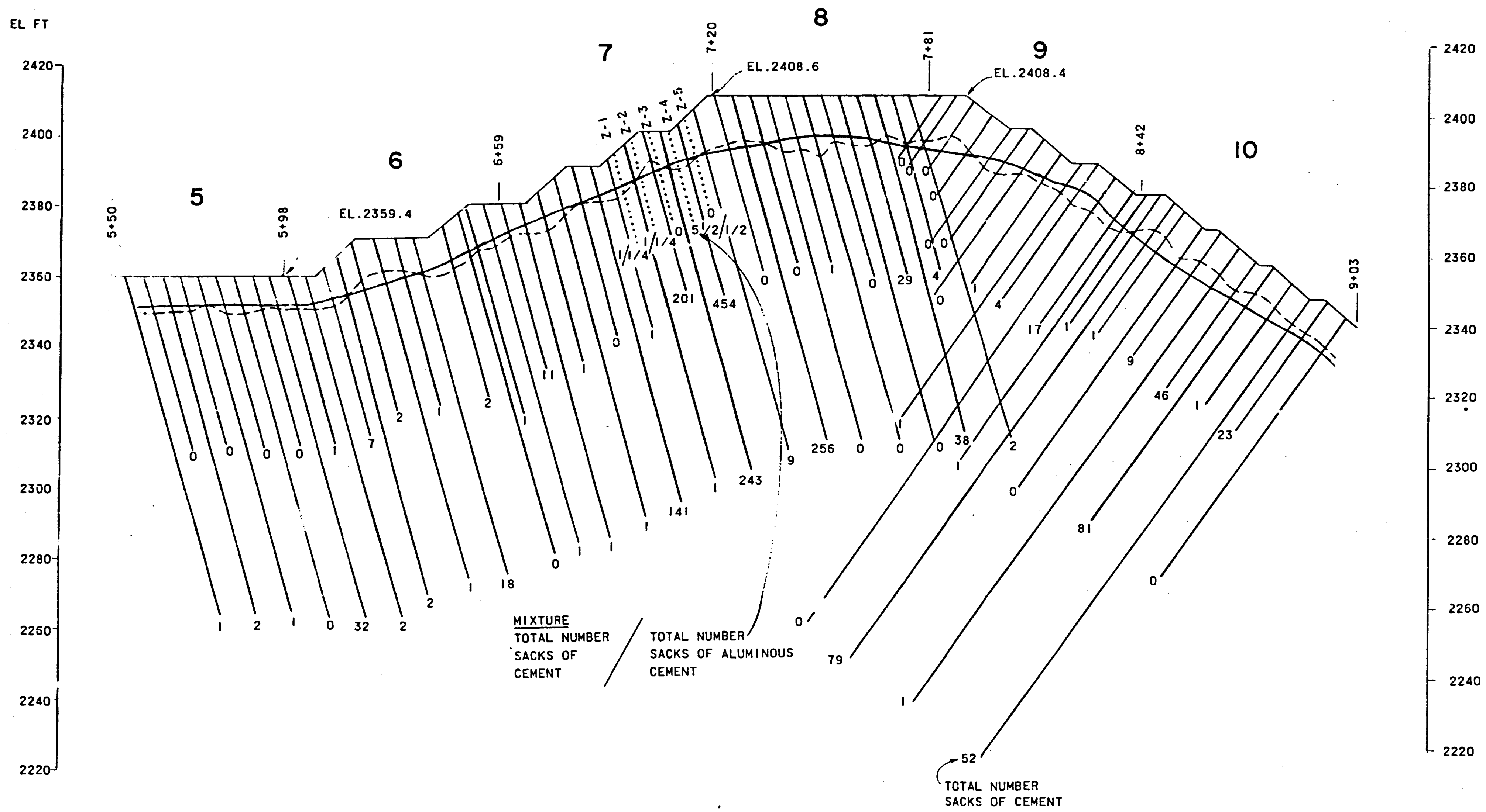
SCALE IN FEET

U. S. ARMY ENGINEER DISTRICT, SEATTLE
CORPS OF ENGINEERS
SEATTLE, WASHINGTON

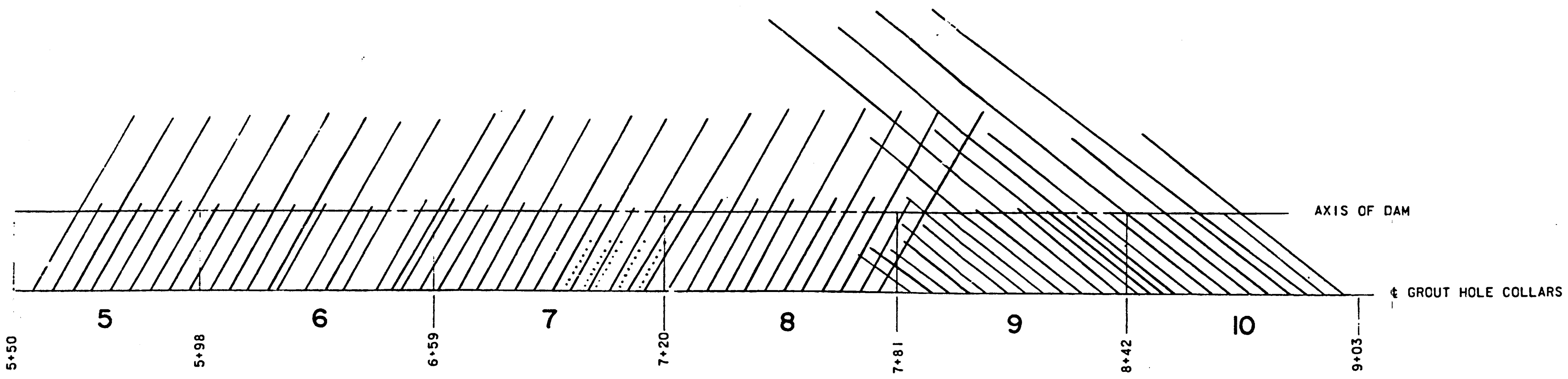
FOUNDATION REPORT
DRAINAGE & GROUTING GALLERY
GROUT HOLES-MONOLITHS 0 THRU 4
LIBBY DAM

KOOTENAI RIVER MONTANA

SIZE	INVITATION NO.	FILE NO.	DATE	PLATE
		E-53-6-74	JUN 79	9
DSGN. ECKERLIN		CHK. GALSTER	SHEET	



PROFILE VIEW UPSTREAM



PLAN

NOTES:

1. ········ INDICATES GROUT HOLES DRILLED IN APRIL 1977. CONTRACT NO. 67-77-0030
2. FOR TYPICAL SECTION THROUGH DAM, SEE SHEET 9.

LEGEND

——— ROCKLINE DETERMINED BY FOUNDATION MAPPING

— — — ROCKLINE DETERMINED BY GROUT HOLE DRILLING

SCALE IN FEET

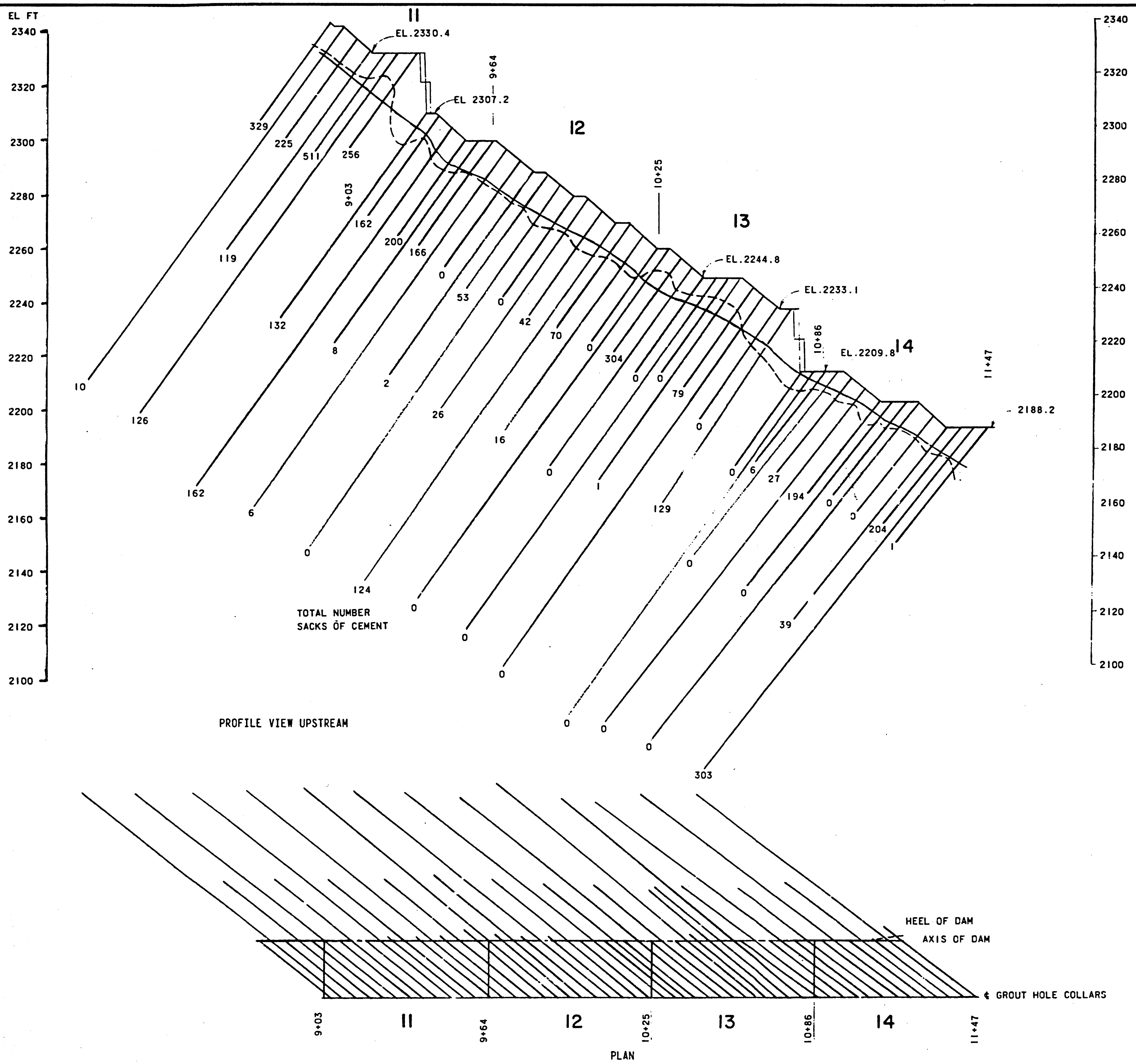
20' 10' 0 20' 40'

U. S. ARMY ENGINEER DISTRICT, SEATTLE
CORPS OF ENGINEERS
SEATTLE, WASHINGTON

FOUNDATION REPORT
DRAINAGE & GROUTING GALLERY
GROUT HOLES-MONOLITHS 5 THRU 10
LIBBY DAM

KOOTENAI RIVER MONTANA

SIZE	INVITATION NO.	FILE NO.	DATE	PLATE
		E-53-6-74	JUN 79	10
DSGN. ECKERLIN		CHK. GALSTER	SHEET	



NOTE:
FOR TYPICAL SECTION THROUGH DAM, SEE SHEET 9.

LEGEND

ROCKLINE DETERMINED BY FOUNDATION MAPPING

ROCKLINE DETERMINED BY GROUT HOLE DRILLING

SCALE IN FEET

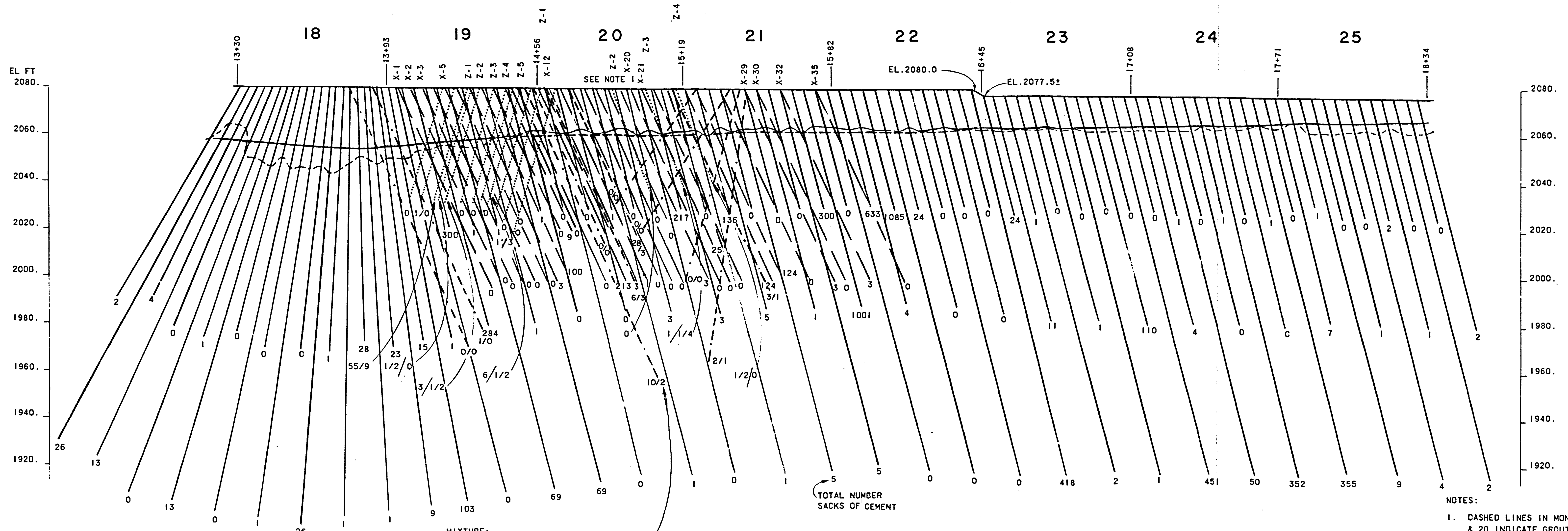
20' 10' 0 20' 40'

U. S. ARMY ENGINEER DISTRICT, SEATTLE
CORPS OF ENGINEERS
SEATTLE, WASHINGTON

FOUNDATION REPORT
DRAINAGE & GROUTING GALLERY
GROUT HOLES-MONOLITHS 11 THRU 14
LIBBY DAM

KOOTENAI RIVER MONTANA

SIZE	INVITATION NO	FILE NO	DATE	PLATE
		E-53-6-74	JUN 79	11
DSGN. ECKERLIN		CHK. GALSTER	SHEET	



PROFILE VIEW UPSTREAM

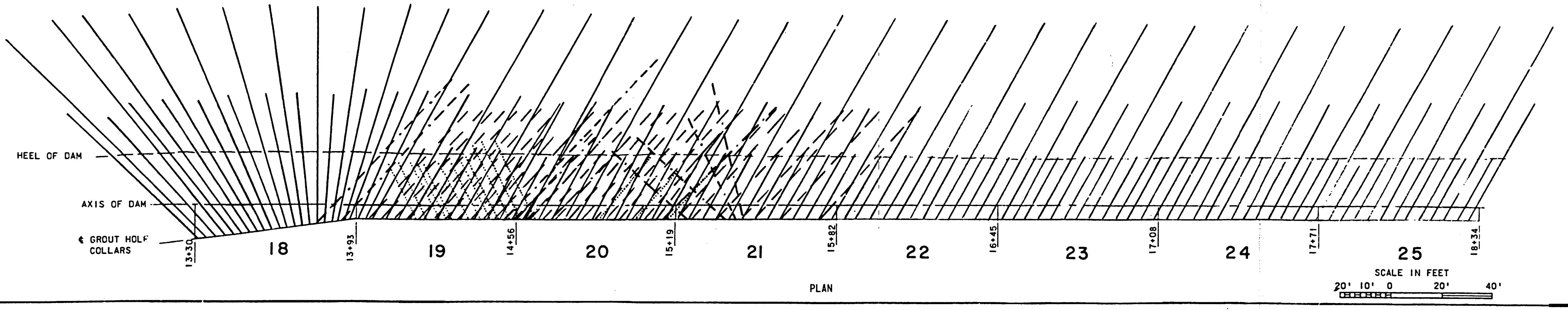
LEGEND

——— ROCKLINE DETERMINED BY FOUNDATION MAPPING

– – – ROCKLINE DETERMINED BY GROUT HOLE DRILLING

NOTES:

1. DASHED LINES IN MONOLITHS 18, 19 & 20 INDICATE GROUT HOLES DRILLED APRIL 74, CONTRACT NO. DACW 67-74-C-0085.
2. EXISTING HOLES X-1, X-2, X-3, X-5, X-12, X-20, X-21, X-29, X-30, X-32, AND X-35 REDRILLED AND REGROUTED, CONTRACT NO. DACW 67-75-C-0074.
3. — — · — INDICATES GROUT HOLES DRILLED IN MAY, JUNE 1975 CONTRACT NO. DACW 67-75-C-0074.
4. .... INDICATES GROUT HOLES DRILLED IN MARCH, APRIL 1977 CONTRACT NO. DACW 67-77-0030.
5. FOR TYPICAL SECTION THROUGH DAM, SEE SHEET 9.



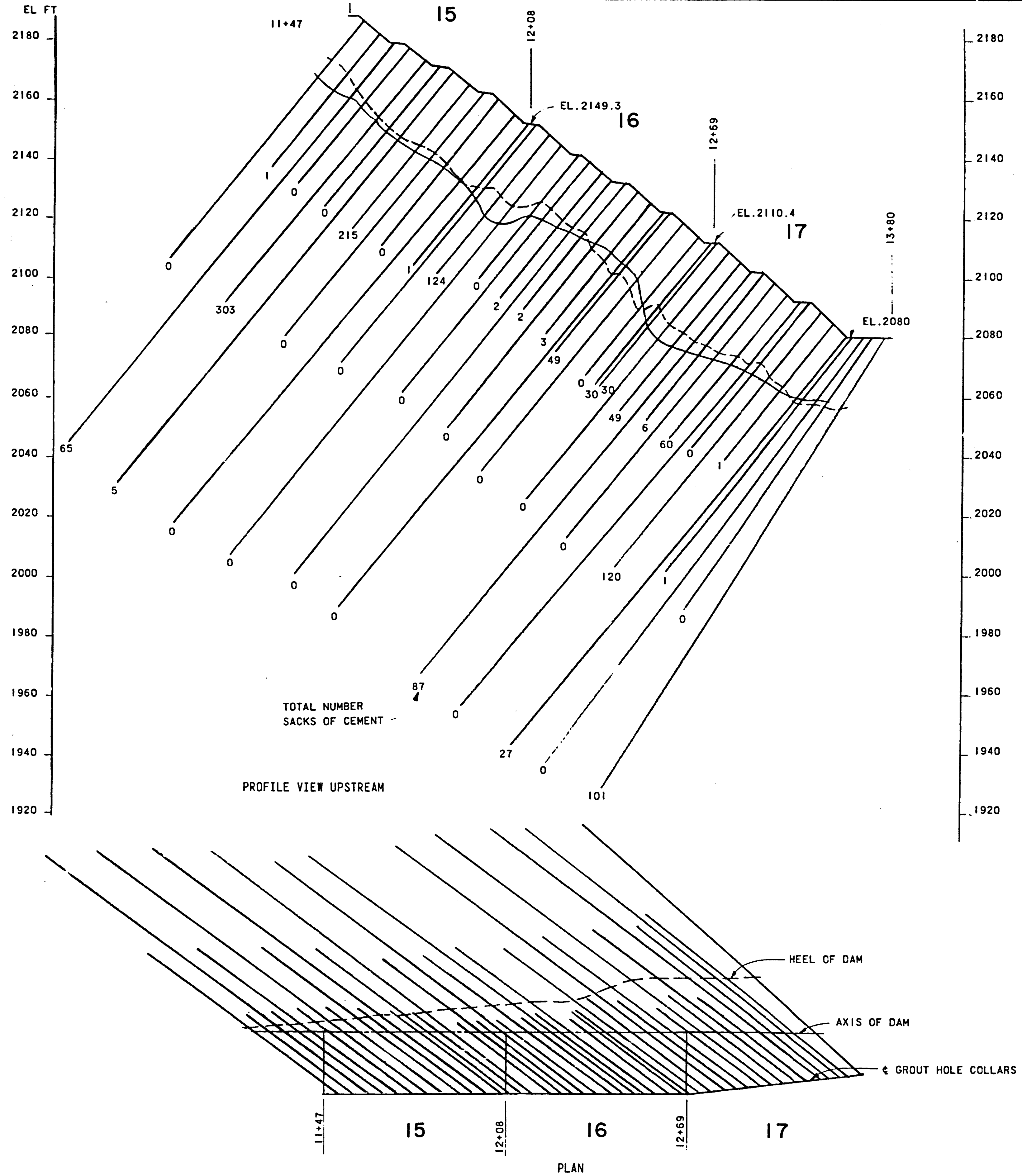
PLAN

U. S. ARMY ENGINEER DISTRICT, SEATTLE
CORPS OF ENGINEERS
SEATTLE, WASHINGTON

FOUNDATION REPORT
DRAINAGE & GROUTING GALLERY
GROUT HOLES MONOLITHS 18 THRU 25
LIBBY DAM

KOOTENAI RIVER MONTANA

SIZE	INVITATION NO.	FILE NO.	DATE	PLATE
		E-53-6-74	JUN 79	13
DSGN. ECKERLIN		CHK. GALSTER	SHEET	



LEGEND

—— ROCKLINE DETERMINED BY FOUNDATION MAPPING

– – – ROCKLINE DETERMINED BY GROUT HOLE DRILLING

NOTE:

FOR TYPICAL SECTION THROUGH DAM, SEE SHEET 9.

SCALE IN FEET

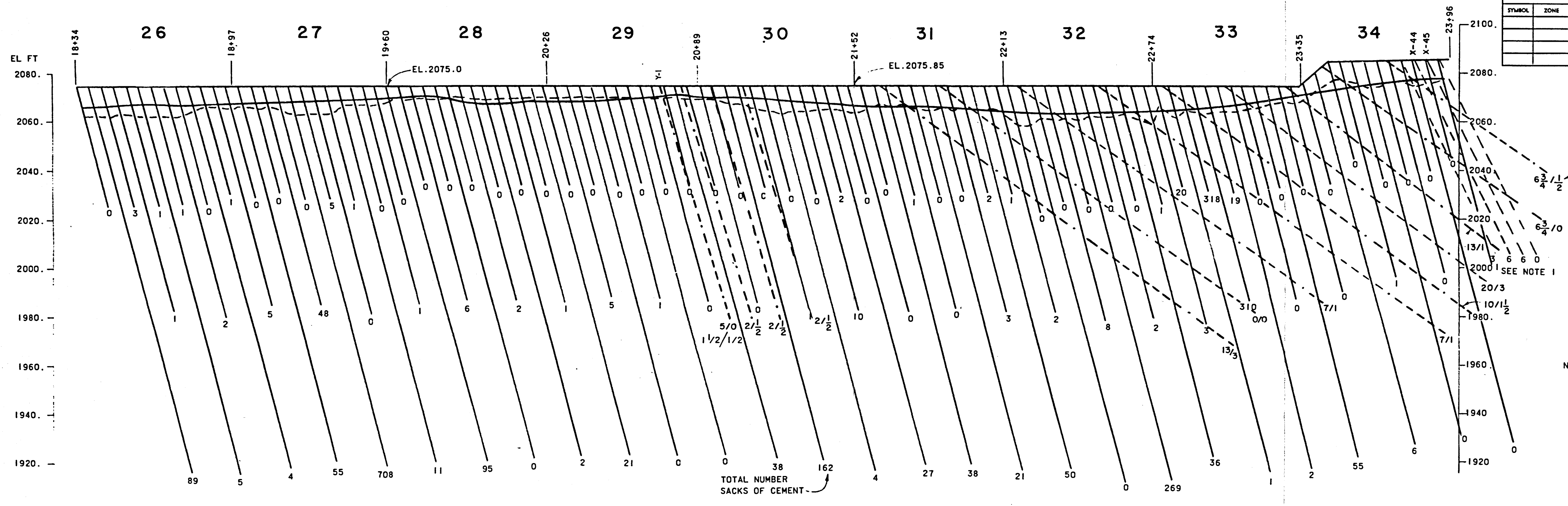
20' 10' 0 20' 40'

U. S. ARMY ENGINEER DISTRICT, SEATTLE
CORPS OF ENGINEERS
SEATTLE, WASHINGTON

FOUNDATION REPORT
DRAINAGE & GROUTING GALLERY
GROUT HOLES-MONOLITHS 15 THRU 17
LIBBY DAM

KOOTENAI RIVER			MONTANA	
SIZE	INVITATION NO.	FILE NO E-53-6-74	DATE JUN 79	PLATE 12
DSGN. ECKERLIN		CHK. GALSTER	SHEET	

REVISIONS				
SYMBOL	ZONE	DESCRIPTION	DATE	BY



PROFILE VIEW UPSTREAM

LEGEND

——— ROCKLINE DETERMINED BY FOUNDATION MAPPING

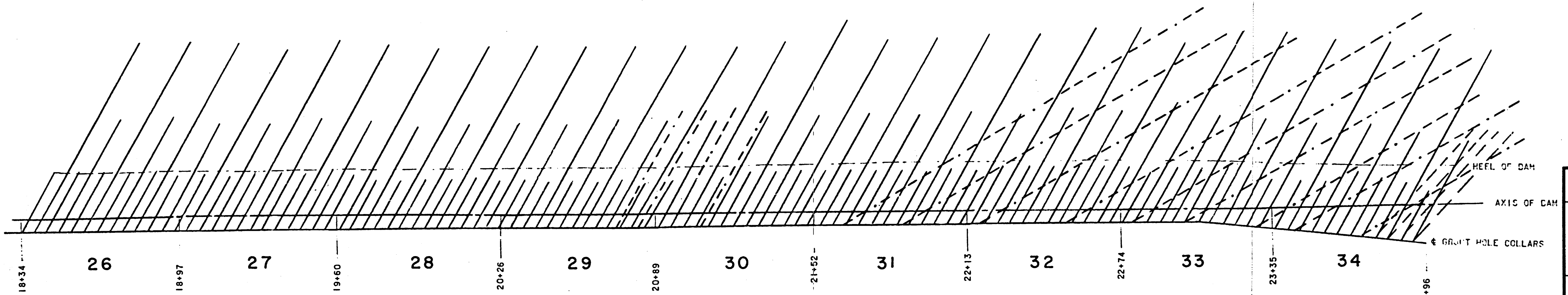
— — — ROCKLINE DETERMINED BY GROUT HOLE DRILLING

NOTES:

1. DASHED LINES IN MONOLITH 34 INDICATE NEW GROUT HOLES DRILLED APRIL 74, CONTRACT NO. DACW 67-74-C-0085
2. EXISTING HOLES X-44 AND X-45 REDRILLED AND REGROUTED, CONTRACT NO. DACW 67-75-C-0074
3. ——·—— INDICATES GROUT HOLES DRILLED IN MAY, JUNE 1975, CONTRACT NO. DACW 67-75-C-0074
4. EXISTING HOLE Y-1 REDRILLED AND REGROUTED, CONTRACT NO. DACW 67-77-0030
5. FOR TYPICAL SECTION THROUGH DAM, SEE SHEET 9.

SCALE IN FEET

20' 10' 0 20' 40'



PLAN

U. S. ARMY ENGINEER DISTRICT, SEATTLE
CORPS OF ENGINEERS
SEATTLE, WASHINGTON

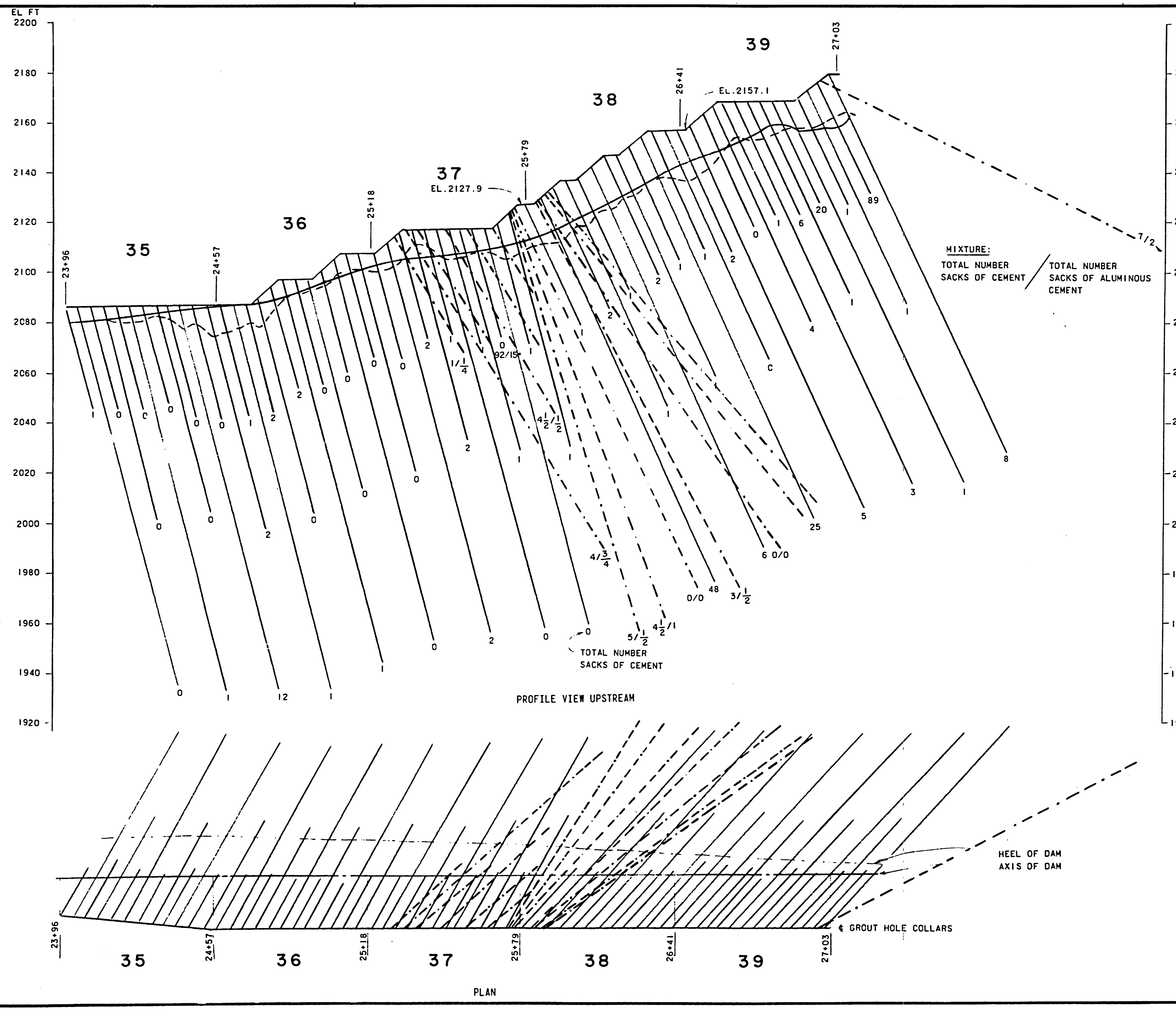
FOUNDATION REPORT

DRAINING & GROUTING GALLERY
GROUT HOLES-MONOLITHS 26 THRU 34
LIBBY DAM

KOOTENAI RIVER — MONTANA

SIZE	INVITATION NO.	FILE NO.	DATE:	PLATE
		E-53-6-74	JUN 79	14
DSGN. ECKERLIN		CHK. GALSTER	SHEET	

REVISIONS				
SYMBOL	ZONE	DESCRIPTION	DATE	BY



NOTES:

1. —·—·— INDICATES GROUT HOLES DRILLED IN MAY, JUNE 1975 CONTRACT NO. DACW 67-75-C-0074.
2. FOR TYPICAL SECTION THROUGH DAM, SEE SHEET 9.

LEGEND

——— ROCKLINE DETERMINED BY FOUNDATION MAPPING

— — ROCKLINE DETERMINED BY GROUT HOLE DRILLING

SCALE IN FEET

20' 10' 0 20' 40'

U. S. ARMY ENGINEER DISTRICT, SEATTLE
CORPS OF ENGINEERS
SEATTLE, WASHINGTON

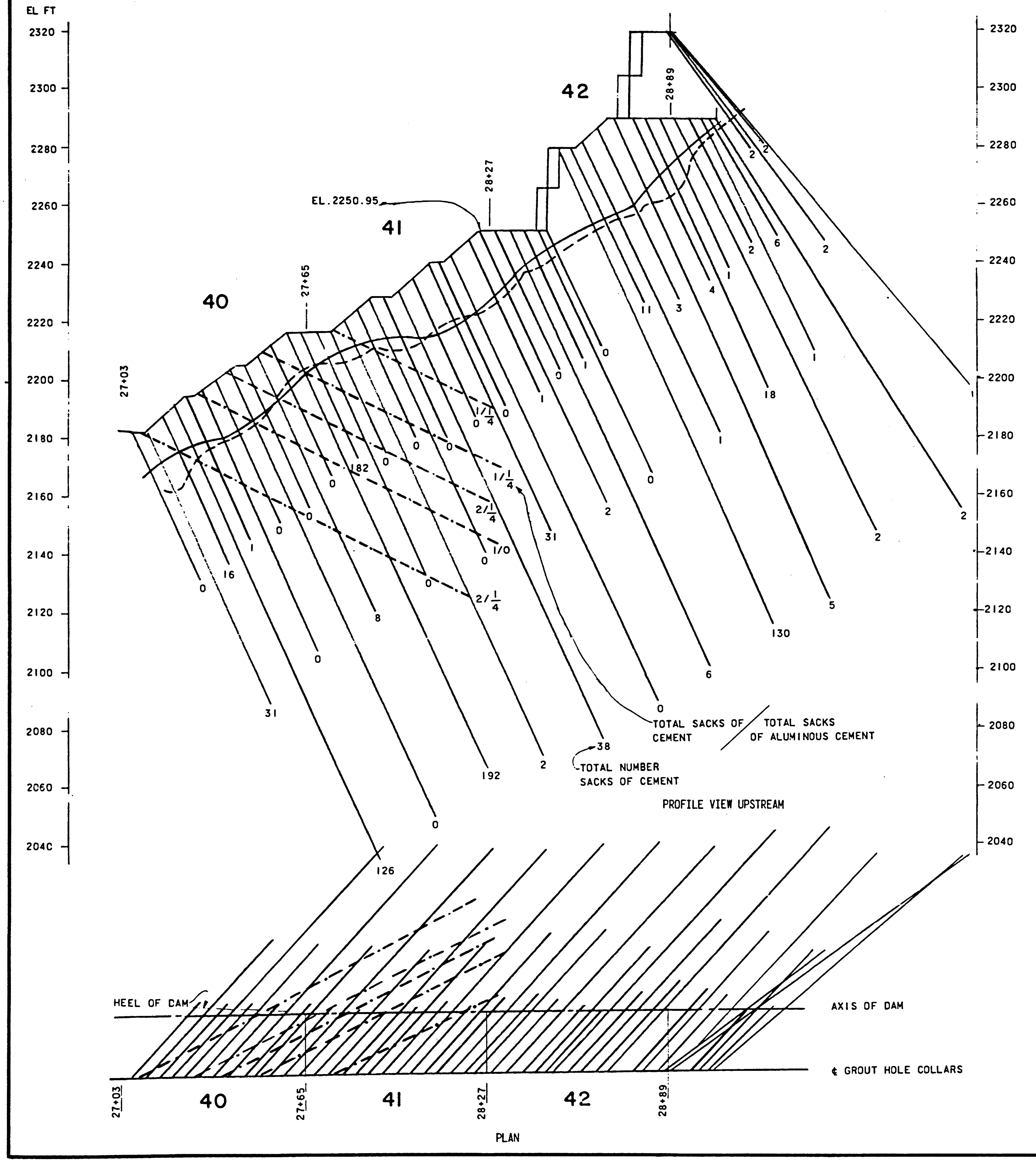
FOUNDATION REPORT
DRAINAGE & GROUTING GALLERY
GROUT HOLES-MONOLITHS 35 THRU 39
LIBBY DAM

KOOTENAI RIVER — MONTANA

SIZE	INVITATION NO	FILE NO	DATE	SHEET
		E-53-6-74	JUN 79	15
DSGN ECKERLIN		CHK GALSTER		

PLATE I-J9

REVISIONS				
SYMBOL	ZONE	DESCRIPTION	DATE	BY



NOTES:

1. — — — INDICATES GROUT HOLES DRILLED IN MAY, JUNE 1975 CONTRACT NO. DACW 67-75-C-0074.
2. FOR TYPICAL SECTION THROUGH DAM, SEE SHEET 9.

LEGEND

——— ROCKLINE DETERMINED BY FOUNDATION MAPPING

– – – ROCKLINE DETERMINED BY GROUT HOLE DRILLING

SCALE IN FEET

20' 10' 0 20' 40'

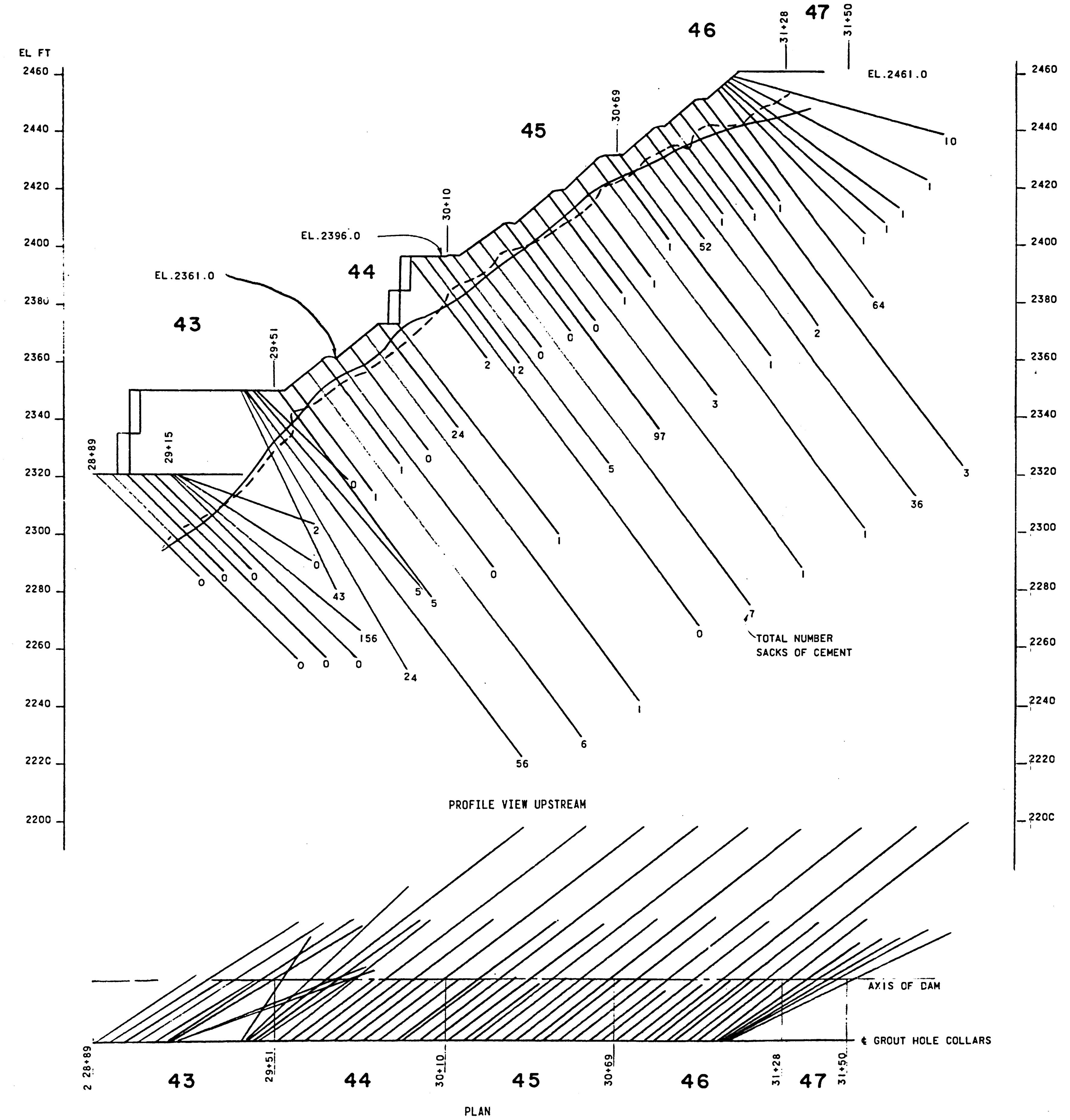
U. S. ARMY ENGINEER DISTRICT, SEATTLE
CORPS OF ENGINEERS
SEATTLE, WASHINGTON

FOUNDATION REPORT
DRAINAGE & GROUTING GALLERY
GROUT HOLES-MONOLITHS 40 THRU 42
LIBBY DAM

KOOTENAI RIVER — MONTANA

SIZE	INVITATION NO	FILE NO	DATE	PLATE
		E-53-6-74	JUN 79	16
DSGN. ECKERLIN		CHK GALSTER	SHEET	

PLATE I-J10



NOTE:

FOR TYPICAL SECTION THROUGH DAM, SEE SHEET 9

LEGEND

ROCKLINE DETERMINED BY FOUNDATION MAPPING

ROCKLINE DETERMINED BY GROUT HOLE DRILLING

SCALE IN FEET

20' 10' 0 20' 40'

U. S. ARMY ENGINEER DISTRICT, SEATTLE
CORPS OF ENGINEERS
SEATTLE, WASHINGTON

FOUNDATION REPORT
DRAINAGE & GROUTING GALLERY
GROUT HOLES-MONOLITHS 43 THRU 47
LIBBY DAM

KOOTENAI RIVER — MONTANA

SIZE	INVITATION NO	FILE NO	DATE	PLATE
		E-53-6-74	JUN 79	17
DSGN. ECKERLIN		CHK GALSTER	SHEET	

PROJECT K: LAUREL DAM

(This case history was developed with the assistance of Marvin Simmons, Wayne Swartz, and John Stanton, Nashville District)

Location and Description of Project

K1. The dam is located on Laurel River, 2.3 miles above its confluence with the Cumberland River in Laurel and Whitley Counties, Ky., approximately 2 river miles east of Corbin, Ky. The dam is a rockfill structure with a thin, central impervious core section and is approximately 1,420 ft long as measured along its axis which is upstream. The embankment rises about 300 ft above its lowest foundation level to a 40-ft-wide crest at elevation 1036. Other major project features include a 750-ft uncontrolled spillway near the left abutment, a powerplant with a 19-ft-diam power tunnel, and a 17-ft-diam tunnel temporarily connected to the power tunnel for diversion during construction. The project was designed and constructed by the Nashville District. Construction was divided into four major contracts. The first included the portals and tunnels and was completed in December 1967. The second, completed in July 1969, consisted of foundation excavation to develop a foundation suitable to place embankment fill. The third contract, completed in September 1977, consisted of the final embankment foundation including all grouting and foundation treatment, construction of the embankment, spillway, and power intake structure. The prime contractor for the third contract which included drilling and grouting was Oman Construction Company, Inc., and Codell Construction Company, Inc., a joint venture.

Geology

K2. The project is situated within the Cumberland Plateau province just west of the folded and thrust faulted Ridge and Valley province. The plateau is well dissected and the topography is rugged with about 400 ft of relief at the project area. The stratigraphy consists of flat lying sandstones and shales with minor beds of coal of Pennsylvanian age. The sandstones are moderately hard, massive, and fine-grained with occasional conglomeratic zones. The shales are dark gray to black, moderately hard and silty.

The strata in the valley at the site have been ruptured and broken probably as a result of valley stress release. The deformation at the site is in the form of thrust faults with minor displacement, upwarping of beds, fracturing, and bedding plane breaks. Several members of the Lee formation were identified at the site. Three sandstone members serve as foundation for the concrete appurtenances. Three shale members serve as the foundation for portions of the embankment and a major portion of the powerhouse.

Foundation Investigations

K3. Fifty-six vertical, 13 angle, and two horizontal NX borings and five 6-in. core borings were made in the area of the dam prior to the development of the plans and specifications for the embankment foundation excavation contract. Some were drilled for other project features but were also used in the embankment design studies. Three borings were photographed with the borehole camera and four borings were examined with a TV borehole camera. Other investigations included detailed geologic study and mapping of excavated faces for tunnels and portals, exploratory excavations and natural exposure of rocks within the area. Plate I-K1 shows a plan of the project and subsurface exploration. Plate I-K2 shows a generalized geologic section.

Technical Considerations

K4. The designed grouting plan consisted of the construction of a 60-ft-deep curtain in two 30-ft zones with two lines 10 ft apart along the center line of the dam. It was anticipated that grout takes would be relatively small as most of the weathered and open rock would have been removed. Provisions for foundation treatment also included dental treatment and area type grouting for sealing open joints and bedding planes beneath the core section. There was a differing site condition clause in the specifications. There was also a statement that described the program as being tentative and presented for the purpose of canvassing bids. The amount would be governed by conditions encountered as the work progressed. There were nine pay items including mobilization and demobilization, drilling grout holes, drilling NX exploratory holes, drilling 1-1/2-in. percussion exploratory holes, cement, sand, mineral filler, placing grout (by cubic foot), and connections to grout holes. The grouting was designed by Messrs. B. E. Clark and M. D. Simmons of the Nashville District. The grout curtain was constructed essentially as designed with the exception of a reach in the valley floor which required a third line (USACE 1969). Paragraph 15 states the reasons for adding a third line.

Contractual Considerations

K5. The contract for Laurel Dam - Stage II, which included the drilling and grouting was firm-fixed price contract awarded to the lowest bidder (USACE 1969). The subcontractor for the drilling and grouting was ATEC. The contract was managed by Mr. R. L. Thomas and his staff. The relations between the government and the prime contractor were good and were satisfactory with the subcontractor. The prime contractor claimed that the subcontractor delayed him. One modification for additional excavation impacted the grouting schedule. Another modification required use of packers in grout holes in the valley floor. There were no claims relating to drilling and grouting.

Drilling and Grouting Method

K6. Grouting operations began in September 1969 and were completed in November 1970 (USACE 1973). Two parallel lines of EX holes, located 5 ft upstream and 5 ft downstream of the axis were installed in two generally 30-ft zones to a depth of 60 ft. The upstream line was grouted prior to starting the downstream line. A third line to check the first two lines was installed for a portion of the valley section. Holes were staggered on the two lines.

Drilling

K7. The curtain grout holes were 1-1/2 in. in diameter and drilled with rotary drilling equipment. Core was not required. The spacing of primary and secondary holes on respective lines were staggered on 20- and 10-ft centers with the usual split spacing, and staging of holes as necessary. The holes were angled 45 deg into the abutments.

Washing and pressure testing

K8. Washing and pressure testing of the holes was required prior to grouting. There was no separate pay items for this work. The costs were to be included in the drilling.

Grouting mixtures

K9. Only neat cement grout was used even though two items were included for sand and mineral filler in grout. The specification stated that the water-cement ratio of the mixtures would range between 3:1 and 0.6:1 with the greater part probably being placed at about 1:1. It also stated that mixtures would be in proportion directed by the contracting officer to suit conditions. Actual mixtures varied from an infrequent 12:1 to 1:1. The water-cement ratio was generally reduced to 1:1 after a take was indicated.

Pressure

K10. Grouting pressures varied between 0 and 90 psi as directed by project personnel. The specifications called for pressures to be measured at the hole by an accurate gage. In one area of grouting it was found that the gages for grouting were faulty which resulted in higher pressures which resulted in higher takes due to jacking the foundation.

Refusal rate

K11. Grouting of a hole was not considered complete until that hole refused to take grout at three-fourths of the maximum required pressure for that stage.

Field Procedures

K12. The grout curtain was installed essentially as designed. The upstream line of holes were grouted prior to grouting the downstream line. Primary holes were on 20-ft centers, split to 10 and 5 ft where necessary. Grouting started in the valley and progressed upward into each abutment. Grouting was done in two zones, each generally 30 ft in depth. A center line was installed in a portion of the valley section to check the upstream and downstream line. Grouting was done by stage grouting methods. A modification to use packers for grouting in the valley floor was necessary. The foundation was grouted with neat cement grout and the water-cement ratio was generally reduced to 1:1 after a take was indicated.

Equipment

K13. Requirements included a plant capable of supplying, mixing, stirring, and pumping the grout with a minimum capacity of 30 gpm at a pressure not greater than 100 psi. A progressing cavity pump capable of operating at a maximum discharge pressure of 100 psi similar to the Moyno Pump was specified.

Also included were the mechanical grout mixer, sump, tank for water, and such valves, gages, hoses, etc., necessary to perform the job. A colloidal mixer was not specified but in hindsight would have been specified.

Grout takes

K14. Total drilling for the left abutment was 5304 ft with 1,177 cu ft of cement placed for a ratio of 0.22 cu ft/lin ft. Total drilling for the right abutment was 7,246 ft with 3,328 cu ft of cement placed for a ratio of 0.46 cu ft/lin ft. Total drilling for the valley section was 5,015 ft with 6,429 cu ft of cement placed for a ratio of 1.28 cu ft/lin ft. Totals for the project are 17,565 ft drilled and 10,934 cu ft of cement placed for a ratio of 0.62 cu ft/lin ft. Table K1 shows the general order and summation of grouting for each section. Plate I-K3 shows the plan of grout lines and Plates I-K4, I-K5 and I-K6 show the grout profiles.

Unexpected Geological Conditions Encountered During Construction

K15. With the exception of a shear zone in the valley floor, there were no unusual geological conditions encountered. However, in grouting a section of the valley floor it was recognized that grouting results were not as expected from conditions indicated by exploratory holes. Most of the grout had been pumped into the foundation while grouting the 30-ft stage at gage pressures indicated as 0. Surface vents were also experienced. The program was then reevaluated and the faulty gages were discovered along with the possibility of having disturbed the foundation with attendant increased grout takes in the upper section of the foundation. Then it was decided to add the third line in that section.

Evaluation of Grouting

K16. In reviewing the grouting data it appears that a progressive filling of voids was accomplished in the left abutment with systematic tightening of the abutment as evidenced by the small takes in the tertiary holes. Grout takes varied from an average high of 0.44 cu ft in the A-line primary holes to a low of 0.05 cu ft in the A-line tertiary holes. The same does not appear to be true for the right abutment where grout takes were relatively high in the latter series of holes. The sandstone took slightly more grout than the shales. It was determined that grouting from the bottom up to the 775 berm on the right abutment and grouting of the left abutment was adequate. Above the berm the grout holes took water freely, but only a few accepted more than nominal grout, which relation was inferred to be abnormal. Those anomalies could be caused by sand in many of the openings since sand can take water freely, but no grout. If the openings were sand filled they could not be grouted, but in most cases it appears that the sand only limited the grout travel. If this is the condition, it could explain the downstream right abutment leakage observed during the April 1974 periodic inspection.

Costs and Quantities

K17. No data on actual costs were available for review. The following table compares the Government estimate, bid, and actual quantities and costs for the drilling and grouting related items.

Government Estimate					Actual		
Item	Description	Quantities	Unit Cost	Estimated Amount	Unit Cost	Quantities	Amount
24-a	Mobilization and Demobilization		Lump Sum	$ 12,400			$ 3,150.00
b	Drilling Grout Holes	20,000	6.78	135,600	2.63	17,565	46,195.55
e	Portland Cement in Grout	5,000	2.50	12,500	2.63	10,934	28,756.42
h	Placing Grout	6,000	3.96	23,760	2.63	10,934	28,756.42
i	Connections to Grout Holes	550	6.00	3,300	6.00	550*	3,300.00
				$187,560			$110,158.39

* Unknown

The total drilling footage was 12 percent less than estimated and grout placed was 82 percent over the estimated.

Performance

K18. The Foundation Treatment Supplemental Report (USACE 1974) concluded that the foundations were adequately prepared and treated.

Right abutment leakage was reported at about 55 gpm through sandstone. The water emerged from a near vertical joint set which is both essentially parallel and normal to the abutment surface. All other areas along the grout curtain were believed to be satisfactorily grouted. The seepage on the right abutment was monitored by the district and an investigation was performed in 1977. The information from the investigations are contained in the Report of Investigations of Seepage Conditions (USACE 1979). Piezometers were installed in rock to establish the piezometric head and to check the effectiveness of the grout curtain. The investigation showed that the piezometric levels showed a direct relationship with fluctuations in the reservoir and that drops in the piezometric level across the grout curtain indicate that the curtain is performing as an effective barrier againt seepage. However, areas below and beyond the curtain are open and allow seepage to bypass the curtain. The report concluded that there was no indications of serious seepage problems in either abutment that would require immediate treatment. A drainage and collector system was installed to measure seepage from the right abutment for continuing evaluation.

References

US Army Corps of Engineers. 1969. Abstract of Bids for Laurel Dam - Stage II, Laurel River Project, Laurel River, Kentucky, Nashville District, Nashville, Tenn.

____________. 1973. Interim Report on Foundation Treatment - Laurel Dam, Nashville District, Nashville, Tenn.

____________. 1974. Foundation Treatment, Supplemental Report, Dam and Appurtenances, Nashville District, Nashville, Tenn.

____________. 1979. Report of Investigation of Seepage Conditions, Nashville District, Nashville, Tenn.

____________. 1969. Specifications for Laurel Dam - Stage II, Laurel River Reservoir Project, Laurel River, Kentucky, Nashville District, Nashville, Tenn.

Table K1

General Order and Summation of Grouting

Left Abutment

Performance order	Grout line	Series	Stage	Total Footage	Total Cement	Grout take cu ft/lin ft
1	A*	Primary	1st	862	192	0.22
2	A	Primary	2nd	898	396	0.44
3	A	Secondary	1st	846	346	0.40
4	A	Secondary	2nd	120	24	0.20
5	B**	Primary	1st	846	66	0.08
6	B	Primary	2nd	---	---	---
7	B	Secondary	1st	808	54	0.07
8	B	Secondary	2nd	---	---	---
9	A	Tertiary	1st	864	96	0.11
10	A	Tertiary	2nd	60	3	0.05
11	B	Tertiary	1st	---	---	---
12	B	Tertiary	2nd	---	---	---
			TOTAL	5304	1177	0.22

Right Abutment

Performance order	Grout line	Series	Stage	Total Footage	Total Cement	Grout take cu ft/lin ft
1	A	Primary	1st	1342	905	0.67
2	A	Primary	2nd	1546	584	0.37
3	A	Secondary	1st	1086	427	0.39
4	A	Secondary	2nd	70	9	0.12
5	B	Primary	1st	870	204	0.23
6	B	Primary	2nd	50	2	0.04
7	B	Secondary	1st	882	113	0.13
8	B	Secondary	2nd	80	829	10.36
9	A	Tertiary	1st	1075	206	0.19
10	A	Tertiary	2nd	0	0	---
11	B	Tertiary	1st	226	31	0.14
12	B	Tertiary	2nd	19	18	0.95
			TOTAL	7246	3328	0.46

Valley Section

Performance order	Grout line	Series	Stage	Total Footage	Total Cement	Grout take cu ft/lin ft
	A	Primary		710	1393	1.96
	A	Secondary		390	968	2.48
	A	Tertiary		833	1096	1.32
	B	Primary		768	1317	1.71
	B	Secondary		418	1636	3.91
	B	Tertiary		846	15	0.02
	C+	Primary		540	4	0.01
	C	Secondary		510	0	0.00
			TOTAL	5015	6429	1.28

\+ C line was between upstream line (A) and downstream line (B).

(Continued)

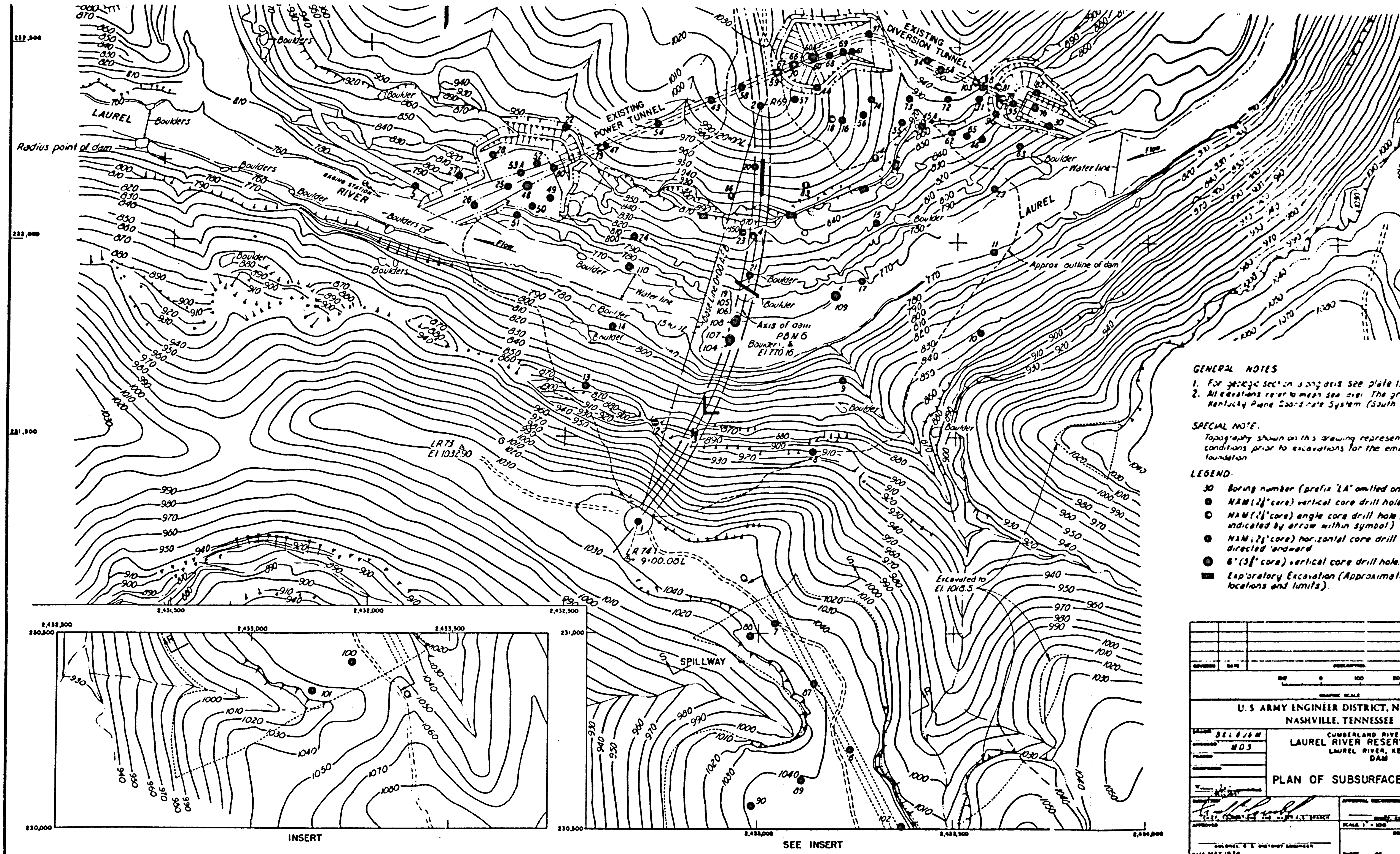
Table K1 (Concluded)

Location	Grout Totals Total Footage	Total Cement	Grout take cu ft/lin ft
Left Abutment	5304	1177	0.22
Right Abutment	7246	5328	0.46
Valley Section	5015	6429	1.28
	17565	10934	0.62

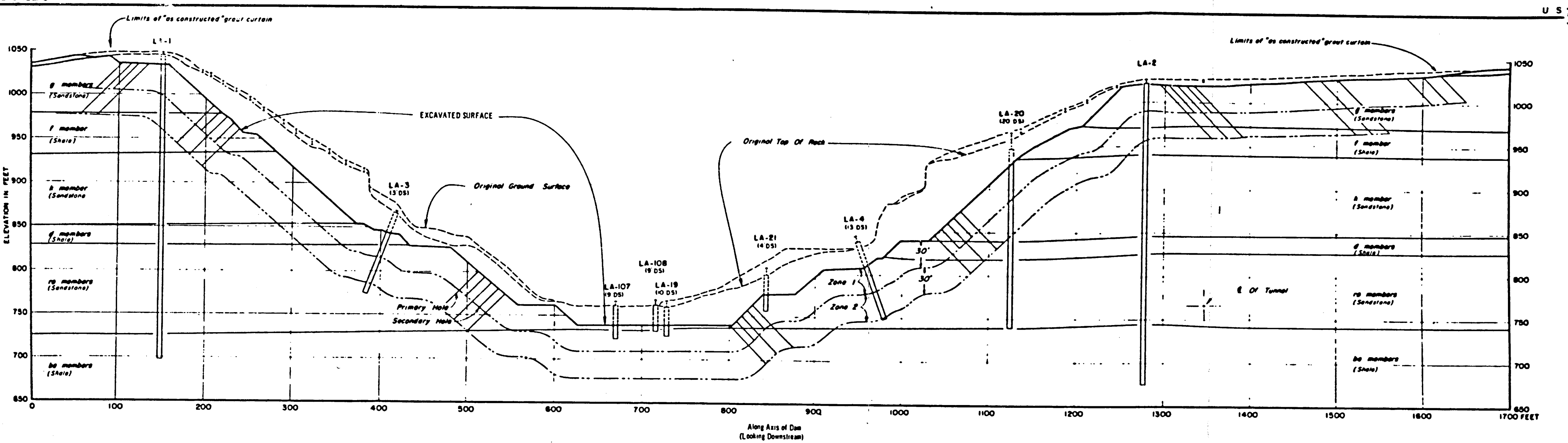
NOTE: Primary holes are located on 20-ft centers.

* Line A is located 5 ft upstream of axis of dam.

** Line B is located 5 ft downstream of axis of dam.


LAUREL
Radius point of dam
Boulders
RIVER
GAGING STATION
EXISTING POWER TUNNEL
EXISTING DIVERSION TUNNEL
Flow
Water line
Approx outline of dam
Axis of dam
SPILLWAY
Excavated to El. 1018.5
INSERT
SEE INSERT
GENERAL NOTES
1. For geologic section along axis see plate 15
2. All elevations refer to mean sea level. The grid ... Kentucky Plane Coordinate System (South zo...
SPECIAL NOTE.
Topography shown on this drawing represents conditions prior to excavations for the emba... foundation
LEGEND
Boring number (prefix "LA" omitted on p...
NXM (2⅛" core) vertical core drill hole
NXM (2⅛" core) angle core drill hole (... indicated by arrow within symbol)
NXM (2⅛" core) horizontal core drill h... directed 'onward'
6" (5⅜" core) vertical core drill hole.
Exploratory Excavation (Approximate locations and limits).
U. S. ARMY ENGINEER DISTRICT, NA...
NASHVILLE, TENNESSEE
CUMBERLAND RIVER
LAUREL RIVER RESERV...
LAUREL RIVER, KEN...
DAM
PLAN OF SUBSURFACE
DATE MAY 1974

CORPS OF ENGINEERS



GENERALIZED GEOLOGIC COLUMN

LOWER PENNSYLVANIAN — LEE FORMATION

MEMBER	BASIC DESCRIPTION
g	Sandstone - with shale partings, stringers and bands
f	Shale - silty
k	Sandstone
d	Shale - silty with coal bed
re	Sandstone Upper Portion - with silty shale interbeds Lower Portion - conglomeratic
be	Shale - silty with coal bed in lower portion

GENERAL NOTES:

1. For location of borings, see Plate 3.
2. Only a limited amount of subsurface information is shown on these sections. For general bedrock member descriptions, see Generalized Geologic Column this plate.
3. The symbol (I) represents probings made with a hand held power auger. The bottom elevation of this symbol represents the lowest level (refusal) that could be obtained at any given location. For the most part, refusal is assumed to be on bedrock. However, a portion of these appear to have refused in the overburden above bedrock as indicated.
4. Geologic member contacts are approximate and are shown for information only.
5. All elevations refer to Mean Sea Level.

Laurel

LEGEND

bnd	band	gvl	gravel	ptg	parting
bky	blocky	h/a	high angle	qtz	quartz
bl	black	hd	hard	rec	recovered
brec	breccia	irr	irregular	sd	sand
brk	broken	l/a	low angle	sdy	sandy
c	coarse	L.C.	lost core	sh	shale
cav	cavity	L.D.W.	lost drill water	sls	siltstone
C.H.	core in hole	ln	lense	sly	silty
cl	clay	lt	light	sl	slightly
cgl	conglomerate	med	medium	sml	small
cont	contact	min	mineralized	so	soft
dk	dark	mod	moderate	ss	sandstone
drl	drilling	nod	nodule	st	stained
D.W.R.	drill water retained	occ	occasional	strg	stringer
f	fine	op	open	styl	stylolite
frac	fracture	pbl	pebble	T.R.	top of rock
frag	fragment	pl	plastic	tr	trace
fri	friable	pla	platy	v	very
gr	gray	pt	paper thin	vert	vertical
gra	grain, grained	prob	probably	w/	with

REVISION	DATE	DESCRIPTION

PLATE I-K2

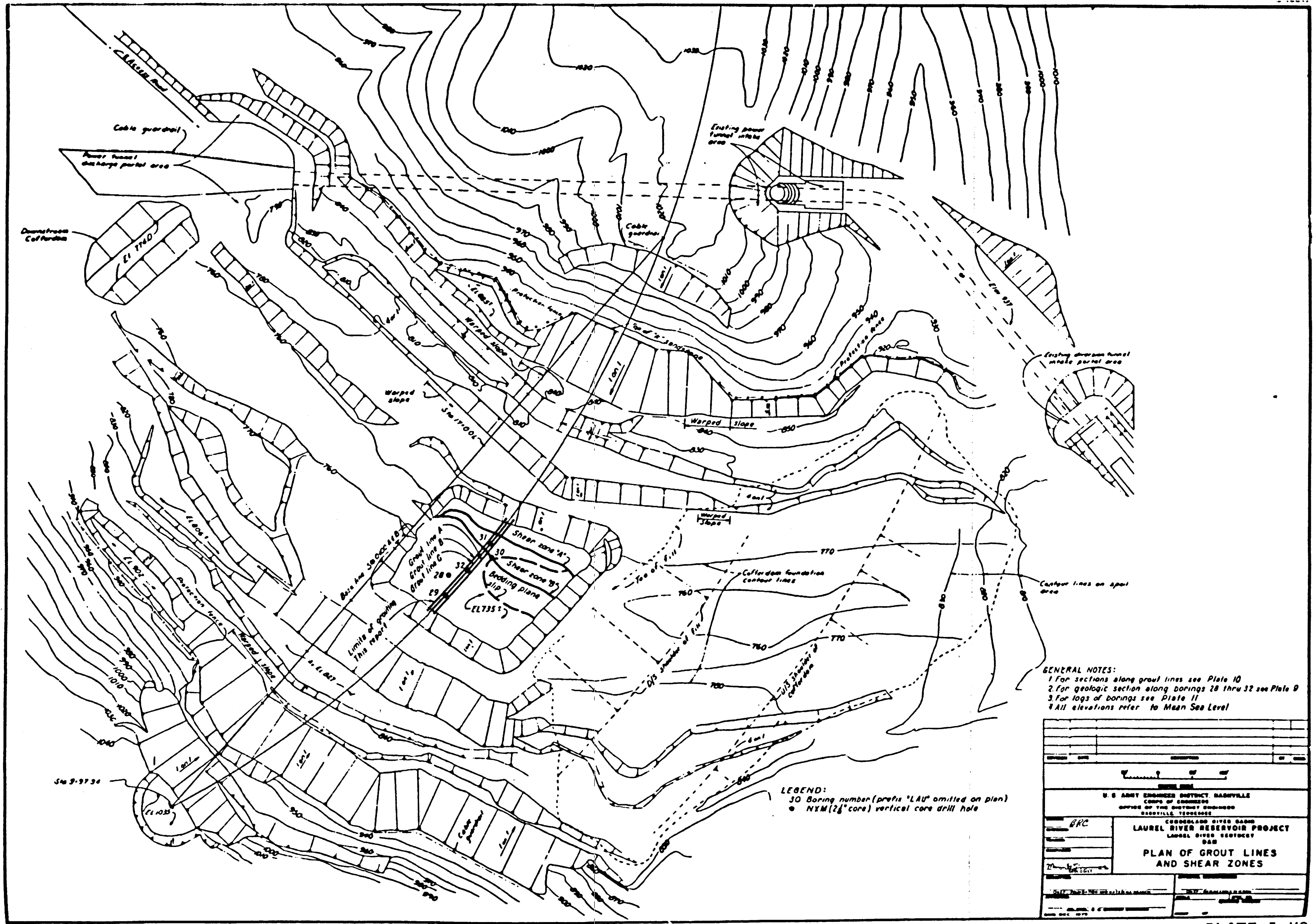
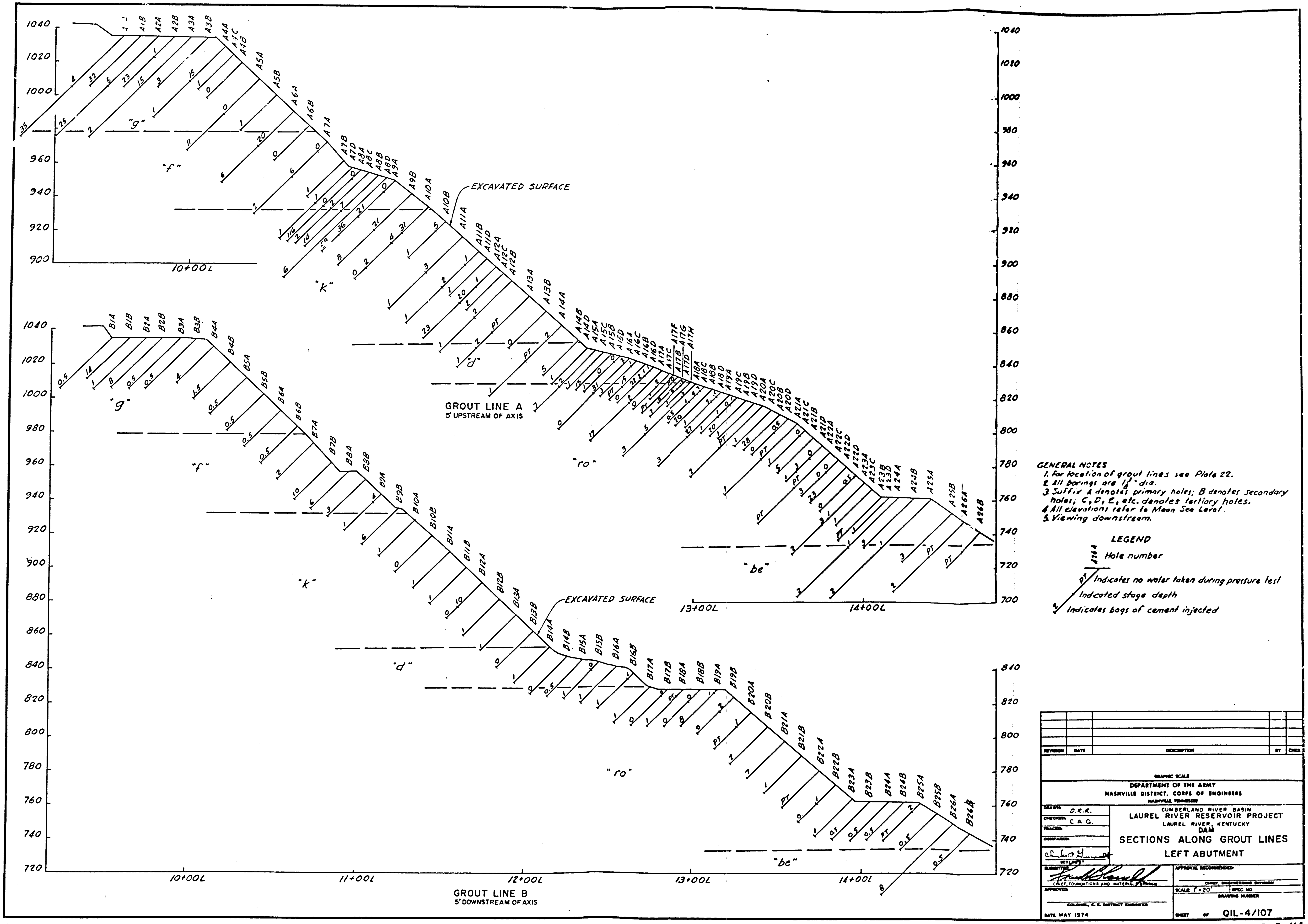
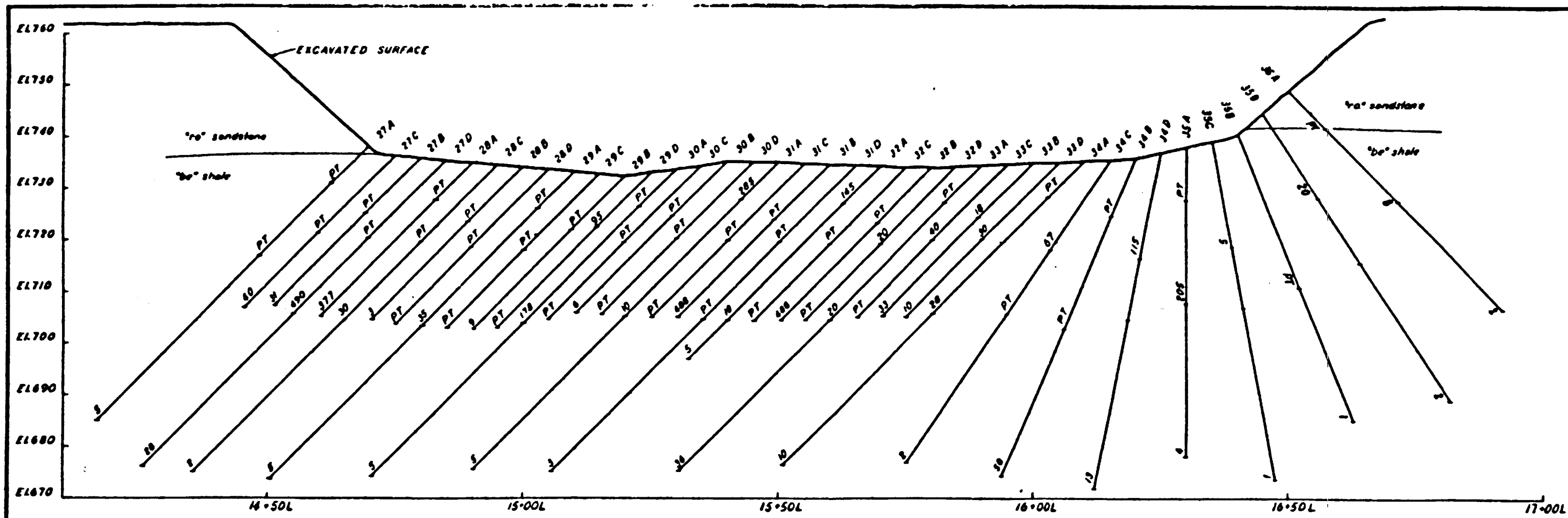

Cable guardrail
Power tunnel discharge portal area
Downstream Cofferdam
Existing power tunnel intake area
Cable guardrail
Protection fence
Warped slope
Existing diversion tunnel intake portal area
Shear zone "A"
Shear zone "B"
Bedding plane slip
EL 735±
Grout line A
Grout line B
Grout line C
Limits of grouting This report
Toe of fill
Cofferdam foundation contour lines
Contour lines on spoil area
D/S shoulder of fill
U/S shoulder of cofferdam
Sta 9+97.34
GENERAL NOTES:
1 For sections along grout lines see Plate 10
2. For geologic section along borings 28 thru 32 see Plate 9
3. For logs of borings see Plate 11
4 All elevations refer to Mean Sea Level
LEGEND:
30 Boring number (prefix "LAU" omitted on plan)
● NXM (2⅛" core) vertical core drill hole
LAUREL RIVER RESERVOIR PROJECT
PLAN OF GROUT LINES
AND SHEAR ZONES

PLATE I-K3

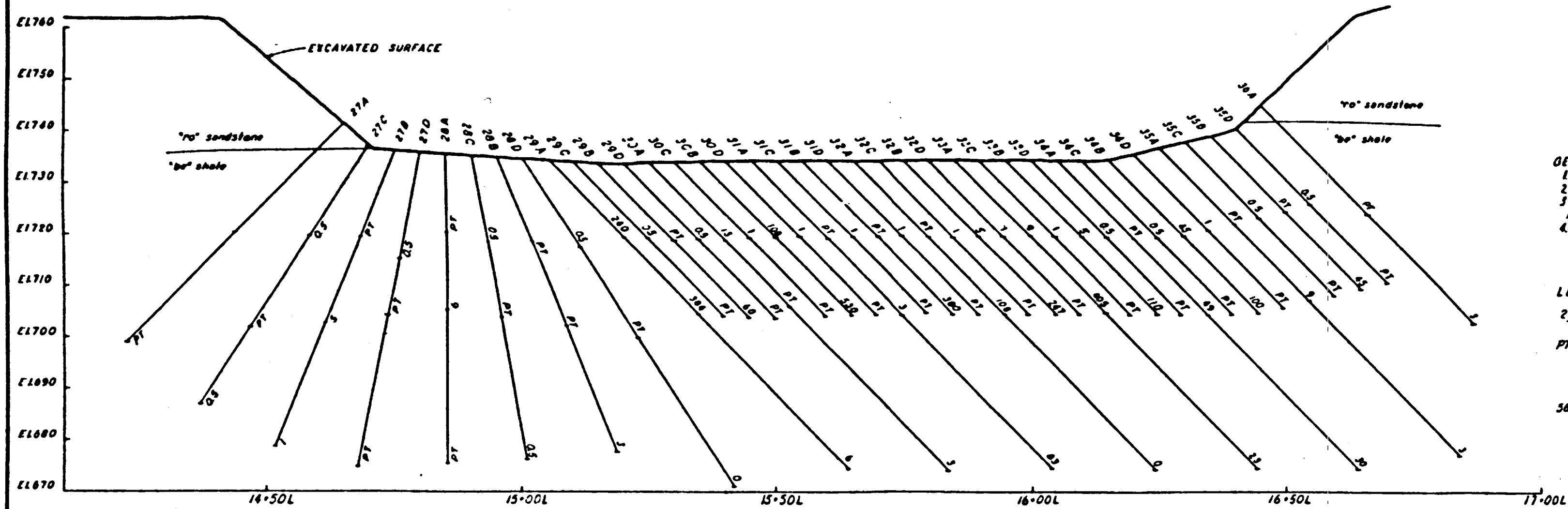


EXCAVATED SURFACE
GROUT LINE A
5' UPSTREAM OF AXIS
10+00L
13+00L
14+00L
"g"
"f"
"k"
"d"
"ro"
"be"
GROUT LINE B
5' DOWNSTREAM OF AXIS
10+00L
11+00L
12+00L
13+00L
14+00L
GENERAL NOTES
1. For location of grout lines see Plate 22.
2. All borings are 1½" dia.
3. Suffix A denotes primary holes; B denotes secondary holes; C, D, E, etc. denotes tertiary holes.
4. All elevations refer to Mean Sea Level.
5. Viewing downstream.
LEGEND
Hole number
Indicates no water taken during pressure test
Indicated stage depth
Indicates bags of cement injected
REVISION
DATE
DESCRIPTION
BY
CHKD.
GRAPHIC SCALE
DEPARTMENT OF THE ARMY
NASHVILLE DISTRICT, CORPS OF ENGINEERS
NASHVILLE, TENNESSEE
CUMBERLAND RIVER BASIN
LAUREL RIVER RESERVOIR PROJECT
LAUREL RIVER, KENTUCKY
DAM
SECTIONS ALONG GROUT LINES
LEFT ABUTMENT
DRAWN: D.R.R.
CHECKED: C.A.G.
TRACED:
COMPARED:
GEOLOGIST
SUBMITTED:
CHIEF, FOUNDATIONS AND MATERIALS BRANCH
APPROVED:
COLONEL, C.E. DISTRICT ENGINEER
APPROVAL RECOMMENDED:
CHIEF, ENGINEERING DIVISION
SCALE: 1"=20'
SPEC. NO.
DRAWING NUMBER
DATE: MAY 1974
SHEET OF
QIL-4/107

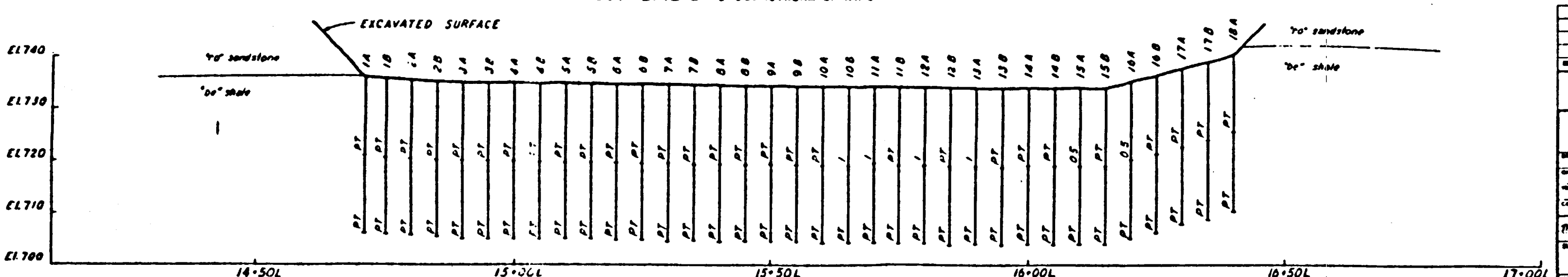
PLATE I-K4



GROUT LINE A 5' UPSTREAM OF AXIS



GROUT LINE B 5' DOWNSTREAM OF AXIS



GROUT LINE C ALONG AXIS

GENERAL NOTES:

1. *For location of grout lines see plate 7*
2. *All borings are 1½" dia.*
3. *Suffix A denotes primary holes; B denotes secondary holes; C & D denotes tertiary holes*
4. *All elevations refer to Mean Sea Level*

LEGEND:

- 27A — *Hole number*
- PT — *Indicates no water take during pressure test*
- *Indicated stage depth*
- 56 — *Indicates bags of cement injected*

U. S. ARMY ENGINEER DISTRICT, NASHVILLE
CORPS OF ENGINEERS
OFFICE OF THE DISTRICT ENGINEER
NASHVILLE, TENNESSEE

CUMBERLAND RIVER BASIN
LAUREL RIVER RESERVOIR PROJECT
LAUREL RIVER, KENTUCKY
DAM
SECTIONS ALONG GROUT LINES
LOOKING DOWNSTREAM

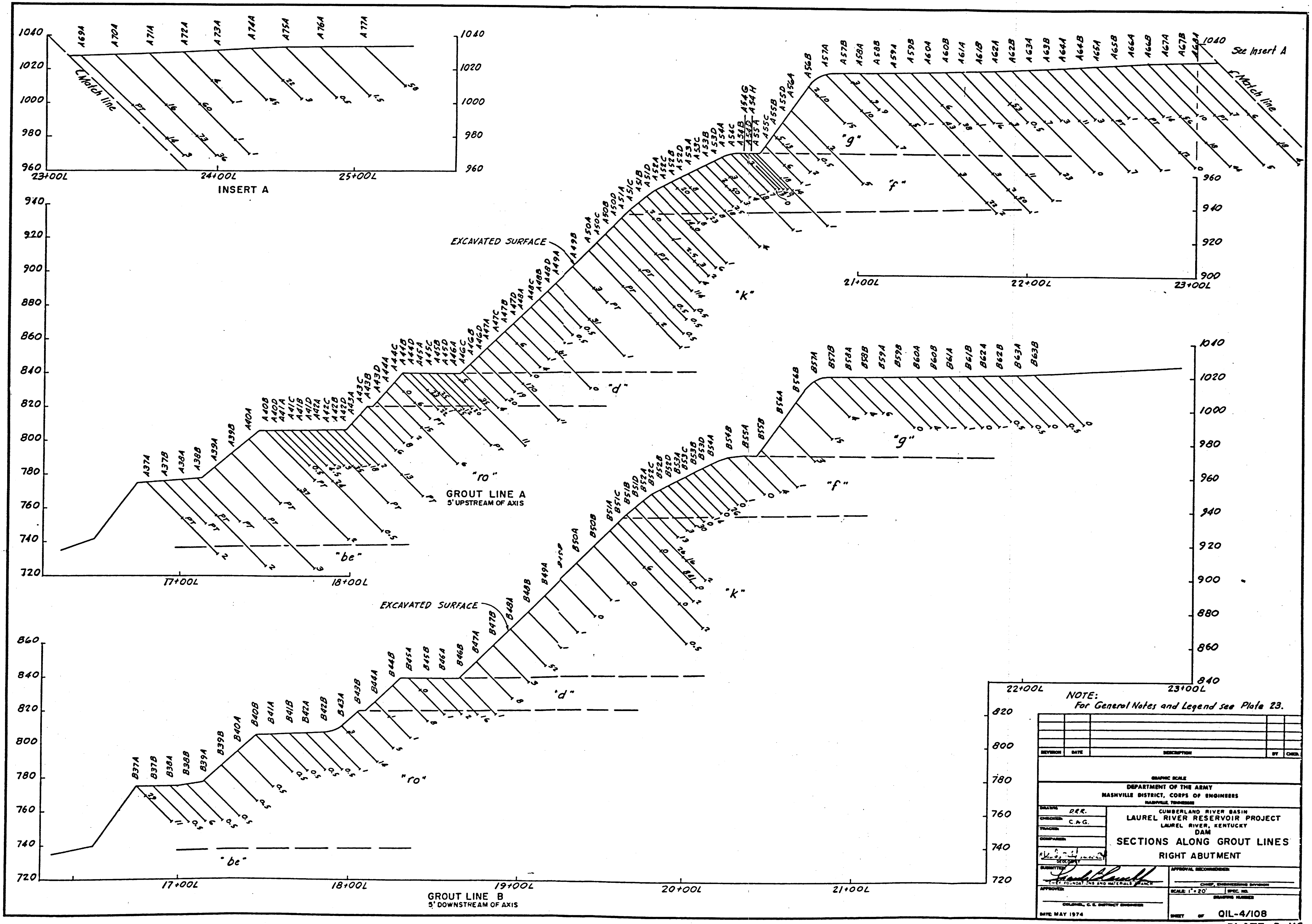

INSERT A
See Insert A
Match line
EXCAVATED SURFACE
GROUT LINE A
5' UPSTREAM OF AXIS
GROUT LINE B
5' DOWNSTREAM OF AXIS
"be"
"ro"
"d"
"k"
"f"
"g"
23+00L
24+00L
25+00L
21+00L
22+00L
17+00L
18+00L
19+00L
20+00L
NOTE:
For General Notes and Legend see Plate 23.
DEPARTMENT OF THE ARMY
NASHVILLE DISTRICT, CORPS OF ENGINEERS
CUMBERLAND RIVER BASIN
LAUREL RIVER RESERVOIR PROJECT
LAUREL RIVER, KENTUCKY
DAM
SECTIONS ALONG GROUT LINES
RIGHT ABUTMENT
DATE MAY 1974
QIL-4/108

PLATE I-K6

PROJECT L: CLARENCE CANNON DAM

(This case history was developed with the assistance of Michael Klosterman, St. Louis District)

Location and Description of Project

L1. The Clarence Cannon Dam is located at mile 63 on the Salt River in northeastern Missouri, approximately 20 miles southwest of Hannibal, Mo. The dam consists of an embankment section tying the left abutment to the concrete dam, and the concrete dam consisting of a left nonoverflow section, powerhouse section, spillway section, and right nonoverflow section. It is a pumped-storage project and has a reregulation dam a few miles downstream from the main dam. Construction of the Clarence Cannon Dam was under the supervision of the St. Louis District. Foundation grouting was accomplished by subcontractors during Phase I construction and Phase II construction, and later by a separate grouting contract awarded in 1979. This case history will only cover the 1979 contract in detail.

Geology

L2. The Clarence Cannon Dam and reservoir are located in the Dissected Till Plains Section of the Central Lowland Physiographic Province. Glacial, karst and valley stress release processes and features contributed to design and construction considerations relevant to grouting. Bedrock formations at the site consist of nearly horizontal, Mississippian limestone and shale. In descending order they are the Burlington and Choteau limestones, Hannibal shale and Louisiana limestone. Pennsylvanian sandstone boulders occur as float on the uplands of the right abutment and Pennsylvanian sediments occur in a filled sink on the right abutment and in other filled sinks in the Burlington and Choteau formations in the region. Upland soils are a mixture of Pennsylvanian or Mississippian residual materials and thin glacial deposits. At the damsite a thin topsoil layer of silt and clay overlies a considerable thickness of residual chert which lies upon and grades into the Burlington limestone. Valley soils are comprised of channel fill and sand, talus, colluvial and alluvial floodplain deposits. During construction the left abutment was found to contain clay-filled joints and several significant solution features which were treated by constructing a concrete cutoff wall above the Hannibal shale through the Choteau and Burlington formations.

Subsurface Investigations

L3. Extensive subsurface investigations were made at the Clarence Cannon damsite prior to award of the Phase I construction contract in 1971 and the Phase II main dam construction contract in 1973. These investigations and related tests were aimed primarily at determining engineering properties of rock foundations for design purposes. The exploration for grout curtain design was not as extensive. Some grouting was included in the Phase I contract and specifications for the complete grout curtain were included in the main dam Phase II contract. During excavation of the left abutment in 1977, large-scale solution cavities were discovered in the Burlington and Choteau limestones (Klosterman, Easterly and Jahren 1982). Additional explorations and evaluation led to redesign of the grout curtain and cutoff trench, and in the installation of a concrete cutoff wall in the abutment. The wall was 12 ft wide at its base and was constructed from the bottom of the cutoff trench to the Hannibal shale (60 ft deep) and extended approximately 185 ft into the left abutment (Plates I-L1 and I-L2). Because of the differing site conditions encountered in the left abutment, design changes, cost escalation, contract changes, and contract management difficulties; grouting under the main dam contract which began in the fall of 1977 was held to a minimum. The contract was terminated for the convenience of the government and a new contract prepared to complete the grouting. Exploration for the new contract included 20 core borings to an average depth of 300 ft along the grout curtain. Six of these were angle holes drilled at angles varying from 30 to 45 deg from vertical. Minimum diameter of the holes was 3 in. See Plate I-L3 for boring locations. All borings were pressure tested in 5-ft increments using straddle packers. Results of the previous contract grouting were included in the plans and specifications. In addition, geophysical investigations were made using cross-hole seismic methods. The seismic measurements and results as well as interpretation were included in the contract.

Grouting Design

General

L4. As specified, the 1979 grouting contract required construction of triple line curtains from dam axis station 20+00 to 25+00 (Reach 5) and from dam axis station 1+35 to Hwy S-JB South station 77+00 (Reach 2), and single line curtains (Reach 4) from dam axis station 25+00 to 30+00 and (Reach 1) from S-JB South station 77+00 to 85+00. Consolidation grouting was required around the existing cutoff wall in the left abutment (Reach 6), and curtain grouting through the right abutment monoliths D-16 and D-17 (Reach 3) (Plate I-L1). A single line grout curtain was also required on the upstream side of the ~~lower gallery utilizing existing holes and split~~ spaced new holes as required (Reach 7) (Plate I-L4). In addition, the contract called for drilling exploratory borings and the drilling of drains on the downstream side of the gallery.

Consolidation grouting

L5. Consolidation grout holes were required on a general 5-ft pattern around the previously constructed cutoff wall to a depth of 10 ft. This resulted in consolidation grouting of the full 40-ft width of the bottom of the cutoff trench with five lines of grout holes (three lines downstream of the 16-ft wide concrete foundation wall and two lines upstream of the wall) (see Plate I-L1).

Curtain grouting

L6. Curtain grouting was required as described in paragraph 4. The gallery curtain beneath the concrete dam extended approximately 60 ft into the Louisiana limestone. The curtain in the abutments and upland areas extended to the top of the Hannibal shale, approximately 100 to 150 ft below the ground surface. Except for reaches 3 and 7, the program consisted of drilling and grouting using the stop grouting, split-spacing method. Primary holes were on 40-ft centers with secondary and tertiary holes mandatory yielding a maximum spacing of 10 ft. Quaternary and higher order holes would be located by the split-spacing method and drilled and grouted in any zone which experienced takes exceeding specified criteria. Where triple lines were required, the downstream line was grouted first, the upstream line second, and the middle line last. The curtain was divided into three zones as shown in Plate I-L1. Gallery grouting was done using a single zone and primary holes on 10-ft spacing. Gallery holes were split spaced if the take per hole exceeded 20 sacks of cement.

Contractual Considerations

Contract

L7. The 1979 grouting contract was a firm fixed-price contract awarded to the lowest responsible bidder. The contractor was Boyles Brothers.

Specification drilling and grouting requirements

L8. Standard rotary-drilling equipment was specified and the use of water or an air-water mixture was required as a circulating medium, except percussion drilling with air was allowed for consolidation drilling. No core was required except for exploratory drilling. The minimum size grout hole was specified as 3 in.

L9. The technical provisions of the drilling and grouting specifications for this job were unique in that they contained not only specifications for drilling and grouting, but information normally furnished the government construction personnel in the form of "in house" instructions to the field. The intent was apparently to reduce the need for having experienced people in the field by providing more detailed plans and specifications. The District felt that because of the geologic information gained from previous grouting, excavation, geophysical investigations, borings and test data, a complete "cookbook" specification could be prepared detailing exact procedures to be used for all phases of grouting including the following: (a) equipment operation, (b) sequence of drilling and grouting, (c) pressure testing, (d) raising and seating the packer, (e) initial hookup, mix and pressure, (f) injection of grout, (g) when and how to change mixtures and pressures, (h) maximum and minimum quantities of grout to be injected of any specific mixture, (i) when to add sand and other admixtures, (j) intermittent grouting, (k) unusual conditions, and (l) reaching refusal (Klosterman, Easterly and Jahren 1982).

L10. Grouting equipment specified allowed either a mechanical or high speed mixer for premixing bentonite, fluidifier and/or accelerator with water and a mechanical grout mixer. A progressing cavity grout pump was required. In addition, a mechanical sump, circulating grout header, expandable packers and such valves, pressure gages, pressure hoses, small tools, and accessories as may be necessary were required.

L11. Grouting materials specified included Portland cement, water, fluidifier, accelerator, bentonite, and sand.

L12. This specification stated that the general program would be as shown in the drawings and described in the technical provisions. The contract general and special provisions were not available for this study. The specifications stated that all pressure grouting operations shall be performed in the presence of and under the direction of the Contracting Officer, who shall determine the actual mixes, pumping rates, and pressures to be used.

L13. The specified range of water-cement ratios was from 6:1 to 0.6:1. Stop grouting, split-spacing procedures were specified and "cookbook" criteria were given for changing water-cement ratios, split spacing, intermittent grouting, etc. Pay items, estimated quantities and prices are shown in Table L1. Table L2 shows contract bid prices and actual quantities.

Contract management

L14. The contractor - Corps relationship for this contract was good. No adversary relationship developed, and a team approach was used at the working level. The only problems were involved with labor relations and contract interpretations. Labor unions in this area required that almost all labor had to be hired locally. Local labor was not experienced in either drilling or grouting and had to be trained by the contractor.

L15. No differing site conditions claims were reported; however, three claims are pending litigation after having been denied by the contracting officer. A time extension of 60 days was allowed for additional gallery grouting.

L16. The uppermost zone in one reach was so weathered that the contractor's driller thought it was overburden and drilled and cased all the holes through the upper zone. The government inspectors did not realize the problem, and it was not caught for several weeks. The upper zone then had to be grouted. This resulted in additional contract costs of $167,000.

L17. Approximately $146,000 was paid to the contractor for casing which he did not remove in accordance with the specifications.

L18. Had qualified, experienced people been in residence and in control of the grouting, in lieu of depending on a "cookbook" specification, the above costs of over $300,000 might have been saved. While the detailed plans and specifications may have been an improvement over normal plans and specifications, they did not justify reducing the requirements for experienced Corps' field personnel to supervise the job (USACE 1984).

Drilling and Grouting Methods

Drilling

L19. All grout holes were 3 in. or larger in diameter and were drilled with rotary drills except percussion drilling was allowed for consolidation grouting. Most of the holes were angle holes drilled 20 deg from vertical. Several holes were lost due to mechanical failure of equipment which could have been prevented with good equipment maintenance.

Washing and pressure testing

L20. Washing and pressure testing were required prior to grouting. Detailed procedures were prescribed in the specifications for pressure testing and grouting the holes in sets of three. The three holes were pressure tested and the lowest take zone of the three was grouted first with packers placed in all three holes. Zones of no water take were not grouted and the packer was moved to the next higher zone until pressure testing indicated the need for grouting.

Grouting mixtures

L21. Water-cement ratios were varied from 6:1 to 0.6:1 as required by the specifications. The criterion for various mixtures were specified.

Grouting pressures

L22. Maximum grouting pressures were specified as follows: Zone 1, 1.5 psi per foot of depth; Zone 2, 1.0 psi per foot of depth and Zone 3, 1.0 psi per foot of depth. The depth of each zone was calculated as the midpoint of the zone.

Field procedures

L23. Stop grouting, split-spacing procedures were used. Details of the field procedures used were not available; however, it is assumed that the detailed procedures specified were generally used. In certain instances, various deviations from design procedures, mixtures, etc., were made. These were attributed to a lack of communication and a complex chain of command among management personnel.

Grout take

L24. Average grout take for the job was moderate. A total of 91,876 lin ft of grout holes were drilled and 50,495 cu ft of grout were placed excluding backfill grout. The average take was 0.55 cu ft per linear foot of grout hole.

Refusal criteria

L25. Refusal was defined in the specifications as takes of 1 cu ft or less of grout over a 10 min period.

Backfilling

L26. All exploratory and grout holes were backfilled using the tremie method and a neat cement grout with water-cement ratio of 1:1.

Records

L27. The contracting officer was responsible for keeping records of all grouting, washing, and pressure testing operations. The contractor was required to furnish driller's logs of grout and exploratory holes.

Unexpected Geological Conditions Encountered During Construction

L28. The 1979 grouting contract documents were prepared after the discovery of unexpected geological conditions in the left abutment and contract delays. No major unexpected geologic conditions were encountered during the grouting contract.

Evaluation of Grouting

L29. Insufficient as-built records were available to evaluate construction of the Clarence Cannon grouting program.

Costs (Drilling Grout Holes and Grouting)*

Government Estimate	$2,597,675
Contractor's Bid	1,847,925
Actual	1,874,327 ($37.12/cu ft)

Performance

L30. Observations will be made by the District to evaluate grout curtain performance during and after reservoir filling. No data are available at this time due to the recent date the project was completed.

* Items No. 3, 4, 5, 9 and 19 in Tables L1 and L2 are excluded from the above totals.

References

Klosterman, Michael J., Easterly, Michael M., and Jahren, Nels G. 1982. Grouting at Clarence Cannon A New Approach: Proceedings, ASCE Specialty Conference "Grouting in Geotechnical Engineering," New Orleans, Published by ASCE, New York.

US Army Corps of Engineers. 1979. Plans and Contract Technical Provisions for Foundation Drilling and Grouting, Clarence Cannon Dam, St. Louis District.

____________. 1984. Grouting Technology, EM 1110-2-3506, Department of the Army, Corps of Engineers, Washington, DC.

Table L1

Government Estimate

Bidding Schedule

Item No.	Description	Quantity	Unit	Unit Price	Estimated Amount
1	Mobilization and demobilization	Sum	job	$160,000	$160,000
2	Environment protection	Sum	job	10,000 (?)	10,000
3	Overburden drilling:				
	a. First 4,100 lin ft	4,100	lin ft	6.00	24,600
	b. All over 4,100 lin ft	3,100	lin ft	6.00	18,600
4	Exploratory hole drilling: Rock, inclined:				
	a. First 1,040 lin ft	1,040	lin ft	25.00	26,000
	b. All over 1,040 lin ft	1,040	lin ft	25.00	26,000
5	Exploratory hole drilling: Rock, vertical:				
	a. First 975 lin ft	975	lin ft	20.00	19,500
	b. All over 975 lin ft	975	lin ft	20.00	19,500
6	Grout hole drilling, rock:				
	a. First 50,100 lin ft	50,100	lin ft	12.00	601,200
	b. All over 50,100 lin ft	33,000	lin ft	12.00	396,000
7	Grout and drain hole drilling: Concrete monoliths:				
	a. First 11,800 lin ft	11,800	lin ft	30.00	354,000
	b. All over 11,800 lin ft	2,350	lin ft	30.00	70,500

(Continued)

Table L1 (Continued)

Item No.	Description	Quantity	Unit	Unit Price	Estimated Amount
8	Consolidation grout hole drilling:				
	a. First 1,950 lin ft	1,950	lin ft	6.00	11,700
	b. All over 1,950 lin ft	500	lin ft	6.00	3,000
9	Redrilling grouted or obstructed holes:				
	a. First 500 lin ft	500	lin ft	6.00	3,000
	b. All over 500 lin ft	800	lin ft	6.00	4,800
10	Casing and nipples left in grout and drain holes:				
	a. First 1,200 lin ft	1,200	lin ft	15.00	18,000
	b. All over 1,200 lin ft	500	lin ft	15.00	7,500
11	Packers left in grout holes:				
	a. First 15 packers	15	ea.	200.00	3,000
	b. All over 15 packers	50	ea.	200.00	10,000
12*	Connections to grout holes:				
	a. First 1,650 connections	1,650	ea.	15.00	24,750
	b. All over 1,650 connections	1,000	ea.	15.00	15,000
13	Portland cement in grout:				
	a. First 15,000 cu ft	15,000	cu ft	5.00	75,000
	b. All over 15,000 cu ft	40,000	cu ft	5.00	200,000
14	Bentonite in grout:				
	a. First 21,000 lb	21,000	lb	0.25	5,250
	b. All over 21,000 lb	55,000	lb	0.25	13,750

(Continued)

Table L1 (Concluded)

Item No.	Description	Quantity	Unit	Unit Price	Estimated Amount
15	Fluidifier in grout:				
	a. First 7,000 lb	7,000	lb	0.60	4,200
	b. All over 7,000 lb	20,000	lb	0.60	12,000
16	Sand in grout:				
	a. First 1,500 cu ft	1,500	cu ft	1.25	1,875
	b. All over 1,500 cu ft	4,000	cu ft	1.25	5,000
17	Pressure testing:				
	a. First 420 hr.	420	hr	210.00	88,200
	b. All over 420 hr.	250	hr	210.00	52,500
18	Placing grout:				
	a. First 16,500 cu ft	16,500	cu ft	8.00	132,000
	b. All over 16,500 cu ft	40,000	cu ft	8.00	320,000
19	Backfill grout:				
	a. First 1,400 cu ft	1,400	cu ft	5.00	7,000
	b. All over 1,400 cu ft	1,100	cu ft	5.00	5,500
	(Low Bid: $2,161,095)		TOTAL - 2,752,175		

* Bid Item 12a and 12b. The unit prices for these items have been established by the Government. Bidders shall not change these prices.

Table L2

Contract Cost - Bid Prices and Actual Quantities

Bidding Schedule

Item No.	Description	Quantity	Unit	Bid Price	Amount
1	Mobilization and demobilization	Sum	job	$ 32,500	$ 32,500
2	Environment protection	Sum	job	10,000	10,000
3	Overburden drilling:				
	a. First 4,100 lin ft	4,100	lin ft	12.50	51,250
	b. All over 4,100 lin ft	13,992	lin ft	12.50	174,900
4	Exploratory hole drilling: Rock inclined:				
	a. First 1,040 lin ft	1,040	lin ft	24.00	24,960
	b. All over 1,040 lin ft	2,717	lin ft	24.00	65,208
5	Exploratory hole drilling:				
	Rock vertical:				
	a. First 975 lin ft	975	lin ft	20.00	19,500
	b. All over 975 lin ft	705	lin ft	20.00	14,100
6	Grout hole drilling, rock:				
	a. First 50,100 lin ft	50,100	lin ft	11.15	558,615
	b. All over 50,100 lin ft	23,975	lin ft	11.15	267,321
7	Grout and drain hole drilling: Concrete monoliths:				
	a. First 11,800 lin ft	11,800	lin ft	15.00	177,000
	b. All over 11,800 lin ft	3,183	lin ft	15.00	47,745

(Continued)

Table L2 (Continued)

Item No.	Description	Quantity	Unit	Bid Price	Amount
8	Consolidation grout hole drilling:				
	a. First 1,950 lin ft	1,950	lin ft	4.50	8,775
	b. All over 1,950 lin ft	868	lin ft	4.50	3,906
9	Redrilling grouted or obstructed holes:				
	a. First 500 lin ft	500	lin ft	10.00	5,000
	b. All over 500 lin ft	60	lin ft	10.00	600
10	Casing and nipples left in grout and drain holes:				
	a. First 1,200 lin ft	1,200	lin ft	12.00	14,400
	b. All over 1,200 lin ft	12,715	lin ft	12.00	152,580
11	Packers left in grout holes				
	a. First 15 packers	8	ea.	100.00	800
	b. All over 15 packers	0	ea.	100.00	0
12*	Connections to grout holes:				
	a. First 1,650 connections	1,650	ea.	15.00	24,750
	b. All over 1,650 connections	459	ea.	15.00	6,885
13	Portland cement in grout:				
	a. First 15,000 cu ft	15,000	cu ft	4.40	66,000
	b. All over 15,000 cu ft	33,332	cu ft	4.40	146,660

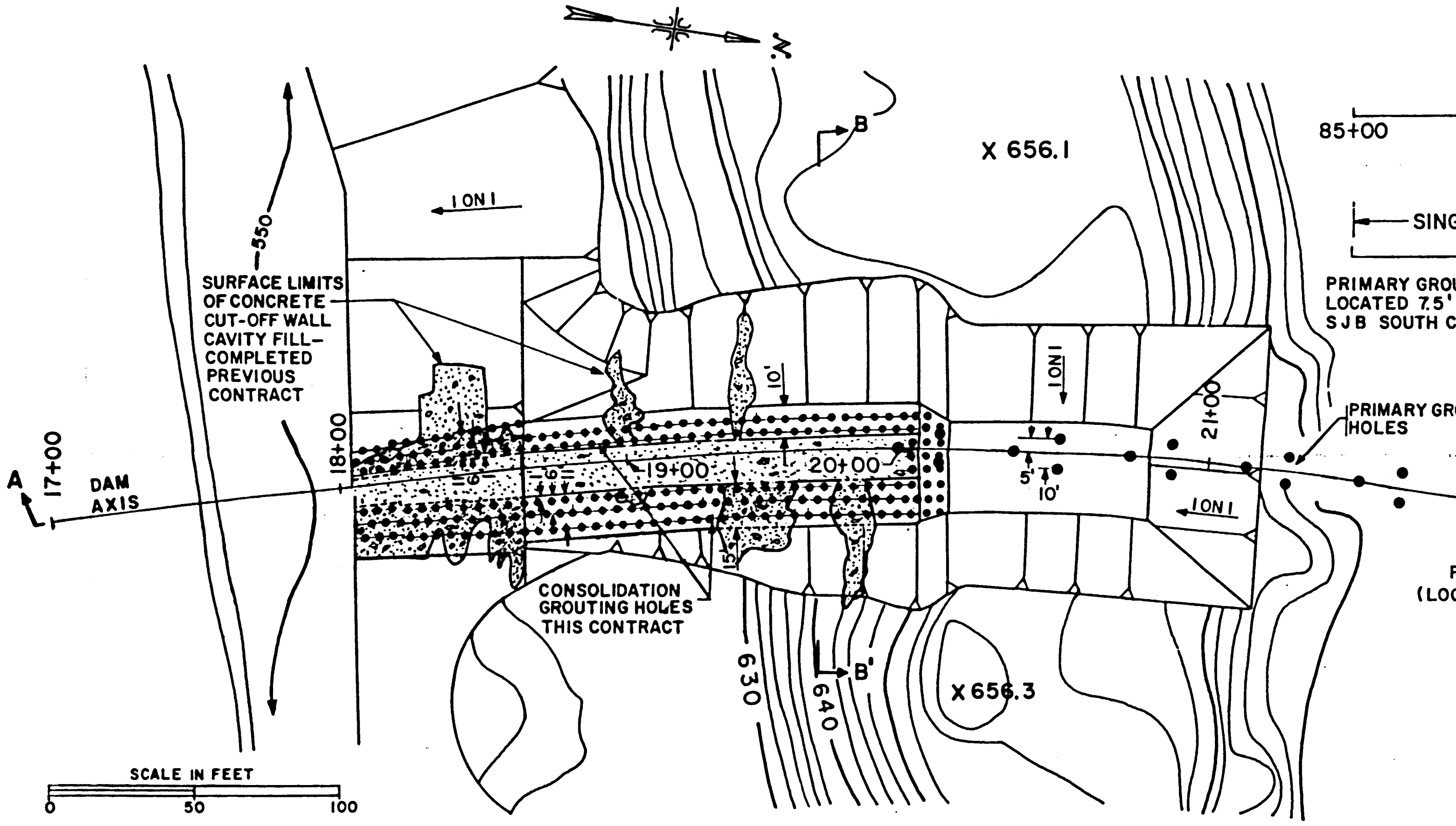
(Continued)

Table L2 (Concluded)

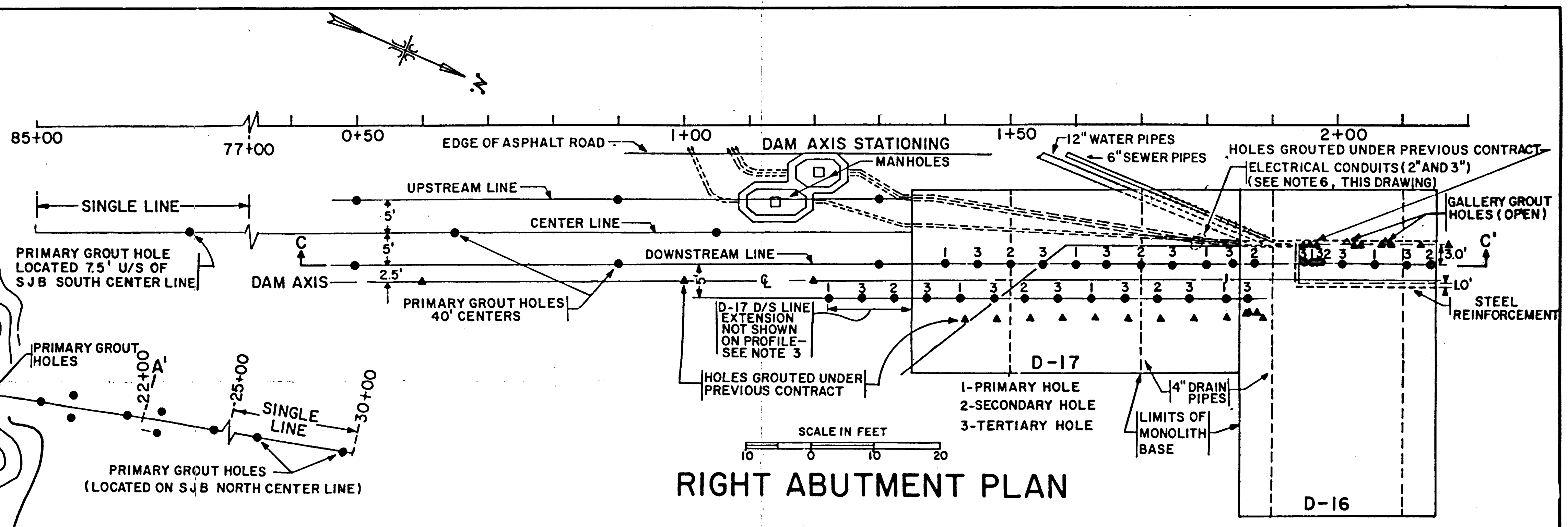
Item No.	Description	Quantity	Unit	Bid Price	Amount
14	Bentonite in grout:				
	a. First 21,000 lb	7,327	lb	0.07	513
	b. All over 21,000 lb	0	lb	0.07	0
15	Fluidifier in grout:				
	a. First 7,000 lb	7,000	lb	0.70	4,900
	b. All over 7,000 lb	9,120	lb	0.70	6,384
16	Sand in grout:				
	a. First 1,500 cu ft	1,159	cu ft	2.30	2,666
	b. All over 1,500 cu ft	0	cu ft	4.00	0
17	Pressure testing:				
	a. First 420 hr	324	hr	117.00	37,908
	b. All over 420 hr	0	hr	117.00	0
18	Placing grout:				
	a. First 16,500 cu ft	16,500	cu ft	5.75	195,875
	b. All over 16,500 cu ft	33,995	cu ft	5.75	195,471
19	Backfill grout:				
	a. First 1,400 cu ft	1,400	cu ft	8.50	11,900
	b. All over 1,400 cu ft	4,812	cu ft	8.50	40,902
			ACTUAL - 2,282,647		

(See NOTES on BS-4)

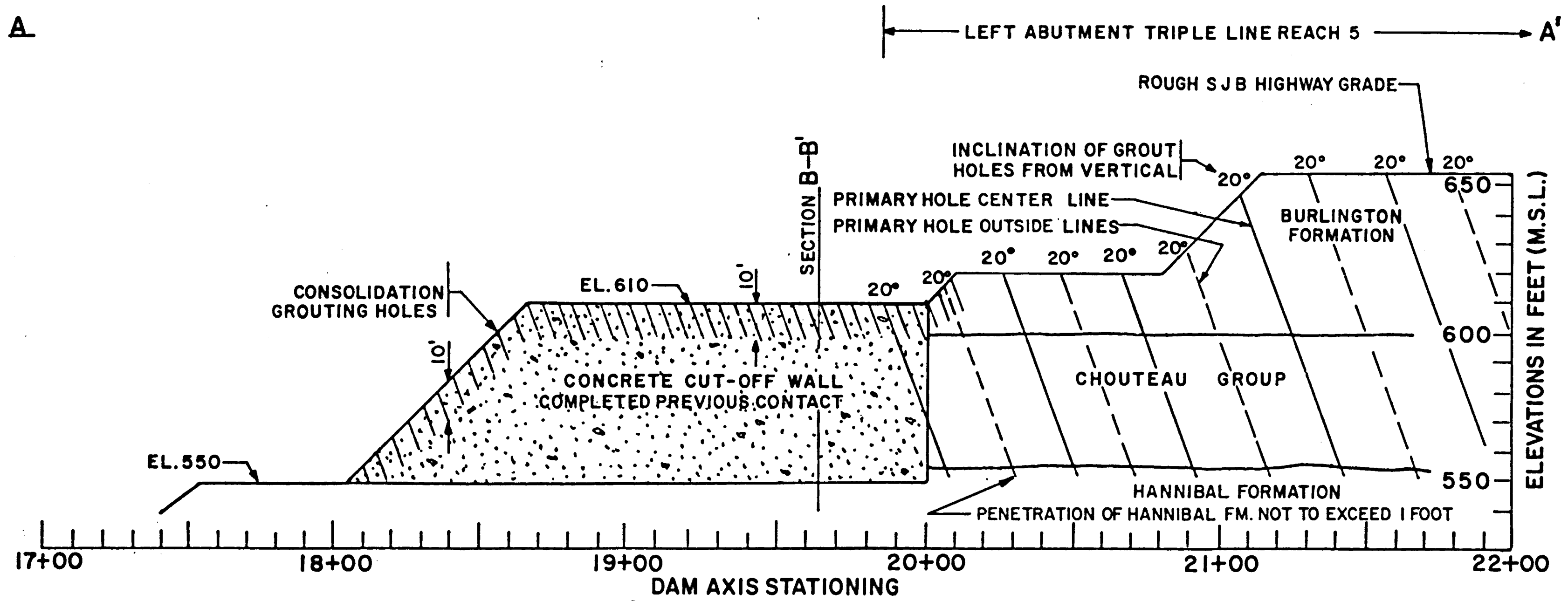
* Bid Item 12a and 12b. The unit prices for these items have been established by the Government. Bidders shall not change these prices.



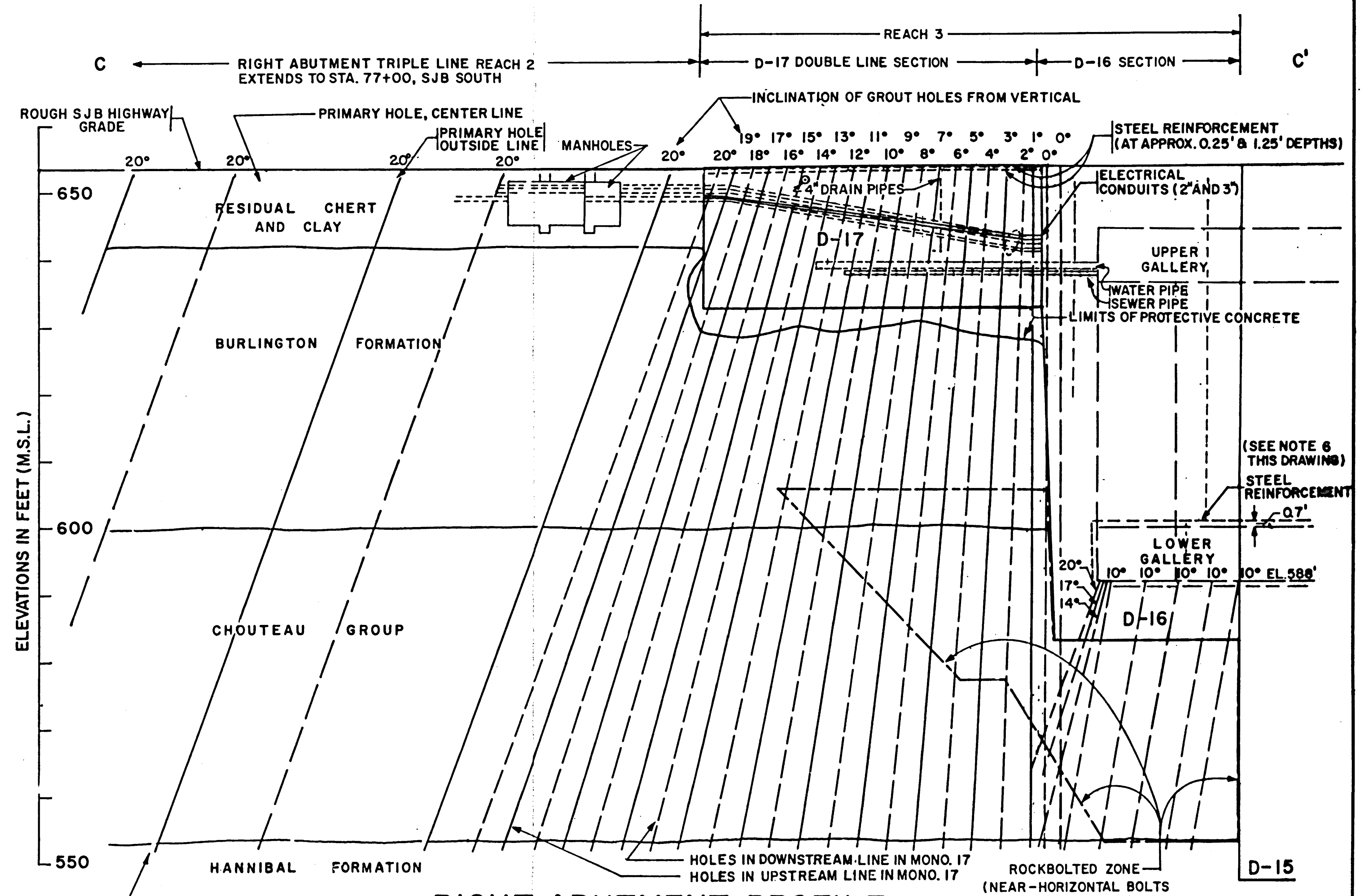
LEFT ABUTMENT PLAN



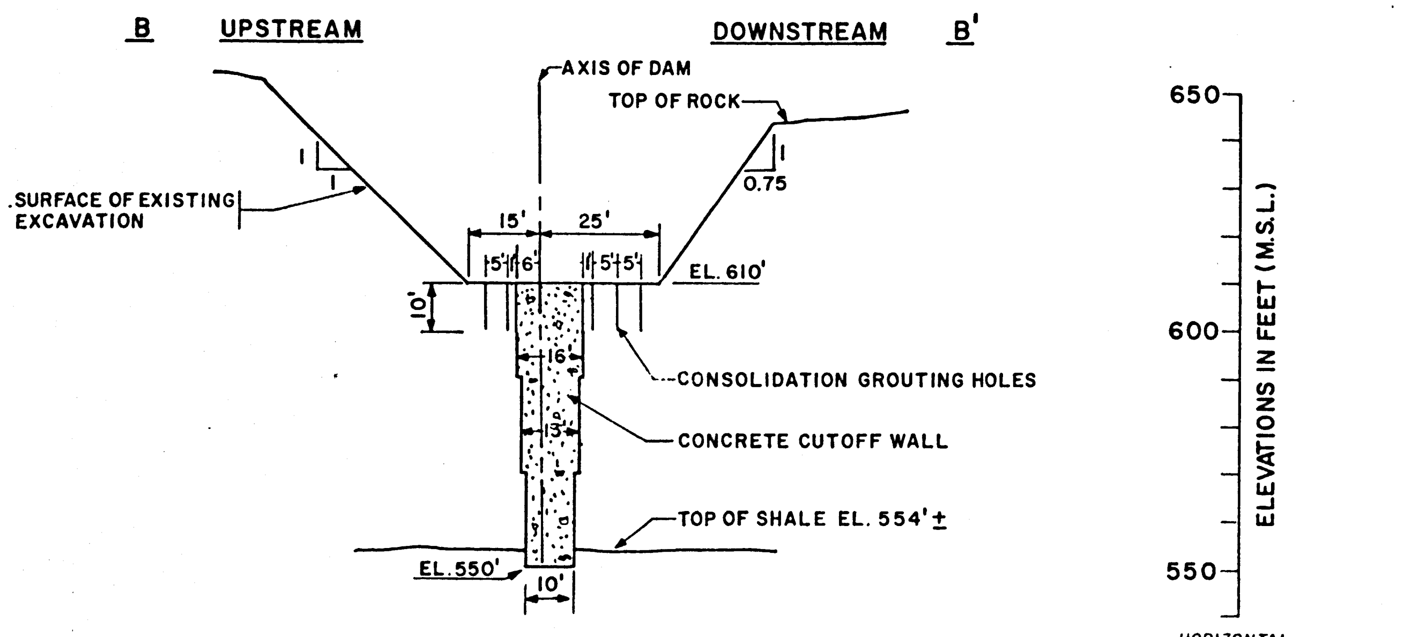
RIGHT ABUTMENT PLAN



LEFT ABUTMENT PROFILE



RIGHT ABUTMENT PROFILE



TYPICAL SECTION LEFT ABUTMENT (19+65)

NOTES:

1. THE CURTAIN GROUTING HOLES BELOW D-16 AND D-17 SHALL BE DRILLED IN THE VERTICAL PLANE OF THE DAM AXIS AT THE ANGLES FROM VERTICAL AS SHOWN ON THE RIGHT ABUTMENT PROFILE. IN GENERAL ALL OTHER CURTAIN GROUTING HOLES SHALL BE DRILLED AT AN ANGLE OF 20° FROM VERTICAL, LANDWARD, PARALLEL TO THE DAM OR HIGHWAY CENTERLINE AT THE HOLE LOCATION.
2. ONLY PRIMARY HOLES ARE SHOWN IN THE TRIPLE LINES; HOWEVER ALL PRIMARY, SECONDARY, AND TERTIARY HOLES ARE SHOWN IN THE D-16 AND D-17 SECTIONS, AND THE RESPECTIVE ANGLES AND ORDERS ARE ALSO SHOWN. IF FOUNDATION CONDITIONS INDICATE THE NEED FOR ADDITIONAL GROUTING IN D-16 AND D-17, THE CONTRACTING OFFICER WILL DIRECT THE DRILLING AND GROUTING OF HIGHER ORDER HOLES AT VARYING ANGLES AND LOCATIONS.
3. D-17 D/S LINE EXTENSION HOLES WILL BE INCLINED 20° FROM VERTICAL.
4. FOR LOCATION OF U/S GALLERY GROUT HOLES SHOWN AS ▲, SEE DRAWING S-CC 17/28.
5. BOTH CURTAIN AND CONSOLIDATION GROUT HOLES WILL BE DRILLED ON IRREGULAR 1 ON 1 ROCK SLOPES AS INDICATED ON THE LEFT ABUTMENT PLAN AND PROFILE.
6. FOR DETAILS OF CONDUIT LOCATIONS AND REINFORCEMENT DETAILS SEE DRAWINGS AVAILABLE IN THE DISTRICT OFFICE.

SYMBOL	DESCRIPTION	DATE	APPROVED

REVISIONS

DRAWN BY: F.W.P., M.L.D.
TRACED BY: J.M.N.
CHECKED BY: M.M.E., S.S.P.
DATE: 28 MAY 1979

SUBMITTED [signature] CHIEF SOILS SECTION
APPROVED [signature] CHIEF, FOUNDATIONS & MATERIALS BR.
APPROVED FOR THE DIST. ENGR. [signature] Act. CHIEF, ENGINEERING DIVISION

U. S. ARMY ENGINEER DISTRICT, ST. LOUIS
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

UPPER MISSISSIPPI RIVER BASIN
SALT RIVER, MISSOURI

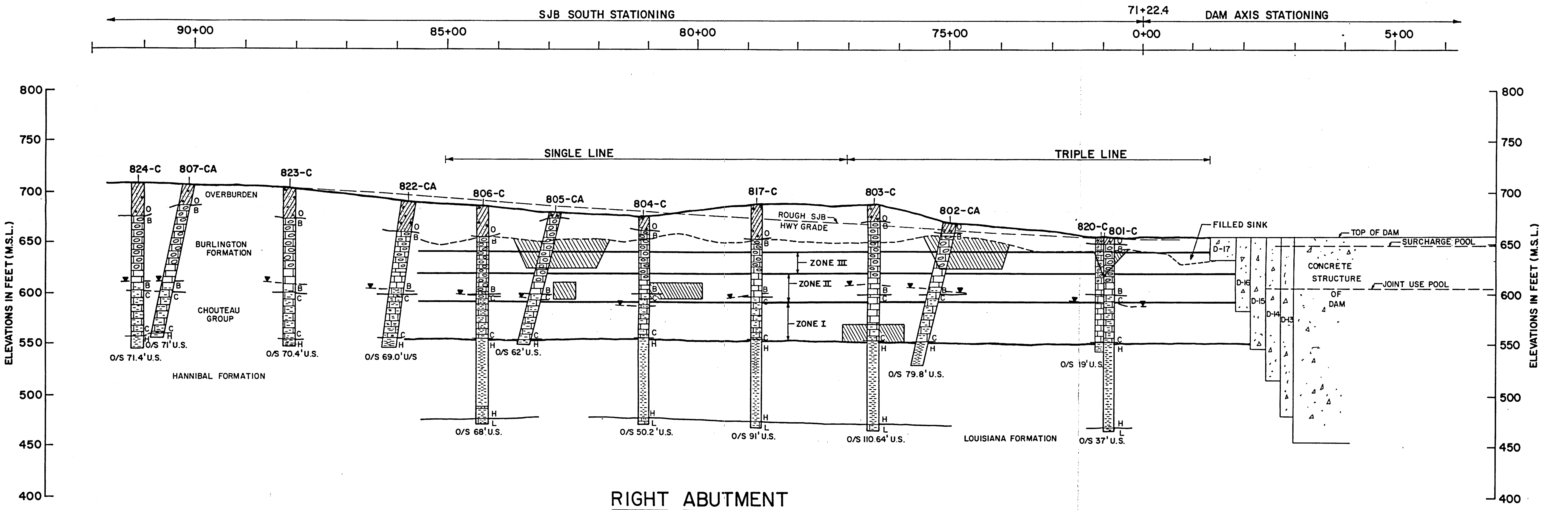
CLARENCE CANNON RESERVOIR
DRILLING AND GROUTING

ABUTMENTS
PLANS AND PROFILES

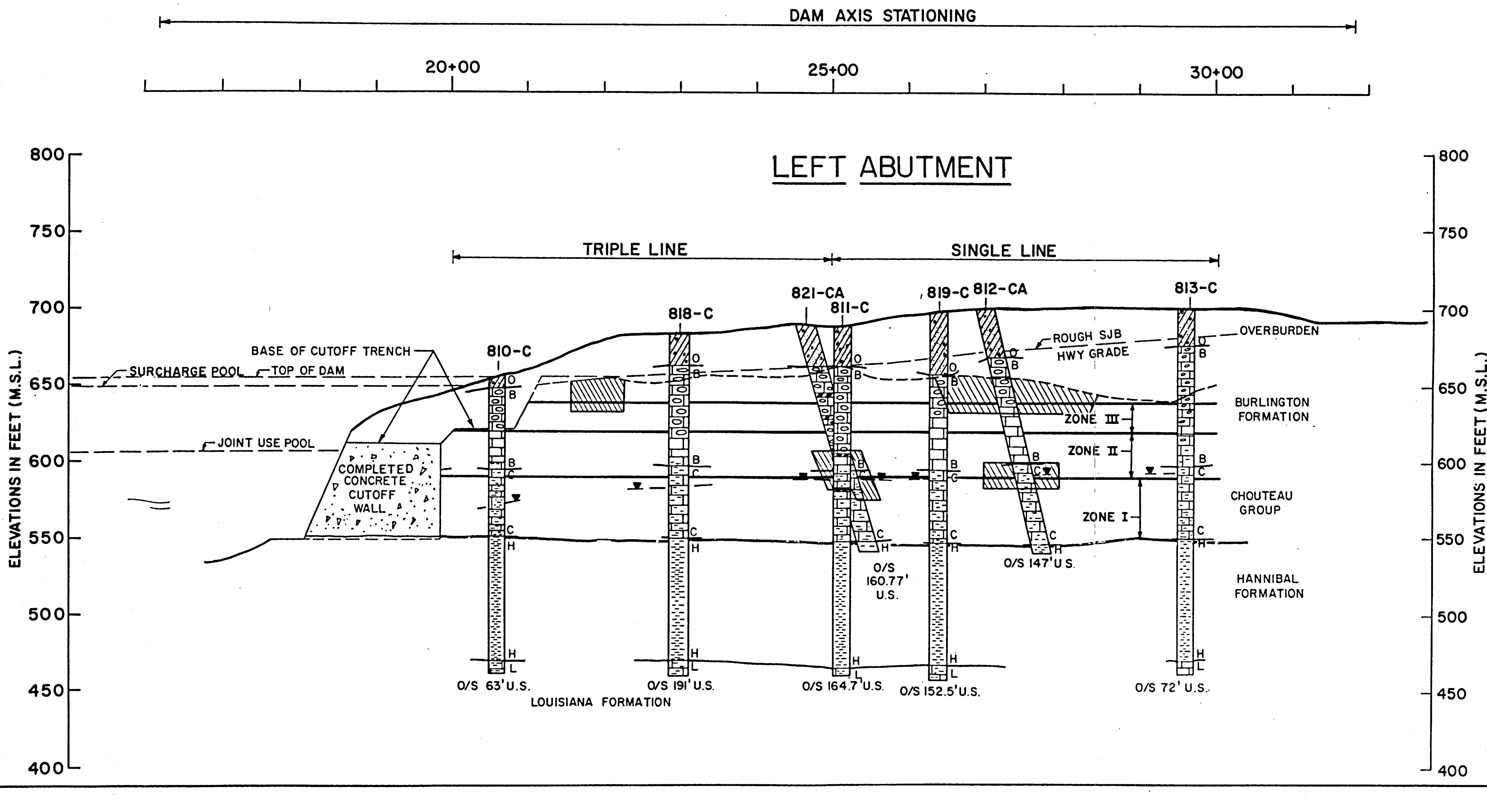
SIZE	CODE IDENT. NO.	DRAWING NO.
F	DACW 43	S-CC 17/27

SCALE AS SHOWN | INV. NO. DACW 43 -79-B-0052 | SHEET 2 OF 6

PLATE I-L1



RIGHT ABUTMENT



LEFT ABUTMENT

LEGEND

- O/B OVERBURDEN - BURLINGTON FM. CONTACT
- SEISMICALLY DETERMINED TOP OF FIRM ROCK
- B/C BURLINGTON FM. - CHOUTEAU GP. CONTACT
- APPROXIMATE GROUNDWATER LEVEL
- C/H CHOUTEAU GROUP - HANNIBAL FM. CONTACT
- H/L HANNIBAL FM. - LOUISIANA FM. CONTACT

- CLAY
- SAND
- GRAVEL, COBBLES, BOULDERS
- LIMESTONE
- CHERTY LIMESTONE
- SHALE
- CLAY FILLED VOID
- LOW VELOCITY SEISMIC ANOMALIES - INDICATING ROCK VOLUMES OF POTENTIALLY GREATER GROUT TAKES THAN AVERAGE (EVALUATED ALONG A LINE OF EXPLORATION DRILLING).

NOTES

1. BORINGS ON THIS PROFILE ARE OFFSET FROM THE GROUTING AXIS, CONSEQUENTLY, CONSIDERABLE VARIATIONS FROM THE TOP OF ROCK SHOWN ALONG THE EXPLORATION LINE SHOULD BE EXPECTED.
2. THE TOP OF ROCK AND STRATIGRAPHIC UNIT CONTACTS ARE KNOWN AT THE BORINGS; THESE CONTACTS HAVE BEEN PROJECTED, WHERE SHOWN, BY GEOPHYSICS.
3. THE WATER TABLE MAY BE EXPECTED TO FLUCTUATE SEASONALLY FROM THE READINGS TAKEN DURING DRILLING AND SHOWN ON THE BORINGS.
4. FOR BORING LOCATIONS, SEE DRAWING S-CC 1/33
5. FOR BORING LOG SUMMARIES, SEE DRAWINGS S-CC 98/227-237
6. THIS PROFILE WAS DEVELOPED USING ALL BORINGS TAKEN FOR THIS PROJECT AND OTHER GEOLOGIC REPORTS AND DATA. THE ORIGINAL BORING LOGS AND REPORTS ARE AVAILABLE FOR INSPECTION AND REPRODUCTION AS NOTED IN THE SPECIFICATIONS.
7. THE VERTICAL ZONES SHOWN ON THIS DRAWING REPRESENT PACKER SETTING ELEVATIONS FOR CURTAIN GROUTING. SEE SPECIFICATIONS FOR A DETAILED DEFINITION OF "ZONE".
8. ALL BORINGS ON THIS PROFILE WILL BE BACKFILLED AS WELL AS 808, 809, 814, 815 AND 816 AS SHOWN ON DRAWING

HORIZONTAL — SCALE IN FEET: 80 40 0 80 160

VERTICAL — SCALE IN FEET: 40 20 0 40 80

VERTICAL EXAGGERATION 1:2

SYMBOL	DESCRIPTION	DATE	APPROVED
	REVISIONS		

DRAWN BY: S.S.P.
TRACED BY: G.R.J.
CHECKED BY: M.M.E.
DATE: 28 MAY 1979

U. S. ARMY ENGINEER DISTRICT, ST. LOUIS
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

UPPER MISSISSIPPI RIVER BASIN
SALT RIVER, MISSOURI

CLARENCE CANNON RESERVOIR
DRILLING AND GROUTING

GEOLOGIC PROFILE

SUBMITTED: [signature] HEAD GEOLOGY SECTION
APPROVED: [signature] CHIEF, FOUNDATIONS & MATERIALS BR.
APPROVED FOR THE DIST. ENGR.: [signature] CHIEF, ENGINEERING DIVISION

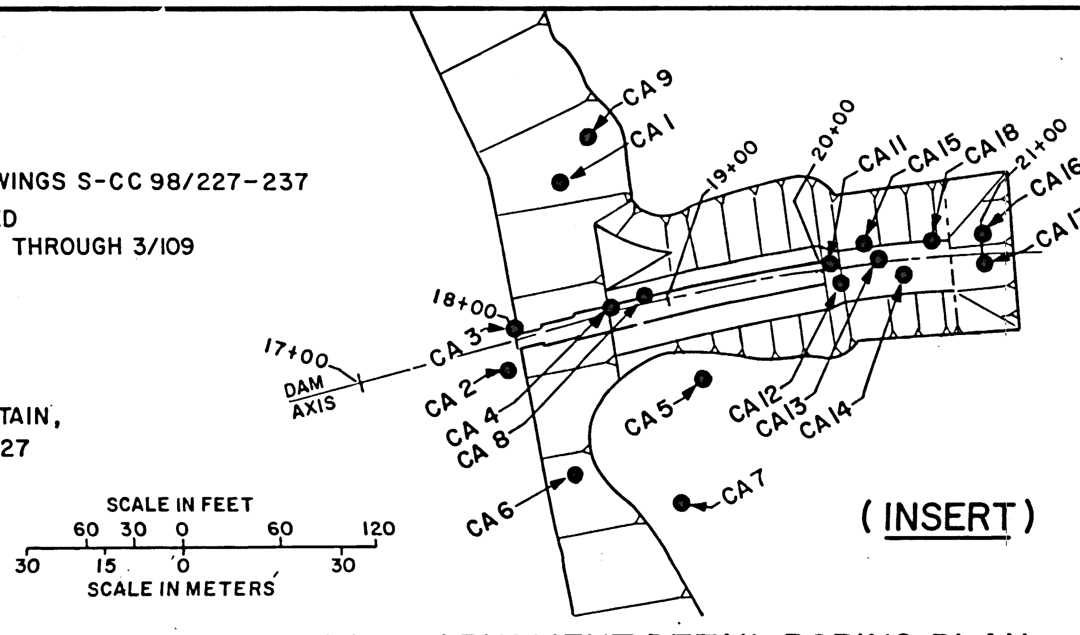
SIZE	CODE IDENT. NO.	DRAWING NO.
F	DACW 43	S-CC 17/26

SCALE AS SHOWN | INV. NO. DACW 43-78-B-0052 | SHEET 1 OF 6

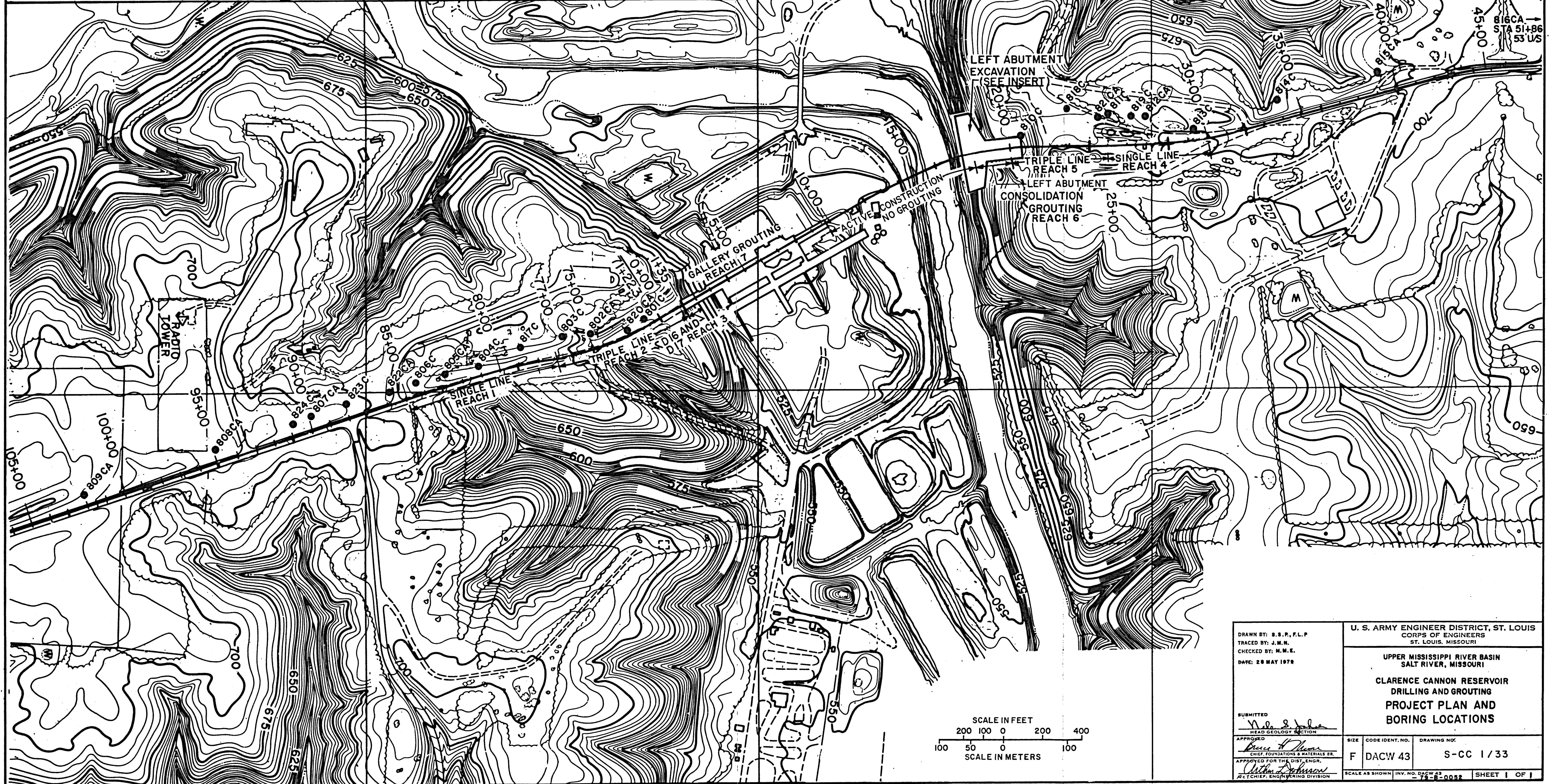
PLATE I-L2

NOTES

1. FOR PROFILES OF BORINGS SHOWN ON THIS PLAN, SEE DRAWINGS S-CC 98/227-237
2. FOR LOCATIONS AND PROFILES OF ALL PREVIOUSLY DRILLED PROJECT BORINGS, SEE REFERENCE DRAWINGS S-CC 3/69 THROUGH 3/109
3. FOR D16 AND D17 AND LEFT ABUTMENT CONSOLIDATION GROUTING DETAILS, SEE DRAWINGS S-CC 17/27
4. FOR GALLERY GROUTING AND DRAIN HOLE DETAILS, SEE DRAWINGS S-CC 17/28 AND 17/29
5. FOR DETAILS OF TRIPLE AND SINGLE LINE GROUT CURTAIN, LEFT AND RIGHT ABUTMENTS, SEE DRAWING S-CC 17/27



LEFT ABUTMENT DETAIL BORING PLAN



U. S. ARMY ENGINEER DISTRICT, ST. LOUIS
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

DRAWN BY: S.S.P., F.L.P
TRACED BY: J.M.N.
CHECKED BY: M.M.E.
DATE: 29 MAY 1979

UPPER MISSISSIPPI RIVER BASIN
SALT RIVER, MISSOURI

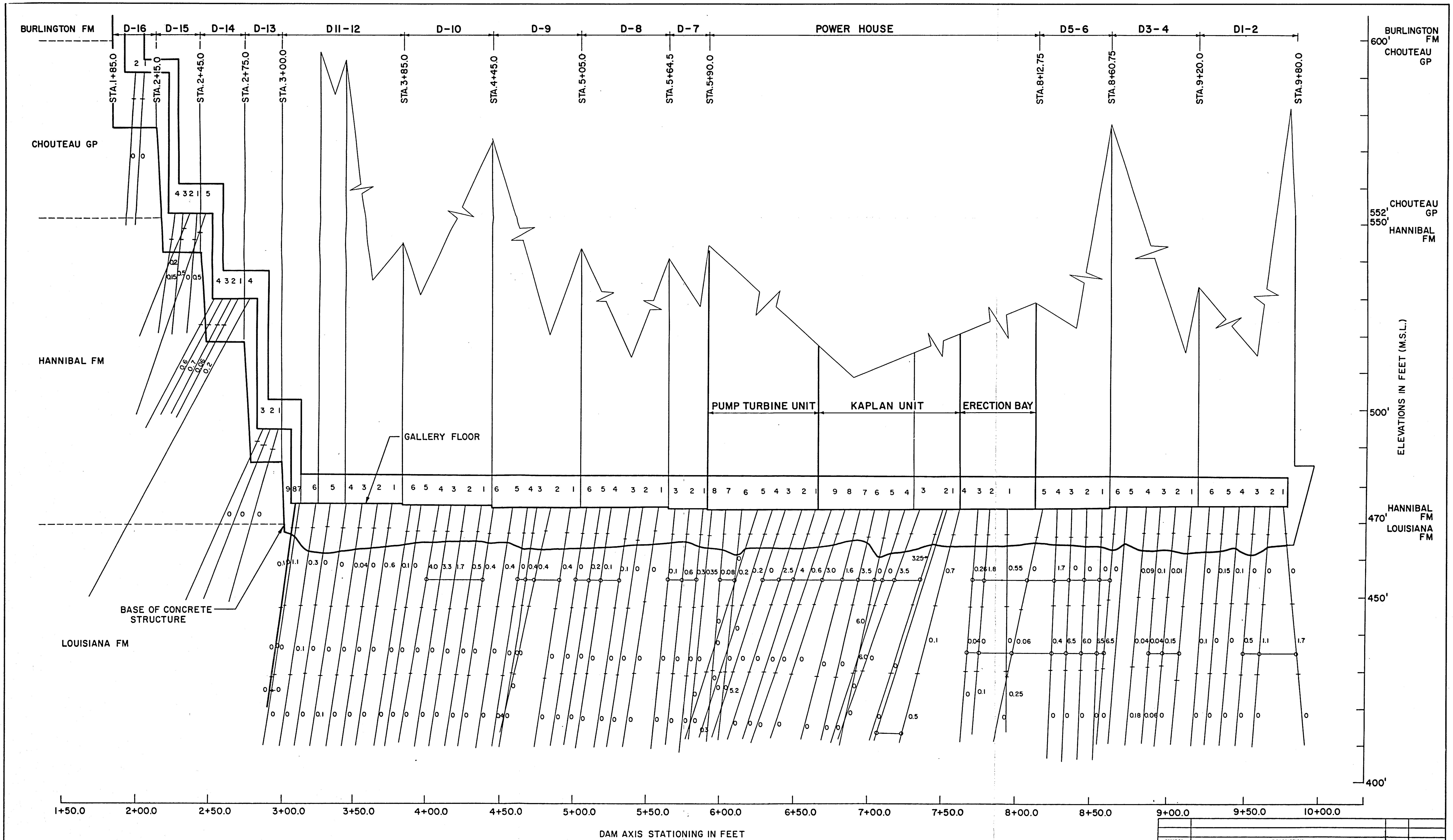
CLARENCE CANNON RESERVOIR
DRILLING AND GROUTING

PROJECT PLAN AND BORING LOCATIONS

SUBMITTED
HEAD GEOLOGY SECTION
APPROVED
CHIEF, FOUNDATIONS & MATERIALS BR.
APPROVED FOR THE DIST. ENGR.
ACT CHIEF, ENGINEERING DIVISION

SIZE	CODE IDENT. NO.	DRAWING NO.
F	DACW 43	S-CC 1/33
SCALE AS SHOWN	INV. NO. DACW 43 - 79-B-0052	SHEET 1 OF 1

PLATE I-L3



HORIZONTAL SCALE — SCALE IN FEET — 25 0 25 50

VERTICAL SCALE — 10 0 10 20

VERTICAL EXAGGERATION 1:2.5

NOTES

1. THE EXISTING HOLES IN D13 AND D15 WILL NOT BE GROUTED, HOWEVER REDRILLING MAY BE REQUIRED AFTER THE GALLERY GROUTING IS COMPLETED.
2. THE ORIENTATION OF SPLIT SPACED GROUT HOLES IN THE GALLERY WILL BE SIMILAR TO THAT OF THE ADJACENT HOLES.
3. NUMBERS NEXT TO HOLE INDICATE PRESSURE TEST RESULTS FOR MARKED ZONES IN CUBIC FEET PER MINUTE.
4. ALL HOLES SHOWN WILL BE GROUTED ACCORDING TO THE SPECIFICATIONS EXCEPT THOSE IN D-13 AND D-15.
5. HORIZONTAL LINES CONNECTING GROUT HOLES INDICATE COMMUNICATION BETWEEN THE HOLES DURING PRESSURE TESTING.

SYMBOL	DESCRIPTION	DATE	APPROVED
	REVISIONS		

DRAWN BY: J.P.L., M.L.D., K.L.L.
TRACED BY: S.R.J.
CHECKED BY: S.S.P., M.M.E.
DATE: 28 MAY 1979

SUBMITTED
HEAD GEOLOGY SECTION
APPROVED
CHIEF, FOUNDATIONS & MATERIALS BR.
APPROVED FOR THE DIST. ENGR.
CHIEF, ENGINEERING DIVISION

U. S. ARMY ENGINEER DISTRICT, ST. LOUIS
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI

UPPER MISSISSIPPI RIVER BASIN
SALT RIVER, MISSOURI

CLARENCE CANNON RESERVOIR

EXISTING GALLERY
GROUT/DRAIN
HOLES PROFILE

SIZE F | CODE IDENT. NO. DACW 43 | DRAWING NO. S-CC 17/28

SCALE AS SHOWN | INV. NO. DACW 43-79-8-0052 | SHEET 3 OF 6

PROJECT M: WOLF CREEK DAM

(This case history was developed with the assistance of Marvin Simmons, Wayne Swartz, and John Stanton, Nashville District)

General

M1. The dam is located in Russell County in southeastern Kentucky on the Cumberland River 460.9 miles above its confluence with the Ohio River (USACE 1975). The site is approximately 10 miles southwest of Jamestown, Ky., and about 12 miles north of Albany, Ky. The dam is a combination concrete gravity and earthfill structure and contains power intakes and a powerhouse. It was designed and constructed by the US Army Corps of Engineers during a period from 1938 to 1952. Construction was delayed from 1943 to 1947 due to the war effort. The Cumberland valley has been deeply incised into the nearly level argillaceous or shaly limestones and shales in the area. The formations at the site in ascending order include the Catheys, Lepors, and Cumberland of Ordovician age, the Chattanooga of Devonian age, and the Ft. Payne of Mississippian age. The Lepers and Catheys formation underlie the valley and are quite susceptible to solutioning. The underlying cannon formation is also susceptible to solution activity, but from investigations it was determined that most of the karstic activity stopped at the contact with the upper Catheys. During the initial construction a single line grout curtain was constructed. It consisted of 32,671 ft of drilling and 20,387 cu ft of cement for an average take of 0.6 cu ft/lin ft. The project operated satisfactory for 15 years before seepage was first noticed in August 1967, followed by muddy flow on two occasions in October 1967 and January 1968 (Simmons 1982). A sinkhole developed downstream of the embankment toe in March 1968. Investigations which began after the first seepage was noted and expanded into a very large and comprehensive program by the Nashville District. The extensive explorations, investigations, and remedial measures have been well documented (Simmons 1982). As a part of the investigative and remedial program, three grout lines were constructed along the crest of the dam tying into the concrete section and extending toward the right abutment, and three lines normal to the three extending from the west toward the downstream toe, thus isolating the wrap around area. Mr. Simmons (1982), in his paper, states "In all probability the emergency grouting saved the structure from a major piping failure but could not be considered a long-term solution to the problem." The investigations connected with the installation of the grout curtains were instrumental in the ensuing design and construction of the diaphragm wall. This review will address only Phase III of the exploratory grout program designed to develop detailed subsurface data along the alignment of the concrete gravity wall on the axis of the dam. The report entitled "Subsurface Investigations Completion of Phase III, Wolf Creek Dam" (USACE 1975) contains a detailed description of the problems, the geology, exploratory drilling, and backfilling methods and equipment. Drawings including plans, sections, and grout profiles are found in that report.

Technical Considerations

M2. The plans and specifications described the work to be performed for the exploratory drilling program designed to develop the detailed subsurface information along the alignment of the concrete diaphragm wall along the axis of the dam. There were 12 pay items for drilling and backfilling (USACE 1974). Mobilization and demobilization and four items for drilling rock or soil, with or without samples, three items for cement, sand, and clay in the backfill, placing backfill, connections to holes, pressure testing, and standby time comprised the pay items. The designers were Messrs. Gordon Prescott, Jack Looney, M. D. Simmons, and F. W. Swartz. This was an unusual grouting contract in so far as it was intended primarily as an exploratory drilling program.

Contractual Considerations

M3. The contract for Phase III subsurface investigations was a firm fixed-price contract awarded to the lowest bidder. Murray Drilling Corporation was the prime contractor. The contractor was completely mobilized 26 August 1974, began drilling on 27 August 1974, and began backfilling on 23 September 1974. All drilling was completed by 21 May 1975, and all backfilling was completed by 22 May 1975. The contractor began demobilization in June 1975, and final job acceptance was given on 10 July 1975. A field office, opened during the first phase of the exploratory program, was maintained throughout the contract. Mr. Bobby Grinder served as resident inspector throughout this contract. He was assisted by a staff of 12 geologists, engineers and technicians. There was a differing site condition clause in the specifications, but none were invoked. Also included was a statement that the program was tentative and presented for the purpose of canvassing bids and that the amount of drilling and coring which would be required was unknown and would be governed by the conditions encountered as the work progressed. Both the contractor and the Corps had qualified people on the job and there was no adversary relationship. The contractor did file a claim seeking an adjustment in the contract in the amount of $100,694.99 due to variations in quantities and alleged contract changes. Of seven items claimed, six were denied. One item (increased pressure testing) was judged to have merit, and the contractor was offered and accepted $13,074.34 for full settlement of that item.

Drilling and Grouting Methods

Drilling

M4. Nonsampled holes through the embankment and overburden were drilled with rotary drills using a 4-3/4-in., 5-in., or 5-1/2-in. tricone roller bits and drilling mud typically containing 20 pounds Baroid Hyseal, 25 pounds Baroid Micatex, and 1 pt Baroid Cordet, in 150 gal of water. Selected portions of the fill and overburden were sampled in 26 of the holes. Samples were standard penetration drill samples taken through the lower embankment contact with overburden. Casing was seated in rock for coring. Rock was cored in primary and secondary holes by NX wireline drilling tools and water. The rock portion of six tertiary and two quarternary holes were drilled with either a 3-in. diamond-plug bit or a 3-in. drag bit. All other testing and quaternary holes were cored. Hole spacing was 3-1/8-ft centers.

Washing and pressure testing

M5. An item was included in the specification for 40 hr for washing and pressure testing. There were 126.53 hr beyond the estimated amount. The original bid was for $40/hr which seemed unreasonably low. A modification changed the unit price for the overrun to $103.33/hr for a total of $13,074.34.

Backfill mixtures

M6. Mixtures consisted of cement, sand, clay, and water in varying proportions. The rock was backfilled with a mixture of 1 cu ft cement, 1 cu ft sand, and 1 cu ft water. The embankment and overburden had a mixture of 1 cu ft cement, 1.5 cu ft clay, 8 cu ft sand, and 4 cu ft water. In the later stages of work the rock backfill was changed to neat cement grout to obtain greater penetration.

Pressure

M7. Pressure was applied only to 1-1/2-in. pipe inserted to near the hole bottom so that only gravity pressure would be applied. Close check of a pressure gage was kept during backfilling.

Refusal rate

M8. The backfilling of any hole by gravity pressure was not considered complete until the hole refused to take with the injection pipe and casing full to the top of hole.

Field procedures

M9. Backfilling was accomplished by placing a 1-1/2-in. I.D. injection pipe within 10 ft of the bottom of hole and pumping material until the hole remained filled to the top of casing. The bottom of the injection pipe was then raised to top of rock, the bottom of the casing lifted 3 to 4 ft above top of rock pumping again until the hole remained full to the top of ground. The injection pipe was removed, the casing removed in sections, and the level of backfill was maintained even with the ground surface by periodic additions at the surface. If the rock portion took over 250 cu ft, the mixture was changed to the overburden mixture to reduce cost and hasten the sealing off. If the stage had not reached refusal by 1,000 cu ft, backfilling was stopped, the hole washed to a level below the grout take, and grout allowed to set for 24 hr. Subsequent injections were to refusal. Twelve holes required at least two stages to obtain refusal. The maximum amount placed in a single hole in rock was 6,971 cu ft in three stages. Two other holes took 1,050 and 1,078 cu ft, respectively, in single injections to refusal. Three holes took over 1,000 cu ft in the embankment and overburden and required a second injection to each refusal. The maximum placed in this zone was 1,265 cu ft in two stages.

Equipment

M10. The specifications required rotary type drilling equipment and water circulation with all items necessary to accomplish the required drilling and sampling. A wireline was required for rock coring.

Grout takes

M11. The total drilling was 156,613.4 ft and the total backfill was 71,687.5 cu ft for an average take of 0.46 cu ft/lin ft.

Unexpected Geological Conditions Encountered

M12. There were no unexpected geological conditions encountered as this was an exploration contract and previous contracts had described the site conditions adequately.

Evaluation of Grouting

M13. Monitoring of a large array of instrumentation during grouting operations was effective. Several areas of solution activity were located areally and vertically. Several large cavities were encountered in which drilling and backfilling operations affected piezometric levels upstream and downstream of the axis as well as along the axis. The exploration revealed that landward of station 57+05L the embankment and foundation were sound and that the cutoff wall could stop there, and that the base of the wall could be raised generally, but deepened locally where deep solutioning had been encountered.

Costs and Quantities

M14. Table M1 gives the Government estimated quantities and the low bid (USACE 1974). The final cost was $590,188 lower than the original estimated cost due to a decrease in exploration. The contract was completed 16 days early.

Performance

M15. The exploratory and backfill program was successful as designed. First, it probably prevented a major piping failure even though it was recognized that it could not be considered a long-term solution to the problem. Secondly, it provided a detailed basis for the design of a concrete diaphragm wall. The wall was successfully completed without major problems about 9 months ahead of schedule in September 1979 and $517,000 under the bid price for that portion directly related to the wall construction.

References

US Army Corps of Engineers. 1974. Abstract of Bids, Subsurface Investigation-Phase III, Wolf Creek Dam, Cumberland River, Kentucky, Nashville District, Nashville, Tenn.

____________. 1974. Specifications for Subsurface Investigations Phase III, Lake Cumberland Project, Cumberland River, Kentucky, Nashville District, Nashville, Tenn.

____________. 1975. Report of Completion of Subsurface Investigations Phase III, Contract No. DACN62-74-C-0230, Nashville District, Nashville, Tenn.

Simmons, Marvin D. 1982. Remedial Treatment Exploration, Wolf Creek Dam, Kentucky, Journal of the Geotechnical Engineering Division, Proceedings of the American Society of Civil Engineers, ASCE, Vol 108, No. GT7.

Table M1

Government Estimate and Bid Prices

Subsurface Investigations Phase III - Wolf Creek Dam

Item No.	Description	Estimated Quantity	Unit	Estimated Unit Price	Estimated Amount	Bid Unit Price	Estimated Amount
1	Subsurface explorations						
a	Mobilization and demobilization		Lump Sum		56,632.00		28,000.00
b	Drilling exploratory holes - embankment and overburden sampled	1,000	lin ft	13.60	13,600.00	14.00	14,000.00
c	Drilling exploratory holes - rock sampled	23,300	lin ft	7.90	184,070.00	6.50	151,450.00
d	Drilling exploratory holes - embankment and overburden - nonsampled	101,200	lin ft	6.10	617,320.00	4.00	404,800.00
e	Drilling exploratory holes - rock nonsampled	70,800	lin ft	5.00	354,000.00	5.00	354,000.00
f	Portland cement in backfill	56,600	cu ft	3.05	172,630.00	2.70	152,820.00
g	Clay in backfill	14,400	cu ft	1.62	23,328.00	1.35	19,440.00
h	Sand in backfill	124,000	cu ft	.53	65,720.00	.60	74,400.00
i	Placing backfill	195,000	cu ft	2.50	487,500.00	2.00	390,000.00
j	Connections to exploratory holes	1,400	ea	8.00	11,200.00	8.00	11,200.00
k	Pressure testing (hydraulic)	40	hr	100.00	4,000.00	40.00	1,600.00
l	Standby time	200	hr	50.00	10,000.00	25.00	5,000.00
				TOTALS	2,000,000.00		1,606,710.00

PROJECT N: LONGVIEW DAM

(This case history was developed with the assistance of John Maylan, Victor Anderson, and William Lowe, Kansas City District)

Location and Description of Project

N1. Longview Lake is the upper of two reservoirs for protection of lands and improvements in the Little Blue River Basin. The lower reservoir, Blue Springs Lake, is located on the East Fork about 1/2 mile south of U. S. Highway 40, and Longview Lake is located on the main stem at approximately 109th Avenue and Raytown Road, Kansas City, Mo. (Plate I-N1). Both lakes are located in Jackson County. Longview Dam is a rolled earthfill embankment with outlet works located near the left abutment and an uncontrolled, limited service spillway in the left abutment (USACE 1974). The embankment is 1,900 ft long. The top of the dam is at elevation 926 msl, about 120 ft above the streambed (Plate I-N2). The dam is currently under construction by the Kansas City District. Foundation grouting was included in Stage I, Main Dam Contract.

Geology

N2. The Longview Dam and Lake are located in the extreme southern part of the Dissected Till Plains Section of the Central Lowland Physiographic Province (USACE 1970). The area is characterized by north-northeast drainage flow in a maturely dissected pattern, scattered thin remnants of glacial till and loess, and low escarpments formed by differential erosion of cyclic sediments. The Little Blue River is a mature stream with occasional incised meanders, cutoffs, and a gradient of about 10 ft/mile. Overburden is comprised of undifferentiated glacial and residual soils on the uplands, colluvial soil at the valley walls, and alluvium in the Blue River Valley. Bedrock at the site consists of the Kansas City and Pleasanton groups of the middle Pennsylvania Series, which overlie about 2,200 ft of older sediments above precambrian gneissic granite. The Kansas City group consists of alternating shales and limestones. The Pleasanton group consists of clayey to silty shales with lenticular interbeds of sandstone, siltstone, and limestone; and occasional thin carbonaceous and underclay units (Plate I-N3). No major faults are known to exist in the area. Jointing is very intensive locally. Primary joints are generally vertical, strike N50°E and have an average spacing of 35 ft. Frequently they are solutioned to widths as great as 5 ft. Secondary joints are generally tight, vertical, strike N75°W, and have an average spacing of 2 ft. Locally, joints may be spaced as close as 0.1 ft, usually having only a hairline width. See Plate I-N4 for General Geological Column.

Subsurface Investigation

N3. Preconstruction subsurface investigations included 188 borings within the embankment, spillway and outlet works areas (Plates I-N5 and I-N6). Overburden drilling was performed with augers, churn drill, standard penetration sampler, and Shelby tubes. Rock was cored with NX, NQ and 5-in. core barrels. Many of the core borings were hydraulically pressure tested. Thirteen open-tube piezometers were installed near the dam and in borrow areas. In addition, refraction seismic and resistivity geophysical surveys were made at the site.

N4. Nine additional core borings (571 lin ft) were drilled during construction at angles ranging from vertical to horizontal. In addition, geotechnical data were updated daily based on information gained from drilling and grouting.

Grouting Design

N5. A tentative program of curtain grouting was presented in the plans and specifications for bidding purposes. This program, as executed, consisted of a triple line grout curtain in the abutments and a single line in the valley and beyond the cutoff trench limits on each abutment. The locations, depths, orientation, and number of grout holes were to be as directed in the field. Only primary holes were shown on the drawings but split spacing was specified as directed based on conditions encountered (Plates I-N7, I-N8, and I-N9). Grout holes were generally angled 30 deg from vertical in the direction shown. Primary hole spacing was 10 ft along the centerline of the cutoff trench, 20 ft along upstream and downstream lines of the triple line portion of grout curtain, and 40 ft in both abutments beyond the cutoff trench.

The depth of grout curtain was approximately 40 ft in the valley section where it was divided into two zones, and up to 120 ft in the abutments where it was divided into four zones. The stop grouting, split-spacing method was used.

Contractual Considerations

Contract

N6. The Longview Dam Stage I Construction Contract included construction of approach structures, intake tower, conduit, consisting of flood control and dual sewer passageways, stilling basin, approach channel, outlet channel, and a portion of the embankment. The work also included foundation drilling and grouting and mechanical and electrical equipment for intake tower. It was a firm fixed-price contract awarded to the lowest responsible bidder, W. A. Ellis Construction Company, Kansas City, Mo. Boyles Brothers Drilling Company, Salt Lake City, Utah, was the subcontractor for drilling and grouting.

Specification drilling and grouting requirements

N7. The specifications required rotary type drilling equipment with circulating water for both grout and exploratory holes. The minimum diameter of grout holes was 1-3/8 in. at the point of maximum penetration. The split-spacing, stop grouting method was required with primary holes shown in the drawings. The location, depth, and orientation of split-spaced holes were to be as directed based on conditions encountered. Grouting mixtures, pressures, pumping rates, and sequence in which holes were drilled, grouted and backfilled were specified to be as directed by and performed in the presence of the contracting officer. No grouting operations were permitted when air temperatures were below freezing unless a written approval of a winter-grouting protection plan was obtained from the contracting officer.

N8. Table N1 shows bid items for grouting along with Government estimated prices and contractor bid prices. Subitems 28b through 28g were excluded from the variations in estimated quantities provisions of the General Provisions by Standard Clauses for subdivided items in the Special Provisions. Even so, a claim was filed because of a reduction in the ratio of grouting to drilling (items 28d and 28b, Table N1). The claim was allowed and a negotiated settlement reached.

N9. Grouting equipment specified included mechanical grout mixer and sump, colloidal bentonite mixer and progressive cavity pump. A circulating header was required along with suitable meters, gages, packers, auxiliary equipment, fittings and tools.

N10. Materials for grout included water, cement (Type I or II), and bentonite.

N11. The specifications for backfilling grout holes required a grout having a water-cement ratio of 0.7, or as directed. "The backfill grout shall extend to the bottom of the drill hole or to the top of "set up" grout. A section of steel pipe of 3/4 in. (minimum) I.D. and 6 ft (minimum) in length shall be attached to the end of the delivery line extending down the hole. The depth to which the delivery tube is inserted shall be measured and recorded. The delivery tube shall remain at maximum depth until the grout has reached the surface and begins flowing from the hole. Then the delivery tube shall be withdrawn with flow through the tube continuing until backfill is completed. After the backfill grout has set, and again prior to placing the embankment, all holes shall be rebackfilled in the event that settlement of the grout has occurred (USACE 1979).

Contract management

N12. Field and management relationships between the grouting subcontractor and the Government were excellent; however, relationships between the Government and the prime contractor were adversary and lacked mutual trust. The Corps' resident staff allowed the specified requirement for a separate bentonite mixer to be deleted. This is an example of construction personnel changing specification requirements without realizing the technical implications.

Drilling and Grouting Methods

Drilling

N13. Grout holes were 1-1/2 in. in diameter and drilled generally at angles 30 deg from vertical as shown on the plans. No core was required. The contractor elected to use a track mounted, hydraulic, air powered, rotary drill with polycrystalline, finger bits. Water was circulated in the hole during drilling. Drilling rates were comparable to percussion drilling rates.

Washing and pressure testing

N14. Each hole was pressure washed and tested just prior to grouting.

Grouting mixtures

N15. All grout was neat cement grout with approximately 4 percent bentonite for stabilization. If a hole took more than 1 cu ft of water in 10 min, it was grouted beginning with grout having a water-cement ratio of 6:1. If the hole accepted grout, the grout was gradually thickened and grouting continued until refusal.

Pressures

N16. Grouting pressures were controlled by the resident geologist and were within the specified range. Actual pressures were below the "rule of thumb" at the top of the zone being grouted.

Field procedures

N17. Split spacing, stop grouting procedures were used with primary grout holes on 10-, 20-, and 40-ft spacing as previously discussed. The program was carried out as designed. Field criteria for split spacing was not available during this study, however, it is assumed that splits were required when holes took significant grout. The resulting curtain was generally on 5-ft spacing with some 2-1/2-ft splits.

N18. Most of the valley section was tight and accepted little grout. In backfilling grout holes, there were grout takes (water cement ratio 0.7:1) in holes which previously took no grout (water cement ratio 6:1). This was attributed to hydraulically fracturing the foundation with pressure during backfilling. Even though the hole was open during this operation, by injecting at a rapid rate, sufficient pressure built up to fracture the rock which was otherwise tight. The problem was remedied by slowing the rate of injection during backfilling of grout holes.

Grout take

N19. Grout takes were generally low. Estimated and actual quantities are shown in Table N2.

Refusal criteria

N20. Refusal was defined as when the grout take at the maximum allowable grouting pressure is less than 1 cu ft in 10 min.

Records

N21. The contracting officer was required to keep records of all grouting operations, such as log of the grout holes, results of washing and pressure testing, time of each change of grouting operation, pressure, rate of pumping, amount of cement for each change in water-cement ratio, percentage of bentonite, and other data deemed by him to be necessary. The contractor was required to furnish all necessary assistance and cooperation to this end.

N22. In addition, the contractor was required to submit a complete drilling and grouting log to the contracting officer. It contained all information necessary for computation of quantities including linear feet of drilled grout holes, number of connections to grout holes, cubic feet of dry portland cement and pounds of bentonite used in grout mixtures and linear feet of drilled exploratory core holes. It also contained a complete description of drilling and grouting equipment used.

Unexpected Geological Conditions Encountered During Construction

N23. The underrun of grouting quantities was considered a differing site condition under GP-4. A negotiated settlement in the amount of $80,000 was awarded the contractor.

Evaluation of Grouting

N24. The design of the grouting program is considered conservatively adapted to the geology. The grout curtain should function adequately as constructed. Problems which could adversely affect performance include:

- a. Lack of grouting experience of the resident staff.
- b. Not requiring a separate mixer for bentonite as specified.
- c. Hydraulically fracturing the foundation during backfilling operations.

Costs (Drilling and Grouting)

Government Estimate	$1,047,200	
Contractors Bid	874,000	
Actual	447,569	(includes $80,000 for negotiated settlement of differing site conditions)

Performance

N25. This dam is still under construction and therefore no performance evaluation can be made.

References

US Army Corps of Engineers. 1970. Longview Lake and Blue Springs Lake General Design Memorandum and Appendix I Geology, Kansas City District, Kansas City, Mo.

____________. 1974. Longview Lake Design Memorandum No. 5 - Soil Data and Embankment Design, Kansas City District, Kansas City, Mo (Revised June 1978).

____________. 1979. Longview Dam Plans and Specifications, Kansas City District, Kansas City, Mo.

Table N1

Grouting Estimate and Bid Prices

Longview Dam

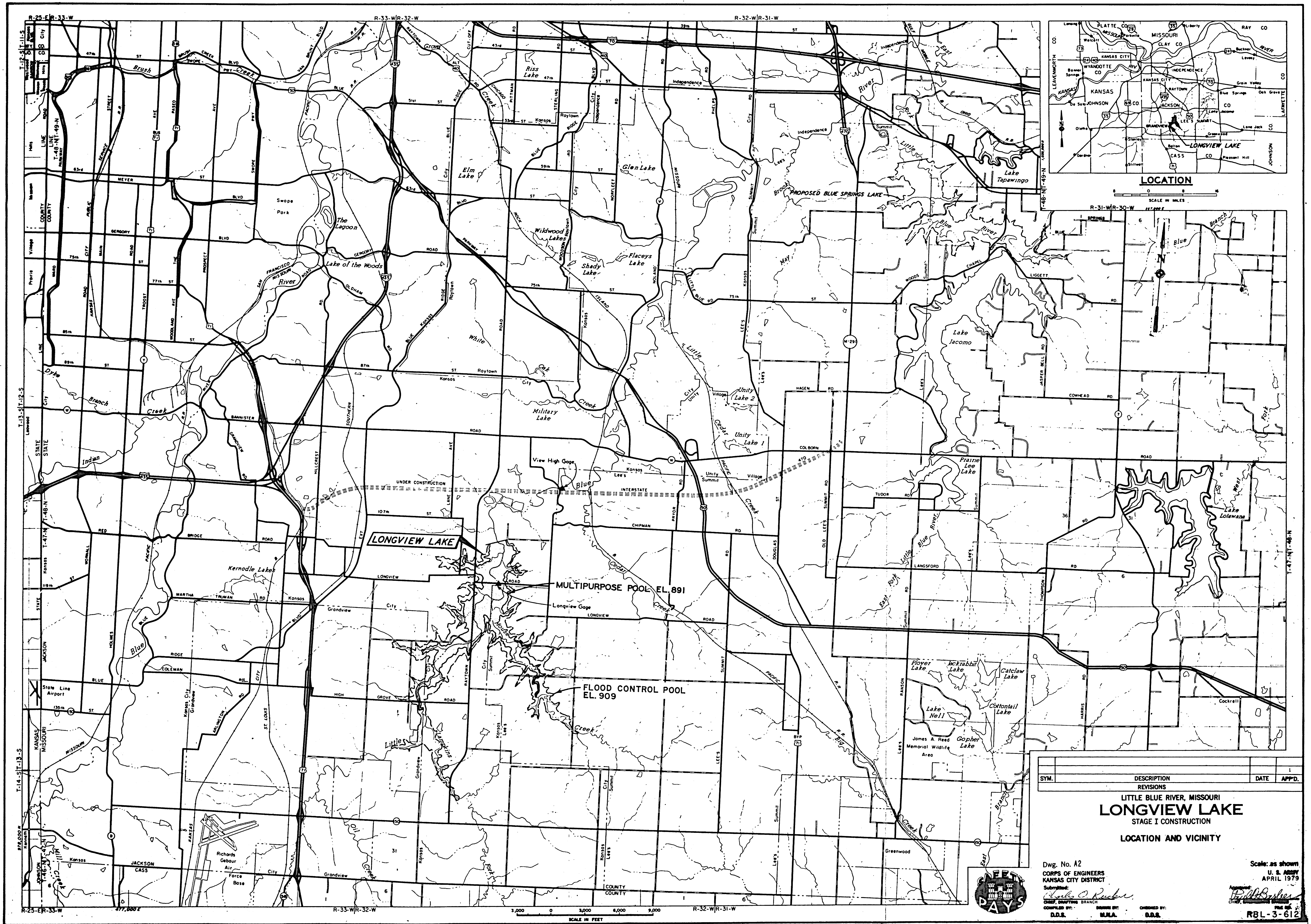
Item No.	Description of Bid Item	Estimated Quantity	Unit	Estimated Unit Price	Estimated Amount	Bid Unit Price	Estimated Amount
28	Foundation Drilling & Grouting						
	a. Mobilization and Demobilization	---	Lump Sum	---	35,100.00	---	100,000.00
	b. Drilling Grout Holes	74,000	lin ft	11.40	843,600.00	7.00	518,000.00
	c. Connection to Grout Holes	3,000	ea	10.00	30,000.00	10.00	30,000.00
	d. Placing Grout	16,000	cu ft	4.40	70,400.00	8.50	136,000.00
	e. Portland Cement	17,000	cu ft	3.80	64,600.00	5.00	85,000.00
	f. Drilling Exploratory Core Holes	500	lin ft	23.40	11,700.00	30.00	15,000.00
	g. Bentonite	50,000	lb	0.07	3,500.00	0.10	5,000.00

Table N2

Estimated and Actual Grouting Quantities

Longview Dam

Bid Item 28	Description	Estimated Quantity	Unit	Final Quantity	% Underrun
a.	Mobilization and Demobilization		Lump Sum		
b.	Drilling Grout Holes	74,000	lin ft	45,374	38.7
c.	Connection to Grout Holes	3,000	ea	585	80.5
d.	Placing Grout	16,000	cu ft	2,608	85.7
e.	Portland Cement	17,000	cu ft	3,225	81.0
f.	Drilling Exploratory Core Holes	500	lin ft	571.6	
g.	Bentonite	50,000	lb	11,509	77.0


LOCATION
SCALE IN MILES
LONGVIEW LAKE
MULTIPURPOSE POOL EL. 891
Longview Gage
FLOOD CONTROL POOL
EL. 909
View High Gage
UNDER CONSTRUCTION
INTERSTATE
PROPOSED BLUE SPRINGS LAKE
Lake Jacomo
Lake Tapawingo
Lake Lotawana
Prairie Lee Lake
Swope Park
The Lagoon
Lake of the Woods
Elm Lake
Glen Lake
Riss Lake
Wildwood Lakes
Shady Lake
Flaceys Lake
Military Lake
Unity Lake 1
Unity Lake 2
Kernodle Lakes
Plover Lake
Jackrabbit Lake
Catclaw Lake
Cottontail Lake
Lake Nell
Gopher Lake
James A. Reed Memorial Wildlife Area
State Line Airport
Richards Gebaur Air Force Base
SCALE IN FEET
SYM.
DESCRIPTION
DATE
APP'D.
REVISIONS
LITTLE BLUE RIVER, MISSOURI
LONGVIEW LAKE
STAGE I CONSTRUCTION
LOCATION AND VICINITY
Dwg. No. A2
CORPS OF ENGINEERS
KANSAS CITY DISTRICT
Scale: as shown
U. S. ARMY
APRIL 1979
RBL-3-612

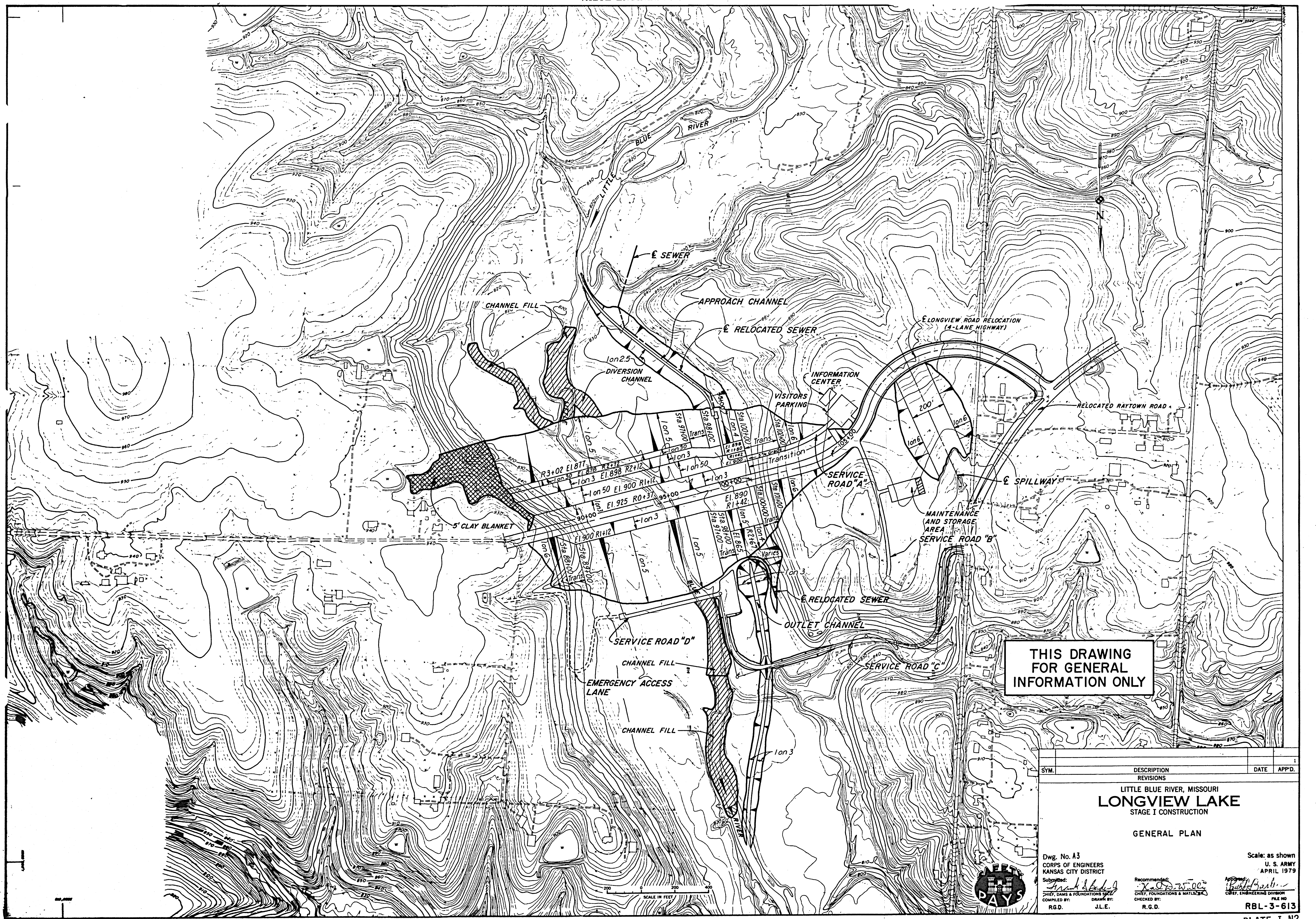

LITTLE BLUE RIVER
€ SEWER
APPROACH CHANNEL
€ RELOCATED SEWER
CHANNEL FILL
DIVERSION CHANNEL
INFORMATION CENTER
VISITORS PARKING
€ LONGVIEW ROAD RELOCATION (4-LANE HIGHWAY)
RELOCATED RAYTOWN ROAD
SERVICE ROAD "A"
€ SPILLWAY
MAINTENANCE AND STORAGE AREA
SERVICE ROAD "B"
5' CLAY BLANKET
€ RELOCATED SEWER
OUTLET CHANNEL
SERVICE ROAD "D"
SERVICE ROAD "C"
CHANNEL FILL
EMERGENCY ACCESS LANE
CHANNEL FILL
RIVER
THIS DRAWING FOR GENERAL INFORMATION ONLY
SYM. DESCRIPTION DATE APP'D.
REVISIONS
LITTLE BLUE RIVER, MISSOURI
LONGVIEW LAKE
STAGE I CONSTRUCTION
GENERAL PLAN
Dwg. No. A3
CORPS OF ENGINEERS
KANSAS CITY DISTRICT
Scale: as shown
U. S. ARMY
APRIL 1979
SCALE IN FEET
RBL-3-613

PLATE I-N2

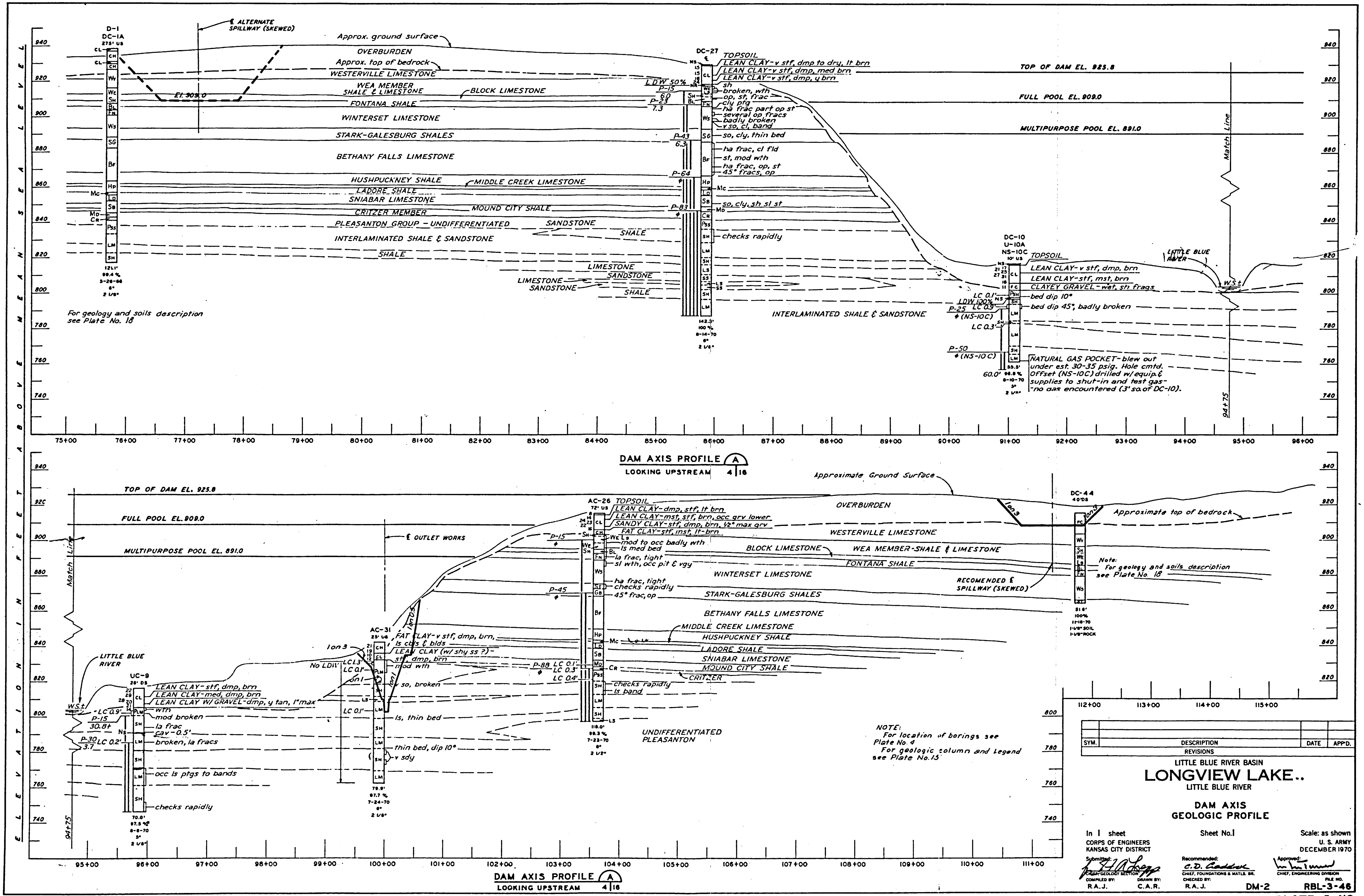

ELEVATION IN FEET
D-1
DC-1A
℄ ALTERNATE SPILLWAY (SKEWED)
Approx. ground surface
OVERBURDEN
Approx. top of bedrock
WESTERVILLE LIMESTONE
WEA MEMBER SHALE & LIMESTONE
BLOCK LIMESTONE
El. 905.0
FONTANA SHALE
WINTERSET LIMESTONE
STARK-GALESBURG SHALES
BETHANY FALLS LIMESTONE
HUSHPUCKNEY SHALE
MIDDLE CREEK LIMESTONE
LADORE SHALE
SNIABAR LIMESTONE
CRITZER MEMBER
MOUND CITY SHALE
PLEASANTON GROUP - UNDIFFERENTIATED
SANDSTONE
INTERLAMINATED SHALE & SANDSTONE
SHALE
LIMESTONE
For geology and soils description see Plate No. 18
DC-27
TOPSOIL
LEAN CLAY-v stf, dmp to dry, lt brn
LEAN CLAY-v stf, dmp, med brn
LEAN CLAY-v stf, dmp, y brn
sh
broken, wth
op, st, frac
cly ptg
ha frac part op st
several op fracs
badly broken
v so, cl, band
so, cly, thin bed
ha frac, cl fld
st, mod wth
ha frac, op, st
45° fracs, op
so, cly, sh sl st
checks rapidly
TOP OF DAM EL. 925.8
FULL POOL EL. 909.0
MULTIPURPOSE POOL EL. 891.0
Match Line
DC-10
U-10A
NS-10C
LEAN CLAY-v stf, dmp, brn
LEAN CLAY-stf, mst, brn
CLAYEY GRAVEL-wet, sh frags
bed dip 10°
bed dip 45°, badly broken
LITTLE BLUE RIVER
W.S.±
NATURAL GAS POCKET-blew out under est. 30-35 psig. Hole cmtd. Offset (NS-10C) drilled w/ equip.& supplies to shut-in and test gas-no gas encountered (3' so. of DC-10).
94+75
DAM AXIS PROFILE A 4/18
LOOKING UPSTREAM
Approximate Ground Surface
AC-26
LEAN CLAY-dmp, stf, lt brn
LEAN CLAY-mst, stf, brn, occ grv lower
SANDY CLAY-stf, dmp, brn, ½" max grv
FAT CLAY-stf, mst, lt brn
mod to occ badly wth
ls med bed
la frac, tight
sl wth, occ pit & vgy
ha frac, tight
checks rapidly
45° frac, op
checks rapidly
ls band
UNDIFFERENTIATED PLEASANTON
℄ OUTLET WORKS
DC-44
Approximate top of bedrock
RECOMENDED ℄ SPILLWAY (SKEWED)
Note: For geology and soils description see Plate No. 18
AC-31
FAT CLAY-v stf, dmp, brn, ls cbls & blds
LEAN CLAY (w/ shy ss ?)-stf, dmp, brn
mod wth
so, broken
ls, thin bed
thin bed, dip 10°
v sdy
UC-9
LEAN CLAY-stf, dmp, brn
LEAN CLAY-med, dmp, brn
LEAN CLAY W/GRAVEL-dmp, y tan, 1"max
wth
mod broken
la frac
cav-0.5'
broken, la fracs
occ ls ptgs to bands
checks rapidly
NOTE: For location of borings see Plate No. 4. For geologic column and Legend see Plate No. 15
SYM. DESCRIPTION DATE APP'D.
REVISIONS
LITTLE BLUE RIVER BASIN
LONGVIEW LAKE
LITTLE BLUE RIVER
DAM AXIS GEOLOGIC PROFILE
In 1 sheet
Sheet No. 1
Scale: as shown
CORPS OF ENGINEERS KANSAS CITY DISTRICT
U. S. ARMY DECEMBER 1970
CHIEF, GEOLOGY SECTION
C. D. Caddock
CHIEF, FOUNDATIONS & MATLS. BR.
CHIEF, ENGINEERING DIVISION
COMPILED BY: R.A.J.
DRAWN BY: C.A.R.
CHECKED BY: R.A.J.
DM-2
RBL-3-46

PLATE I-N3

GENERAL GEOLOGIC COLUMN

SYSTEM	GROUP	FORMATION	MEMBER OR ZONE	SYMBOL	APPROX. THICKNESS	GENERALIZED DESCRIPTION
PENNSYLVANIA	KANSAS CITY	CHERRYVILLE	WESTERVILLE	Wv	*(9.0')	LIMESTONE: moderately hard, finely crystalline to crystalline, medium to thick bedded, fossiliferous, pitted in upper portion, light grey.
			WEA	We	11.5'	SHALE (upper 1/3 of member): soft, blocky, clayey to silty, calcareous, dark grey. AGILLACEOUS LIMESTONE (lower 2/3 of member): moderately hard, dense to finely crystalline, thin to medium bedded, fossiliferous, bluish-grey; with occasional dark grey, shale bands and beds.
			BLOCK	Bl	3.5'	LIMESTONE: moderately hard, finely crystalline, medium to thick bedded, fossiliferous, argillaceous, medium grey; with one or more thin beds of dark grey shale.
			FONTANA	Fn	3.0'	SHALE: soft, platy to blocky, silty, calcareous, dark grey; with limestone nodules common in basal portion.
		DENNIS	WINTERSET	Ws	13.5'	LIMESTONE: moderately hard, finely crystalline, thin to medium bedded, argillaceous, pitted, occasionally fossiliferous, light grey; with wavy partings and occasional thin beds of dark grey shale.
			STARK	Sg	6.0'	SHALE: soft, fissil to blocky, carbonaceous, calcareous, black; lower part is soft, platy to blocky, clayey, dark grey; with limey (fossiliferous) zone common near bottom.
		GALESBURG				
		SWOPE	BETHANY FALLS	Bf	18.0'	LIMESTONE: moderately hard, dense to finely crystalline, thin to thick bedded, occasionally styolific, occasionally pitted, numerous wavy shale partings, light grey; upper 1' to 2' is nodular limestone in greenish-grey shale matrix.
			HUSHPUCKNEY	Hp	6.5'	SHALE: upper part is soft, platy, clayey, calcareous, dark grey; lower part is soft fissil, carbonaceous, calcareous, occasional siltstone partings and pyrite nodules.
			MIDDLE CREEK	Mc	1.5'	LIMESTONE: moderately hard, dense to finely crystalline, thin to medium bedded, argillaceous, medium grey; with thin bed of dark grey shale in middle part.
		LADORE		Ld	3.0'	SHALE: soft, platy, silty, calcareous in lower part, medium grey.
		HERTHA	SNIABAR	Sb	6.0'	LIMESTONE: moderately hard, dense to very finely crystalline, thick bedded, argillaceous, light grey with medium grey mottling; occasional shale partings.
			MOUND CITY	Md	3.5'	SHALE: soft, platy, clayey to silty, brownish-grey to dark grey.
			CRITZER	Cz	2.5'	SHALE: soft, silty, calcareous, blocky, light to medium greyish-grey; with limestone nodules. LIMESTONE: when present occurs in lower part and is moderately hard, argillaceous, sandy, thin to medium bedded, light grey.
	PLEASANTON	(UNDIFFERENTIATED)	ZONE A	Pl_a	6.0'	SANDSTONE: moderately hard, very fine grained, thick bedded to massive, argillaceous, calcareous, light to medium greenish-grey.
			ZONE B	Pl_b	20.0'	SHALE: soft, platy, silty, dark grey; upper part is interlaminated with medium grey siltstone partings and is occasionally calcareous and slightly micaceous.
			ZONE C	Pl_c	6.0'	ARGILLACEOUS LIMESTONE: moderately hard, very fine grained to dense, thick bedded to massive, medium to dark grey; fossiliferous.
			ZONE D	Pl_d	5.0'	CALCAREOUS SILTSTONE: moderately hard, argillaceous, thick bedded to massive; occasionally "shaly" in upper part, fossiliferous in lower part, medium to dark grey.
			ZONE E	Pl_e	50.0'	ARGILLACEOUS SILTSTONE: soft to moderately hard, medium bedded to massive except "platy" where interlaminated, occasionally slightly micaceous, medium to dark grey; with zones of interlaminated wavy and partially discontinuous partings and bands of light grey siltstone; occasionally cross-stratified; upper part locally interlaminated light and dark grey sandstone partings and bands which are commonly slightly calcareous.
			ZONE F	Pl_f	5.0'	SHALE: soft, silty, platy to blocky, dark grey, with medium grey siltstone partings and occasional calcareous nodules.

* ( ) Maximum thickness drilled, full thickness not penetrated

UNIFIED SOIL CLASSIFICATION SYSTEM

GW	Well graded gravels, gravel-sand mixtures, little or no fines.
GP	Poorly graded gravels or gravel-sand mixtures, little or no fines.
GM	Silty gravels, gravel-sand-silt mixtures.
GC	Clayey gravels, gravel-sand-clay mixtures.
SW	Well-graded sands, gravelly sands, little or no fines.
SP	Poorly graded sands or gravelly sands, little or no fines.
SM	Silty sands, sand-silt mixtures.
SC	Clayey sands, sand-clay mixtures.
ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts w/slight plasticity.
CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.
OL	Organic silts and organic silty clays of low plasticity.
MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.
CH	Inorganic clays of high plasticity, fat clays.
OH	Organic clays of medium to high plasticity, organic silts.
Pt	Peat and other highly organic soils.

Classification from actual laboratory tests where LL and PI are shown.
Dual classification, where used, is in accordance with the Unified Soil Classification System.
For details on the Unified Soil Classification System, See Waterways Experiment Station Technical Memorandum No. 3-357 dated March 1953 and revised in 1960.

TERMS FOR CONSISTENCY OF SOIL AND HARDNESS OF BEDROCK

SOIL

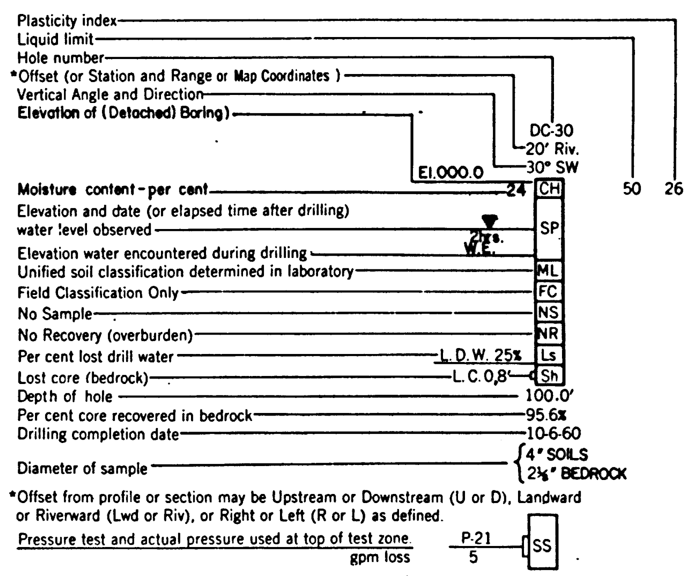
Consistency	Estimated Unconfined Compressive Strength (Tons per square foot)
Very soft	< 0.25
Soft	0.25 0.5
Medium	0.5 1.0
Stiff	1.0 - 2.0
Very stiff	2.0 - 4.0
Hard	> 4.0

BEDROCK

SCALE OF HARDNESS

Very soft or plastic	Can be indented easily with thumb.
Soft	Can be scratched with fingernail.
Moderately hard	Can be scratched easily with knife; Cannot be scratched with fingernail.
Hard	Difficult to scratch with knife.
Very Hard	Cannot be scratched with knife.

LEGEND FOR LOGS OF BORINGS



*Offset from profile or section may be Upstream or Downstream (U or D), Landward or Riverward (Lwd or Riv), or Right or Left (R or L) as defined.

Pressure test and actual pressure used at top of test zone. / gpm loss — P-21 / 5 — SS

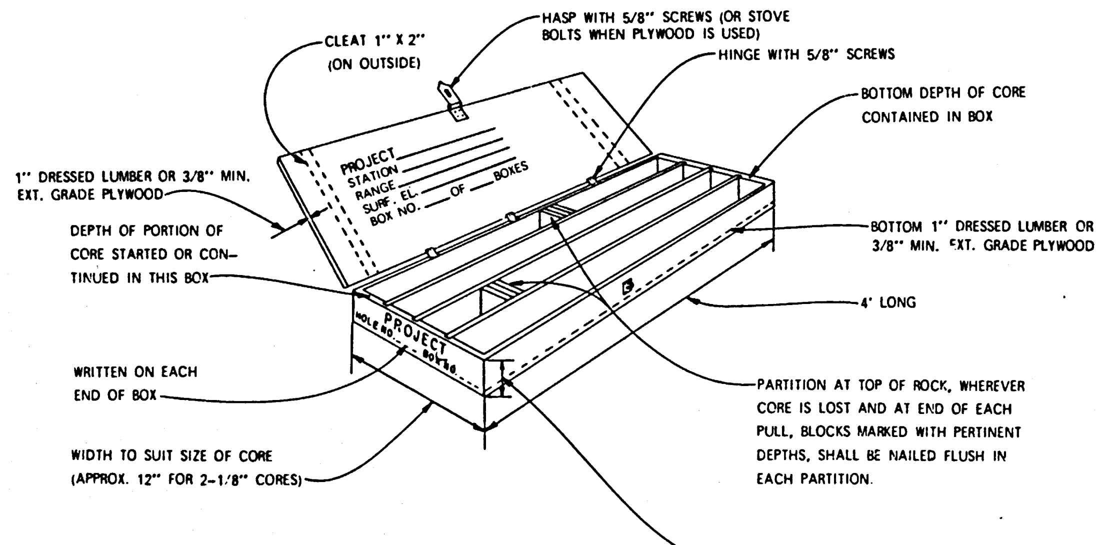
TYPE OF EXPLORATION

MAP SYMBOL

- Vertical boring
- 30° Inclined boring showing direction and vertical angle

CODE DESIGNATION

- D Drive sample hole
- C Core hole
- TP Test pit (includes power auger 24" or larger diameter)
- U Undisturbed sample hole
- A Auger hole-hand or power auger less than 24" diameter.
- NS Not Sampled (Field Classification from cuttings only)
- FS Field Section of outcrop.



NOTE:
LABELS FOR CORE BOX WILL BE PLACED ON OUTSIDE AND INSIDE OF COVER AND OUTSIDE ON EACH END.

CORE BOX DETAILS
(FOR EXPLORATORY DRILLING)

ABBREVIATIONS

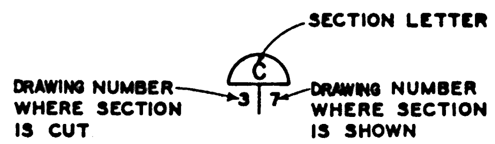
alt	alternating	dmp	damp	lea	leached	rnd (d)	round, (rounded)
ang	angular	dol (c)	dolomite, (dolomitic)	lig	lignite	sat	saturated
an	anhydrite	ext	extremely	ls	limestone	scat	scattered
ar	argillaceous	f (y)	fine, (finely)	lt	light	sd (y)	sand, (sandy)
bdd	bed, bedded, bedding	fe	iron	lo	loose	sev	several
bdr	bedrock	fld	filled	L.C.	lost core	sh (y)	shale, (shaly)
bky	blocky	fm	firm	L.D.W.	lost drill water	si (y)	silt, (silty)
bl	blue	fos (s)	fossil, (fossiliferous)	med	medium	sis	siltstone
bld	boulder	frac (d)	fractures, (fractured)	mic	micaceous	sl	slightly
blk	black	frag (d)	fragments, (fragmented)	min	mineralized	slcs	siliceous
brec (d)	breccia, (brecciated)	fri	friable	mod (y)	moderate, (moderately)	slks	slickensides
brk	broken	fsl	fissile	mot	mottled	so	soft
brn	brown	gr	grain	mss	massive	sol (d)	solution, (solutionized)
c	coarse	gra	gradation	mst	moist	ss	sandstone
calc	calcareous	grn	green	mtl	material	st (g)	stained, (staining)
carb	carbonaceous	grv (y)	gravel, (gravelly)	mtx	matrix	stf	stiff
cav	cavity	gry	gray	nod	nodules	sty	stylolitic
cbl	cobble	gyp	gypsum	num	numerous	v	very
cht	chert	ha	high angle	occ (y)	occasional, (occasionally)	vert	vertical
circl	circulation	hd	hard	op	open	vgy	vuggy
cl (y)	clay, (clayey)	hld	healed	or	orange	w	water
cld	closed	hor	horizontal	org	organic	w/	with
cmtd	cemented	inbd	interbedded	par	partially	wth	weathered
col	columnar	incl	inclusions	pit	pit, pitted, pitting	wht	white
conc	concretions	inlam	interlaminated	pl	plastic	x-bdd	crossed-bedded
cong	conglomerate	irr	irregular	pla	platy	xln	crystalline
crm	crumbly	jt (s)	joint, (joints)	pln	plane	y	yellow
d	dense	la	low angle	ptg (s)	parting, (partings)		
dk	dark	lam (d)	laminae, (laminated)	qtz (e)	quartz, (quartzite)		

When used as log symbol first letter is capitalized

BEDROCK UNIT THICKNESS

Parting	< 0.02'
Band	0.02 to 0.2'
Thin bed	0.2 to 0.5'
Medium bed	0.5 to 1.0'
Thick bed	1.0 to 2.0'
Massive	> 2.0'

PROFILE & SECTIONS



SYM.	DESCRIPTION	DATE	APP'D.

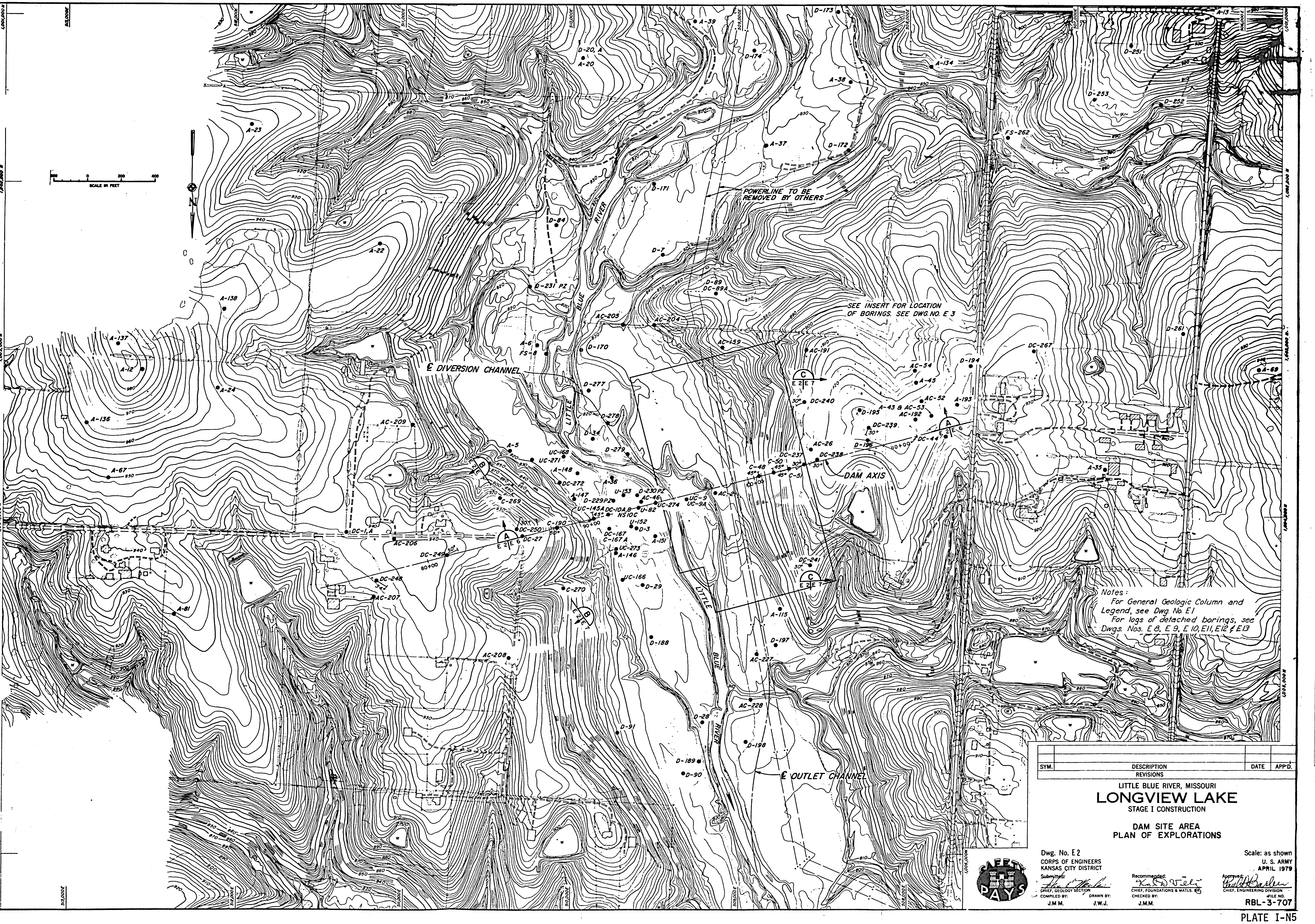
REVISIONS

LITTLE BLUE RIVER, MISSOURI
LONGVIEW LAKE
STAGE I CONSTRUCTION

GENERAL GEOLOGIC COLUMN AND LEGEND

Dwg. No. E1
CORPS OF ENGINEERS
KANSAS CITY DISTRICT
Approved:
CHIEF, FOUNDATIONS & MATLS. BR.
COMPILED BY: R.G.S
DRAWN BY: G.W.D.
CHECKED BY: A.G.M.

Scale: as shown
U. S. ARMY
APRIL 1979
FILE NO. RBL-3-706


SCALE IN FEET
POWERLINE TO BE REMOVED BY OTHERS
SEE INSERT FOR LOCATION OF BORINGS. SEE DWG. NO. E 3
℄ DIVERSION CHANNEL
DAM AXIS
℄ OUTLET CHANNEL
LITTLE BLUE RIVER
Notes:
For General Geologic Column and Legend, see Dwg. No. E1
For logs of detached borings, see Dwgs. Nos. E8, E9, E10, E11, E12 & E13
SYM.
DESCRIPTION
DATE
APP'D.
REVISIONS
LITTLE BLUE RIVER, MISSOURI
LONGVIEW LAKE
STAGE I CONSTRUCTION
DAM SITE AREA
PLAN OF EXPLORATIONS
Dwg. No. E2
CORPS OF ENGINEERS
KANSAS CITY DISTRICT
Scale: as shown
U. S. ARMY
APRIL 1979
Submitted:
CHIEF, GEOLOGY SECTION
Recommended:
CHIEF, FOUNDATIONS & MATLS. BR.
Approved:
CHIEF, ENGINEERING DIVISION
COMPILED BY: J.M.M.
DRAWN BY: J.W.J.
CHECKED BY: J.M.M.
FILE NO.
RBL-3-707

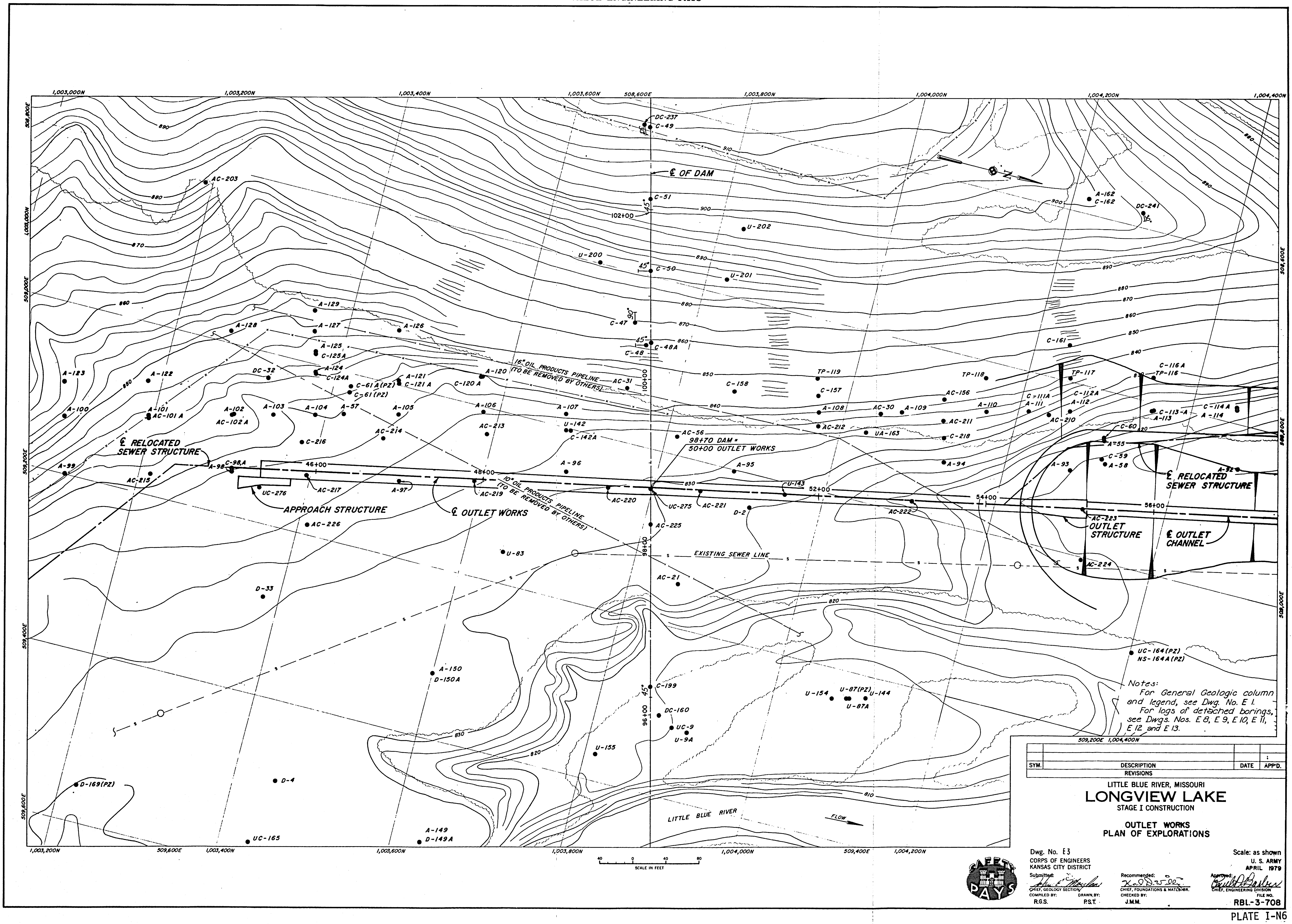
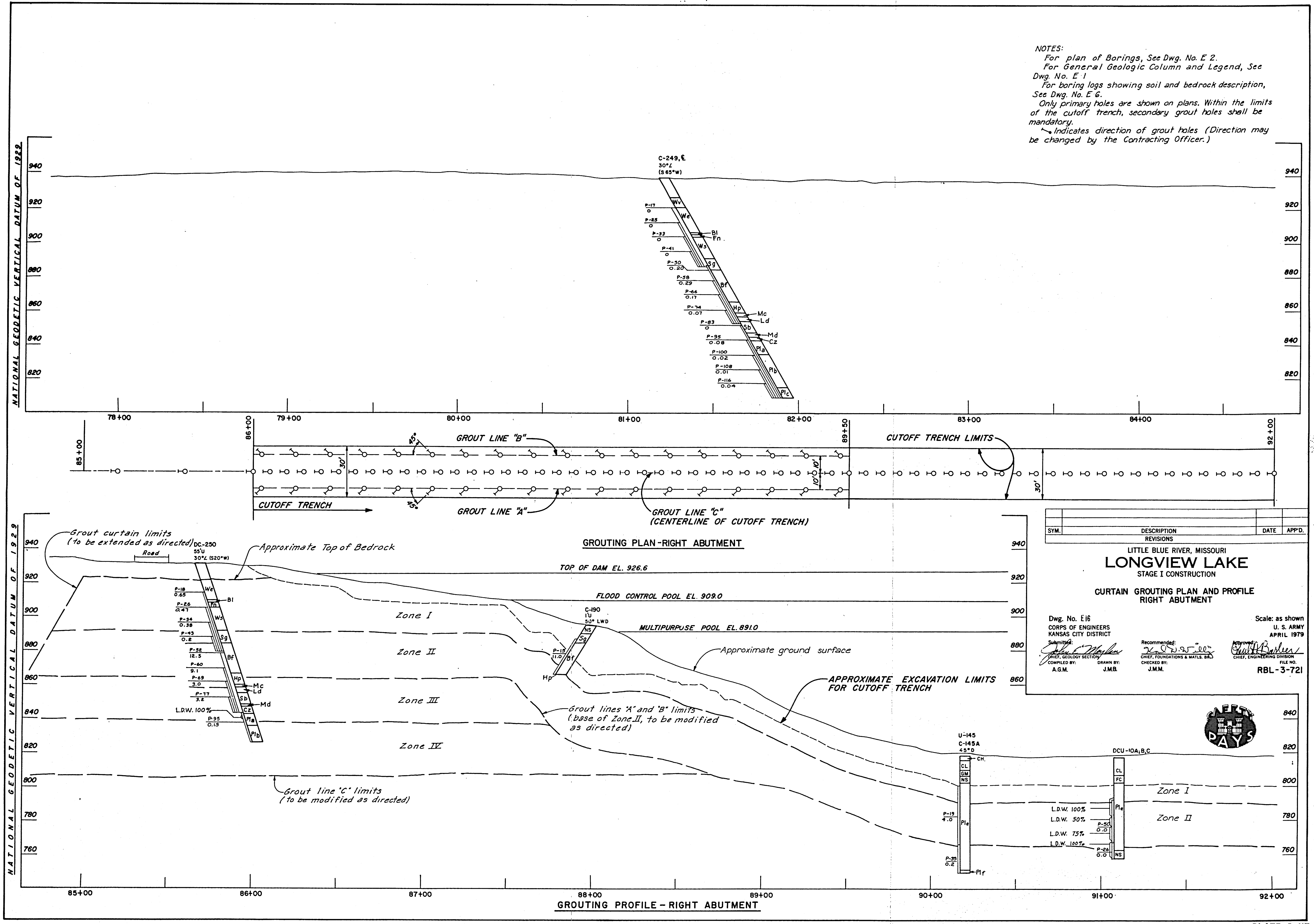

℄ OF DAM
℄ RELOCATED SEWER STRUCTURE
APPROACH STRUCTURE
℄ OUTLET WORKS
16" OIL PRODUCTS PIPELINE (TO BE REMOVED BY OTHERS)
10" OIL PRODUCTS PIPELINE (TO BE REMOVED BY OTHERS)
98+70 DAM = 50+00 OUTLET WORKS
EXISTING SEWER LINE
OUTLET STRUCTURE
℄ OUTLET CHANNEL
LITTLE BLUE RIVER
FLOW
Notes:
For General Geologic column and legend, see Dwg. No. E 1.
For logs of detached borings, see Dwgs. Nos. E 8, E 9, E 10, E 11, E 12 and E 13.
SCALE IN FEET
SYM.
DESCRIPTION
DATE
APP'D.
REVISIONS
LITTLE BLUE RIVER, MISSOURI
LONGVIEW LAKE
STAGE I CONSTRUCTION
OUTLET WORKS
PLAN OF EXPLORATIONS
Dwg. No. E3
CORPS OF ENGINEERS
KANSAS CITY DISTRICT
Scale: as shown
U. S. ARMY
APRIL 1979
CHIEF, GEOLOGY SECTION
CHIEF, FOUNDATIONS & MATLS. BR.
CHIEF, ENGINEERING DIVISION
COMPILED BY: R.G.S.
DRAWN BY: P.S.T.
CHECKED BY: J.M.M.
FILE NO. RBL-3-708
SAFETY PAYS

PLATE I-N6


NOTES:
For plan of Borings, See Dwg. No. E 2.
For General Geologic Column and Legend, See Dwg. No. E 1
For boring logs showing soil and bedrock description, See Dwg. No. E 6.
Only primary holes are shown on plans. Within the limits of the cutoff trench, secondary grout holes shall be mandatory.
Indicates direction of grout holes (Direction may be changed by the Contracting Officer.)
NATIONAL GEODETIC VERTICAL DATUM OF 1929
C-249, ℄
30°∠
(S 65° W)
GROUT LINE "B"
GROUT LINE "A"
GROUT LINE "C"
(CENTERLINE OF CUTOFF TRENCH)
CUTOFF TRENCH
CUTOFF TRENCH LIMITS
GROUTING PLAN-RIGHT ABUTMENT
Grout curtain limits
(to be extended as directed)
Road
DC-250
Approximate Top of Bedrock
TOP OF DAM EL. 926.6
FLOOD CONTROL POOL EL. 909.0
MULTIPURPOSE POOL EL. 891.0
C-190
Zone I
Zone II
Zone III
Zone IV
Approximate ground surface
APPROXIMATE EXCAVATION LIMITS
FOR CUTOFF TRENCH
Grout lines 'A' and 'B' limits
(base of Zone II, to be modified as directed)
Grout line 'C' limits
(to be modified as directed)
U-145
C-145A
DCU-10A, B, C
GROUTING PROFILE - RIGHT ABUTMENT
SYM. | DESCRIPTION | DATE | APP'D.
REVISIONS
LITTLE BLUE RIVER, MISSOURI
LONGVIEW LAKE
STAGE I CONSTRUCTION
CURTAIN GROUTING PLAN AND PROFILE
RIGHT ABUTMENT
Dwg. No. E16
CORPS OF ENGINEERS
KANSAS CITY DISTRICT
Scale: as shown
U. S. ARMY
APRIL 1979
CHIEF, GEOLOGY SECTION
CHIEF, FOUNDATIONS & MATLS. BR.
CHIEF, ENGINEERING DIVISION
COMPILED BY: A.G.M.
DRAWN BY: J.M.B.
CHECKED BY: J.M.M.
RBL-3-721
SAFETY PAYS

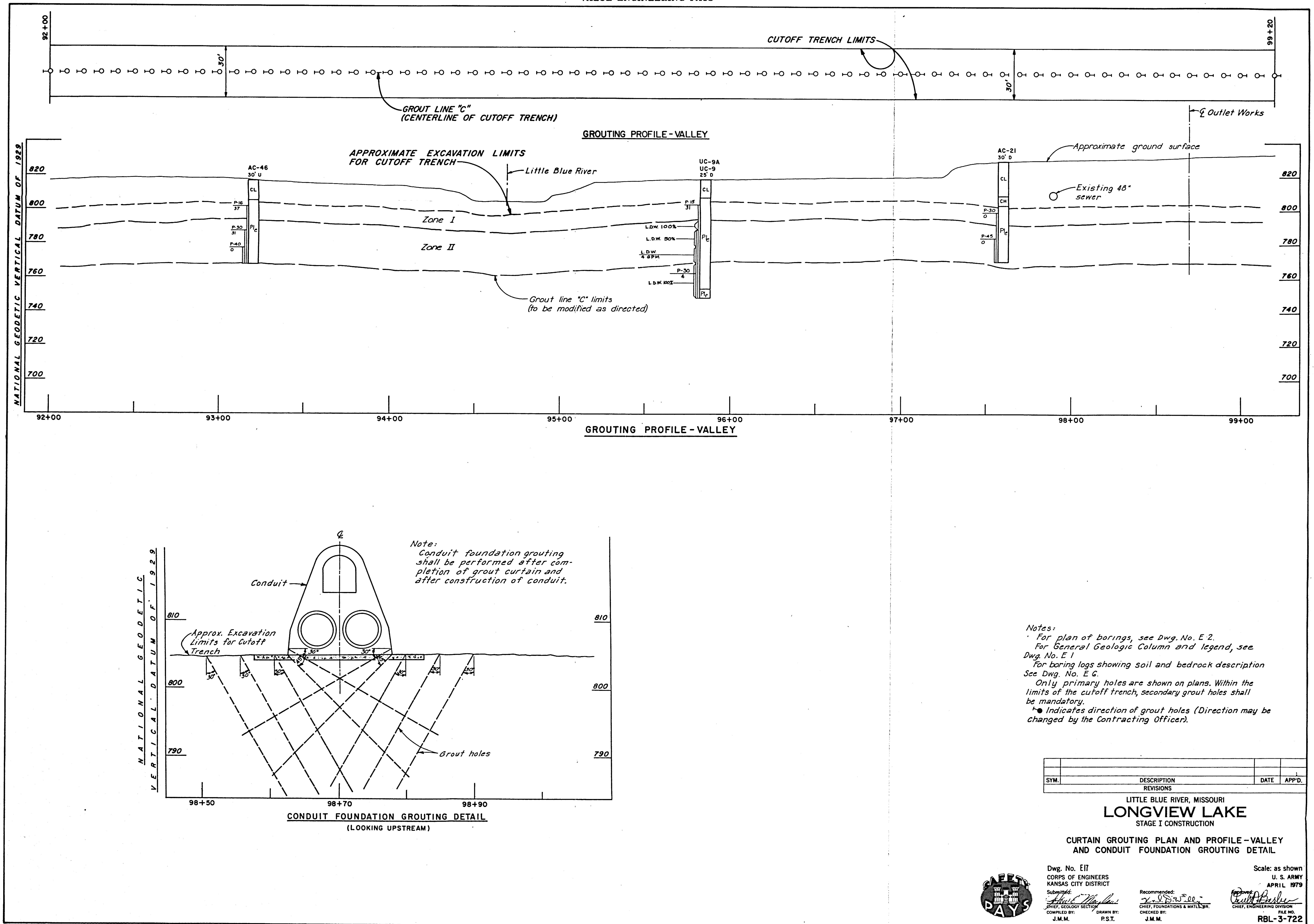
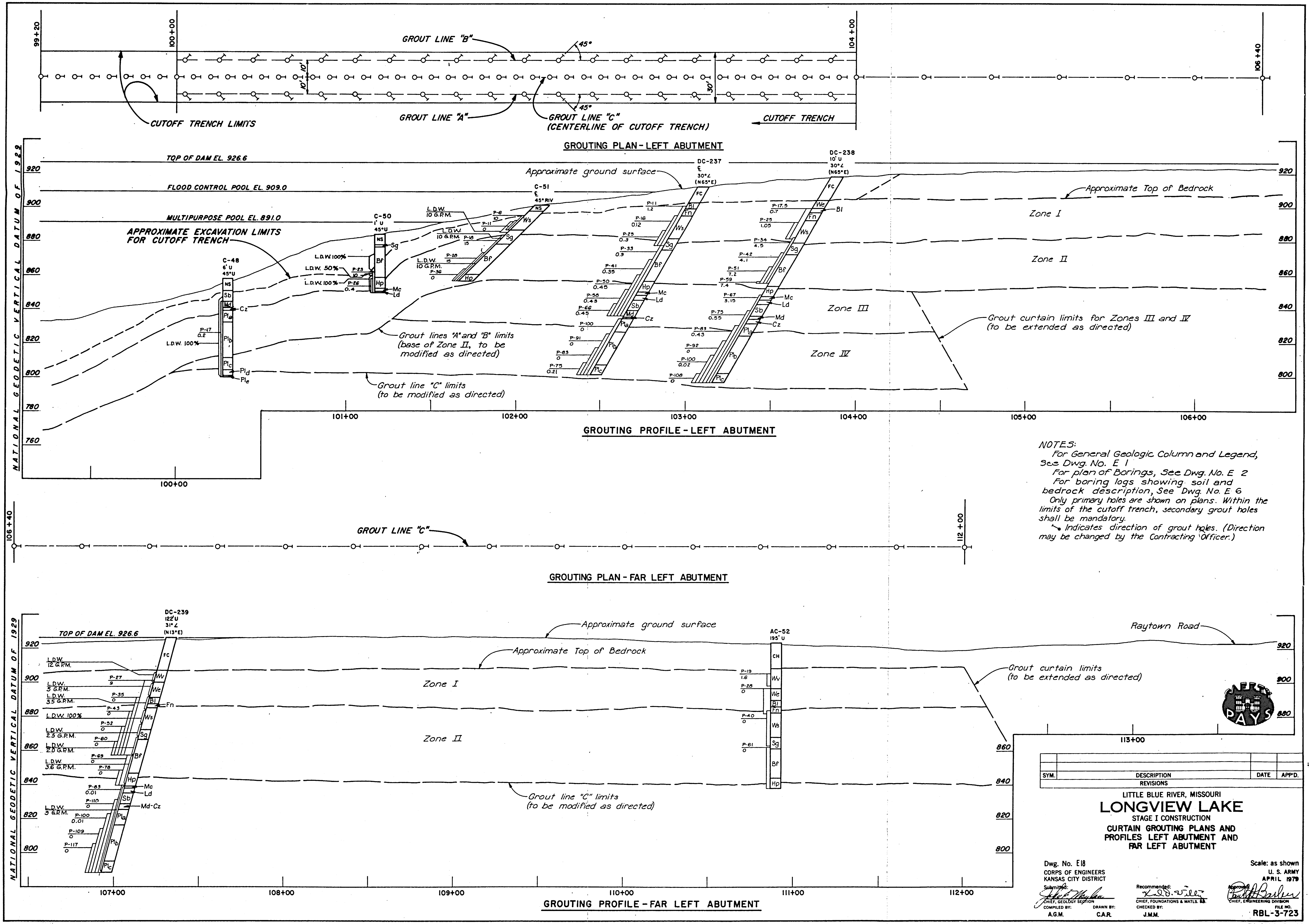

92+00
99+20
30'
CUTOFF TRENCH LIMITS
GROUT LINE "C"
(CENTERLINE OF CUTOFF TRENCH)
℄ Outlet Works
GROUTING PROFILE-VALLEY
NATIONAL GEODETIC VERTICAL DATUM OF 1929
APPROXIMATE EXCAVATION LIMITS FOR CUTOFF TRENCH
Little Blue River
AC-46 30' U
UC-9A UC-9 25' D
AC-21 30' D
Approximate ground surface
Existing 48" sewer
Zone I
Zone II
Grout line "C" limits
(to be modified as directed)
820
800
780
760
740
720
700
92+00
93+00
94+00
95+00
96+00
97+00
98+00
99+00
GROUTING PROFILE-VALLEY
Note:
Conduit foundation grouting shall be performed after completion of grout curtain and after construction of conduit.
Conduit
Approx. Excavation Limits for Cutoff Trench
Grout holes
NATIONAL GEODETIC VERTICAL DATUM OF 1929
810
800
790
98+50
98+70
98+90
CONDUIT FOUNDATION GROUTING DETAIL
(LOOKING UPSTREAM)
Notes:
For plan of borings, see Dwg. No. E 2.
For General Geologic Column and legend, see Dwg. No. E 1
For boring logs showing soil and bedrock description See Dwg. No. E 6.
Only primary holes are shown on plans. Within the limits of the cutoff trench, secondary grout holes shall be mandatory.
Indicates direction of grout holes (Direction may be changed by the Contracting Officer).
SYM.
DESCRIPTION
DATE
APP'D.
REVISIONS
LITTLE BLUE RIVER, MISSOURI
LONGVIEW LAKE
STAGE I CONSTRUCTION
CURTAIN GROUTING PLAN AND PROFILE-VALLEY AND CONDUIT FOUNDATION GROUTING DETAIL
Dwg. No. E17
CORPS OF ENGINEERS
KANSAS CITY DISTRICT
Scale: as shown
U. S. ARMY
APRIL 1979
Submitted:
CHIEF, GEOLOGY SECTION
Recommended:
CHIEF, FOUNDATIONS & MATLS. BR.
Approved:
CHIEF, ENGINEERING DIVISION
COMPILED BY: J.M.M.
DRAWN BY: P.S.T.
CHECKED BY: J.M.M.
FILE NO. RBL-3-722
SAFETY PAYS

PLATE I-N8


GROUT LINE "B"
GROUT LINE "A"
GROUT LINE "C" (CENTERLINE OF CUTOFF TRENCH)
CUTOFF TRENCH LIMITS
CUTOFF TRENCH
GROUTING PLAN - LEFT ABUTMENT
TOP OF DAM EL. 926.6
FLOOD CONTROL POOL EL. 909.0
MULTIPURPOSE POOL EL. 891.0
APPROXIMATE EXCAVATION LIMITS FOR CUTOFF TRENCH
Approximate ground surface
Approximate Top of Bedrock
Zone I
Zone II
Zone III
Zone IV
Grout curtain limits for Zones III and IV (to be extended as directed)
Grout lines "A" and "B" limits (base of Zone II, to be modified as directed)
Grout line "C" limits (to be modified as directed)
GROUTING PROFILE - LEFT ABUTMENT
NATIONAL GEODETIC VERTICAL DATUM OF 1929
GROUT LINE "C"
GROUTING PLAN - FAR LEFT ABUTMENT
Raytown Road
Grout curtain limits (to be extended as directed)
GROUTING PROFILE - FAR LEFT ABUTMENT
NOTES:
For General Geologic Column and Legend, See Dwg. No. E 1
For plan of Borings, See Dwg. No. E 2
For boring logs showing soil and bedrock description, See Dwg. No. E 6
Only primary holes are shown on plans. Within the limits of the cutoff trench, secondary grout holes shall be mandatory.
Indicates direction of grout holes. (Direction may be changed by the Contracting Officer.)
SYM.
DESCRIPTION
DATE
APP'D.
REVISIONS
LITTLE BLUE RIVER, MISSOURI
LONGVIEW LAKE
STAGE I CONSTRUCTION
CURTAIN GROUTING PLANS AND PROFILES LEFT ABUTMENT AND FAR LEFT ABUTMENT
Dwg. No. E18
CORPS OF ENGINEERS
KANSAS CITY DISTRICT
Scale: as shown
U. S. ARMY
APRIL 1979
Submitted:
CHIEF, GEOLOGY SECTION
Recommended:
CHIEF, FOUNDATIONS & MATLS. BR.
Approved:
CHIEF, ENGINEERING DIVISION
COMPILED BY: A.G.M.
DRAWN BY: C.A.R.
CHECKED BY: J.M.M.
FILE NO. RBL-3-723
SAFETY PAYS

APPENDIX II

EXTRACTS - SPECIFICATIONS FOR CONSTRUCTION OF LONGVIEW DAM, STAGE I

Contract No. DACW41-79-B-0049

Note: Numbers 3 ... 70 are General Provisions (GP) of the construction contract.

Numbers SP5 ... SP64 are Special Provisions (SP) of the construction contract.

Section 3B is the Technical Specifications for Curtain Grouting and Exploratory Drilling.

3. <u>CHANGES</u> (1968 FEB)

(a) The Contracting Officer may, at any time, without notice to the sureties, by written order designated or indicated to be a change order, make any change in the work within the general scope of the contract, including but not limited to changes:

(i) in the specifications (including drawings and designs);

(ii) in the method or manner of performance of the work;

(iii) in the Government-furnished facilities, equipment, materials, services, or site; or

(iv) directing acceleration in the performance of the work.

(b) Any other written order or an oral order (which terms are used in this paragraph (b) shall include direction, instruction, interpretation or determination) from the Contracting Officer, which causes any such change, shall be treated as a change order under this clause, provided, that the Contractor gives the Contracting Officer written notice stating the date, circumstances, and source of the order and that the Contractor regards the order as a change order.

(c) Except as herein provided, no order, statement, or conduct of the Contracting Officer shall be treated as a change under this clause or entitle the Contractor to an equitable adjustment hereunder.

(d) If any change under this clause causes an increase or decrease in the Contractor's cost of, or the time required for, the performance of any part of the work under this contract, whether or not changed by any order, an equitable adjustment shall be made and the contract modified in writing accordingly: Provided however, That except for claims based on defective specifications, no claim for any change under (b) above shall be allowed for any costs incurred more than 20 days before the Contractor gives written notice as therein required: And provided further, That in the case of defective specifications for which the Government is responsible, the equitable adjustment shall include any increased cost reasonably incurred by the Contractor in attempting to comply with such defective specifications.

(e) If the Contractor intends to assert a claim for an equitable adjustment under this clause, he must, within 30 days after receipt of a written change order under (a) above or the furnishing of a written notice under (b) above, submit to the Contracting Officer a written statement setting forth the general nature and monetary extent of such claim, unless this period is extended by the Government. The statement of claim hereunder may be included in the notice under (b) above.

(f) No claim by the Contractor for an equitable adjustment hereunder shall be allowed if asserted after final payment under this contract (DAR 7-602.3).

4. DIFFERING SITE CONDITIONS (1968 FEB)

(a) The Contractor shall promptly, and before such conditions are disturbed, notify the Contracting Officer in writing of: (1) subsurface or latent physical conditions at the site differing materially from those indicated in this contract, or (2) unknown physical conditions at the site, of an unusual nature, differing materially from those ordinarily encountered and generally recognized as inhering in work of the character provided for in this contract. The Contracting Officer shall promptly investigate the conditions, and if he finds that such conditions do materially so differ and cause an increase or decrease in the Contractor's cost of, or the time required for, performance of any part of the work under this contract, whether or not changed as a result of such conditions, an equitable adjustment shall be made and the contract modified in writing accordingly.

(b) No claim of the Contractor under this clause shall be allowed unless the Contractor has given the notice required in (a) above; provided, however, the time prescribed therefor may be extended by the Government.

(c) No claim by the Contractor for an equitable adjustment hereunder shall be allowed if asserted after final payment under this contract (DAR 7-602.4).

6. DISPUTES

(a) This contract is subject to the Contract Disputes Act of 1978 (41 U.S.C. 601, et. seq.). If a dispute arises relating to the contract, the Contractor may submit a claim to the Contracting Officer who shall issue a written decision on the dispute in the manner specified in DAR 1-314 (FPR 1-1.318).

(b) "Claim" means

(1) a written request submitted to the Contracting Officer;

(2) for payment of money, adjustment of contract terms, or other relief;

(3) which is in dispute or remains unresolved after a reasonable time for its review and disposition by the Government; and

(4) for which a Contracting Officer's decision is demanded.

(c) In the case of disputed requests or amendments to such requests for payment exceeding $50,000, or with any amendment causing the total request in dispute to exceed $50,000, the Contractor shall certify, at the time of submission as a claim, as follows:

> I certify that the claim is made in good faith, that the supporting data are accurate and complete to the best of my knowledge and belief; and that the amount requested accurately reflects the contract adjustment for which the Contractor believes the Government is liable.

(Contractor's Name)

(Title)

(d) The Government shall pay the Contractor interest

(1) on the amount found due on claims submitted under this clause;

(2) at the rates fixed by the Secretary of the Treasury, under the Renegotiation Act, Public Law 92-41;

(3) from the date the Contracting Officer receives the claim, until the Government makes payment.

(e) The decision of the Contracting Officer shall be final and conclusive and not subject to review by any forum, tribunal, or Government agency unless an appeal or action is timely commenced within the times specified by the Contract Disputes Act of 1978.

(f) The Contractor shall proceed diligently with performance of this contract, pending final resolution of any request for relief, claim, appeal or action related to the contract, and comply with any decision of the Contracting Officer (DAR 7-103.13).

<u>40. CONTRACTOR INSPECTION SYSTEM</u> (1964 NOV)

The Contractor shall (i) maintain an adequate inspection system and perform such inspections as will assure that the work performed under the contract conforms to contract requirements, and (ii) maintain and make available to the Government adequate records of such inspections (DAR 7-602.10(a))

47. SITE INVESTIGATION (1965 JAN)

The Contractor acknowledges that he has investigated and satisfied himself as to the conditions affecting the work, including but not restricted to those bearing upon transportation, disposal, handling and storage of materials, availability of labor, water, electric power, roads and uncertainties of weather, river stages, tides or similar physical conditions at the site, the conformation and conditions of the ground, the character of equipment and facilities needed preliminary to and during prosecution of the work. The Contractor further acknowledges that he has satisfied himself as to the character, quality and quantity of surface and subsurface materials or obstacles to be encountered insofar as this information is reasonably ascertainable from an inspection of the site, including all exploratory work done by the Government, ~~as well as from information presented by the drawings and specifications~~ made a part of this contract. Any failure by the Contractor to acquaint himself with the available information will not relieve him from responsibility for estimating properly the difficulty or cost of successfully performing the work. The Government assumes no responsibility.

51. SUBCONTRACTORS (1972 FEB)

Within seven days after the award of any subcontract either by himself or a subcontractor, the Contractor shall deliver to the Contracting Officer a statement setting forth the name and address of the subcontractor and a summary description of the work subcontracted. The Contractor shall at the same time furnish a statement signed by the subcontractor acknowledging the inclusion in his subcontract of the clauses of this contract entitled "Equal Opportunity," "Davis-Bacon Act," "Contract Work Hours and Safety Standards Act - Overtime Compensation," "Apprentices and Trainees," "Payrolls and Basic Records," "Compliance with Copeland Regulations," "Withholding of Funds," "Subcontracts," and "Contract Termination - Debarment." Nothing contained in this contract shall create any contractual relation between the subcontractor and the Government (DAR 7-602.37).

53. ADDITIONAL DEFINITIONS (1965 JAN)

(a) Wherever in the specifications or upon the drawings the words "directed," "required," "ordered," "designated," "prescribed," or words of like import are used, it shall be understood that the "direction," "requirement," "ordered," "designation," or "prescription," of the Contracting Officer is intended and similarly the words "approved," "acceptable," "satisfactory," or words of like import shall mean "approved by" or "acceptable to," or "satisfactory to" the Contracting Officer, unless otherwise expressly stated.

(b) Where "as shown," "as indicated," "as detailed," or words of similar import are used, it shall be understood that the reference is made to the drawings accompanying this contract unless stated otherwise. The word "provided" as used herein shall be understood to mean "provided complete in place," that is "furnished and installed" (DAR 7-602.41).

55. GOVERNMENT INSPECTORS (1965 JAN)

The work will be conducted under the general direction of the Contracting Officer and is subject to inspection by his appointed inspectors to insure strict compliance with the terms of the contract. No inspector is authorized to change any provision of the specifications without written authorization of the Contracting Officer, nor shall the presence or absence of an inspector relieve the Contractor from any requirements of the contract (DAR 7-602.43).

59. VALUE ENGINEERING INCENTIVE (1977 AUG)

(The following clause is applicable if this contract is in excess of $100,000)

(a) Application. This clause applies to a Contractor developed and documented Value Engineering Change Proposal (VECP) which:

(i) requires a change to this contract to implement the VECP; and

(ii) reduces the contract price without impairing essential function of characteristics, provided that it is not based solely on a change in deliverable end item quantities.

(b) Documentation. As a minimum, the following information shall be submitted by the contractor with each VECP:

(i) a description of the difference between the existing contract requirement and the proposed change, and the comparative advantages and disadvantages of each; justification where function or characteristics of a work item is being altered; and the effect of the change on the performance of the end item;

(ii) an analysis and itemization of the requirements of the contract which must be changed if the VECP is accepted and a recommendation as to how to make each such change (e.g., a suggested specification revision);

(iii) a separate detailed cost estimate for both the existing contract requirement and the proposed change to provide an estimate of the reduction in costs, if any, that will result from acceptance of the VECP, taking into account the costs of development and implementation by the Contractor (including any amount attributable to subcontracts in accordance with paragraph (f) below);

(iv) a prediction of any effects the proposed change would have on related costs to the Military Department such as Government furnished property costs, and costs of maintenance and operation;

(v) a statement of the time by which a change order adopting the VECP must be issued so as to obtain the maximum cost reduction during the remainder of this contract, noting any effect on the contract completion time of delivery schedule; and

(vi) identification of any previous submission of the VECP, including the dates submitted, the agencies involved, the numbers of the Government contracts involved, and the previous actions by the Government, if known.

(c) Submission. To expedite a determination, VECPs shall be submitted to the Resident Engineer at the worksite with a copy to the Contracting Officer. Proposals shall be processed expeditiously; however, the Government shall not be liable for any delay in acting upon any proposal submitted pursuant to this clause. If the evaluation period is likely to exceed 45 calendar days, the PCO shall promptly notify the Contractor of the estimated decision date and provide the reasons for the additional time required. The Contractor has the right to withdraw, in whole or in part, any VECP not accepted by the Government within the period specified in the VECP.

(d) Acceptance. The Contracting Officer may accept, in whole or in part, by contract modification any VECP submitted pursuant to this clause. The Contracting Officer may accept the VECP even though an agreement on price reduction has not been reached, by issuing the Contractor a notice to proceed with the change. Until a notice to proceed is issued or a contract modification applies a VECP to this contract, the Contractor shall remain obligated to perform in accordance with this contract. Contract modifications made pursuant to this clause will so state. The decision of the Contracting Officer as to the acceptance of any VECP under this contract shall be final and shall not be subject to the "Disputes" clause of this contract with the following provisions:

(e) Sharing. If a VECP submitted by the Contractor pursuant to this clause is accepted, the contract price shall be adjusted without regard to profit in accordance with the following provisions:

(i) Definition:

(A) Instant contract savings to the Contractor (ICS) are the estimated reduction in the Contractor's cost of performance resulting from the acceptance of the VECP. The proposed cost reduction includes estimated allowable Contractor development and implementation costs (CC). The Contractor's development and implementation costs include any subcontractor development and implementation costs (see (f) below). For purposes of this clause, Contractor development costs are those costs incurred after the Contractor has identified a specific VE project and prior to acceptance and implementation by the Government.

(B) Government Costs (GC) are those DOD costs which directly result from development and implementation of the VECP, such as test and evaluation of the VECP.

(ii) Calculations and Actions.
Multiply ICS by 45% and GC by 55%.
Add these two results, e.g., (.45 ICS + .55 GC) and subtract from the contract price.

(f) Subcontracts. The Contractor shall include appropriate VE arrangements in any subcontract of $50,000 or greater, and may include such arrangements in contracts of lesser value. To compute any adjustment in the contract price under paragraph (e) above, the Contractor's cost of development and implementation of a VECP which is accepted under this contract shall include any development and implementation costs of a subcontractor which clearly pertains to such VECP, but shall exclude any VE incentive payments which the Contractor may make to a subcontractor. The Contractor may make whatever VE incentive payment arrangements he chooses with his subcontractors, provided that any payments to subcontractors under such arrangements are made from Contractor's, and not the Government's, share of the savings resulting from the VECP.

(g) Data. The Contractor may restrict the Government's right to use any sheet of a VECP or of the supporting data, submitted pursuant to this clause, in accordance with the terms of the following legend if it is marked on such sheet:

"This data furnished pursuant to the Value Engineering Incentive clause of contract ____________________ shall not be disclosed outside the Government, or duplicated, used, or disclosed, in whole or in part, for any purpose other than to evaluate a VECP submitted under said clause. This restriction does not limit the Government's right to use information contained in this data if it is or has been obtained, or is otherwise available, from the Contractor or from another source, without limitations."

In the event of acceptance of the VECP, the Contractor hereby grants to the Government unlimited rights, as defined in the clause of DAR 7-104.9(a), in the VECP and supporting data, except that, with respect to data which qualifies as and is submitted as limited rights technical data in accordance with the clause of DAR 7-104.9(a), the Government shall have the rights specified in the contract modification referred to in paragraph (d) hereof and the data shall be appropriately marked (DAR 7-602.50).

70. VARIATIONS IN ESTIMATED QUANTITIES (1968 APR)

(~~The following clause is not applicable to bid items listed in the "Vari-~~ations in Estimated Quantities - Subdivided Items" clause, and also is not applicable to contracts for dredging work which contain the "Variations in Estimated Quantities - Dredging" clause.)

Where the quantity of a pay item in this contract is an estimated quantity and where the actual quantity of such pay item varies more than fifteen percent (15%) above or below the estimated quantity stated in this contract, an equitable adjustment in the contract price shall be made upon demand of either party. The equitable adjustment shall be based upon any increase or decrease in costs due solely to the variation above one hundred fifteen percent (115%) or below eighty-five percent (85%) of the estimated quantity. If the quantity variation is such as to cause an increase in the time necessary for completion, the Contracting Officer shall, upon receipt of a written request for an extension of time within ten (10) days from the beginning of such delay, or within such further period of time which may be granted by the Contracting Officer prior to the date of final settlement of the contract, ascertain the facts and make such adjustment for extending the completion date as in his judgment the findings justify (DAR 7-603.27).

SP-5. PHYSICAL DATA (1965 JAN)

Information and data ____________ or referred to below are furnished for the Contractor's information. However, it is expressly understood that the Government will not be responsible for any interpretation or conclusion drawn therefrom by the Contractor (DAR 7-603.25).

(a) Physical conditions indicated on the drawings and in the specifications are the result of site investigations by surveys and borings.

(b) Borings: Information shown on the drawings at drill hole locations is from logs of drill holes, whereas information between drill holes is inferred. While the borings are representative of subsurface conditions at their respective locations and for their respective vertical reaches, localized variations characteristic of the subsurface materials of this region are anticipated and, if encountered, such variations will not be considered as differing materially within the purview of Clause 4 of the GENERAL PROVISIONS. Graphic logs of borings located within the areas to be excavated under this contract are shown on the drawings.

(c) Weather conditions: Each bidder should satisfy himself before submitting his bid, as to hazards likely to arise from weather conditions. Complete weather records and reports may be obtained from the local National Weather Service Office.

(d) Transportation facilities: Each bidder before submitting his bid should obtain necessary data as to access highway and railroad facilities. The unavailability of transportation facilities shall not become a basis for claims for damages or extension of time for completion of work.

(e) River conditions: Hydrographs of the Blue River indicated on the drawings. These hydrographs are included for information purposes only to indicate possible river stages in the area. Hydrographs for the Little Blue River are unavailable. The Government will not be responsible for any damage resulting from the supplemental river stages.

SP-7. VARIATIONS IN ESTIMATED QUANTITIES - SUBDIVIDED ITEMS (1976 APR OCE):

This clause is applicable only to the items listed herein.

(a) In order to permit the Contractor to distribute his indirect costs properly to Items Nos. 1, 2, 3, 4, 7, 8, 9, 23, 28, and 38, these items have been subdivided into two or more subitems. All the Contractor's indirect costs for each of these items will be included in the bid price for the first subitem listed under the respective item. Variation from the estimated quantity in the actual work performed under any second or subsequent subitem or elimination of all work under such a second or subsequent subitem will not be the basis for an adjustment in contract unit price.

(b) Where the actual quantity of work performed for Items Nos. 1, 2, 3, 4, 7, 8, 9, 23, and 38, is less than 90% of the quantity of the first subitem listed under such item, the Contractor will be paid at the contract unit price for that subitem for the actual quantity of work performed and, in addition, an equitable adjustment in contract price shall be made upon demand of the Contractor. The equitable adjustment in price for the underrun shall be made on the basis that the Contractor has assumed the risk and is entitled to no adjustment for the first 10% underrun.

(c) If the quantity of work performed under Items Nos. 1, 2, 3, 4, 7, 8, 9, 23, and 38, exceeds 105% or is less than 96% of the total estimated quantity of the subitems under that item, and/or if the quantity of work performed under the second subitem or any subsequent subitem under Items Nos. 1, 2, 3, 4, 7, 8, 9, 23, and 38 exceeds subitem, and if such variation causes an increase or a decrease in the time required for performance of this contract the contract completion time will be adjusted as follows:

(1) If the quantity variation is such that it will cause an increase in the time necessary for completion, the Contracting Officer shall, upon receipt of a written request for an extension within 10 days from the beginning of such delay or within such further period of time which the Contracting Officer grants prior to the date of final settlement of the contract, ascertain the facts and make such adjustments for extending the completion date as in his judgment the findings justify.

(2) If the quantity variation is such that it will cause a decrease in the time necessary for completion, the Contracting Officer shall ascertain the facts and promptly notify the Contractor in writing of his findings and the extent of adjustment.

(d) If the parties fail to agree upon the adjustment to be made the dispute shall be determined as provided in Clause 6, "Disputes," of the GENERAL PROVISIONS (ECI 7-671.7c).

SP-53. LABORATORY AND TESTING FACILITIES

The Contractor shall provide and maintain all measuring and testing devices, laboratory equipment, instruments, transportation, and supplies necessary to accomplish the required testing. All measuring and testing devices shall be calibrated at established intervals against certified standards. The Contractor's measuring and testing equipment shall be made available for use by the Government for verification of their accuracy and condition as well as for any inspection or test desired pursuant to the GENERAL PROVISION clause "Inspection and Acceptance" and "Government Inspectors." The location of the laboratory shall be convenient to the site such that test results are available prior to proceeding with the next sequential phase of the work.

SP-57. COORDINATION BETWEEN CONTRACTORS

The following contract will be considered in the application of Clause 14 of the GENERAL PROVISIONS. The obligations of the Contractor under this Contract will include jointly planning and scheduling the work, on a cooperative basis, with the other Contractor involved in order to minimize delays and interferences. Alterations to systems installed under the other contract, including connections to sewer, waterlines, and bituminous pavement shown as existing, may not be in place.

SP-64. APPROVED EQUAL

The TECHNICAL PROVISIONS of these specifications, in some instances, refer to certain items of equipment, material, or article by trade name. References of this type shall not be construed as limiting cooperation, but shall be regarded as establishing a standard of quality. In this respect, the Contractor's attention is directed to Clause 9 of the GENERAL PROVISIONS.

SECTION 3B

CURTAIN GROUTING AND EXPLORATORY DRILLING

1. SCOPE: This section covers curtain grouting and exploratory drilling, complete.

2. PROGRAM:

2.1 General: The work contemplated consists of constructing a grout curtain as shown and as herein specified. The curtain shall consist of multiple lines of grout holes in the abutments and may consist of single or multiple lines of grout holes in the valley. A single line of grout holes shall be drilled beyond the cutoff trench limit on each abutment. Exploratory drilling will be required to determine foundation conditions or effectiveness of the grout curtain. The program shown on the drawings and described herein is tentative and is presented for bidding purposes only. The amount of drilling and grouting which actually will be required is unknown and will be governed by conditions encountered. The locations, depths, orientation and number of grout holes shall be as directed. Only primary grout holes are shown on the drawings. Subsequent split spaced holes and horizontal holes shall be drilled and grouted at the locations, depths and orientations as directed. Curtain grouting shall be done after cutoff trench excavation is completed to final grade on limestone surfaces, but prior to reaching final grade on shale, siltstones or sandstone surfaces as described in SECTION: EXCAVATION.

2.2 Winter grouting operations: Grout shall be maintained at temperatures above 50°F until injected. The temperature of mixing water shall range from 50°F to 100°F when added to the grout mixer. Storage and handling of grouting materials and equipment shall be at temperatures above freezing. In addition, exposed rock foundations within 15 feet of grout holes shall be maintained at temperatures above 40°F prior to, during, and for 5 days after the holes are grouted, or until placement of a minimum of 3 feet of embankment materials over the foundation. In cold weather, the rock foundation, drill rigs, supply trucks, grout plants, storage sheds, gages, air lines, waterlines, and grout lines shall be heated, inclosed, or insulated as necessary to meet the above temperature requirements. Failure of the Contractor to make adequate preparations for winter operations will not be the basis for any pay or time adjustments.

3. PROCEDURE:

3.1 General: Grouting mixes, pressures, pumping rates, and sequence in which the holes are drilled, grouted and backfilled will be determined in the field and shall be as directed by and performed in the presence of the Contracting Officer. The grout curtain will be subdivided into sections in a manner which will facilitate the Contractor's operations and will conform to the requirements specified. The Contractor shall coordinate his work so that required foundation grouting is performed without interruption. Connections for grout and water injection may be made at the collar of temporary casing, or packers may be placed either in the casing, or on the bedrock as directed. Packers shall be made available for possible use at any depth. The number and depth of packer setting shall be as directed. Positive measures shall be taken to prevent water and grout from discharging uncontrolled onto the bedrock foundation or from discharging on the surface of the earth embankment.

3.2 Abutments: Multiple line grout curtain within the abutments cutoff trench limits shall consist of three lines of grout holes. Each grout line will be subdivided into sections in a manner which will facilitate the Contractor's operations and will conform to the requirements specified. The first section of grout lines "A" (the downstream line) and "B" (the upstream line) shall be drilled and grouted prior to starting grout line "C" (paralleling the dam's centerline). The two outside lines shall be drilled and grouted a minimum horizontal distance of 50 feet ahead of the center grout line at all times during the drilling and grouting program. A single line grout curtain shall be constructed from the ends of the cutoff trench on each abutment to the limits shown on the drawings or as directed.

3.3 Valley: A single line grout curtain is contemplated for the valley portion of the grout curtain. However, in an area where above normal water or grout is injected into grout or exploratory holes, the Contracting Officer may require additional grout lines in that area. Grouting will be required outside the cutoff trench at station 96+20, 25 feet downstream of the dam centerline, where a cavity was encountered during exploratory drilling. The Contractor shall construct necessary temporary dikes in the river channel to permit grout curtain construction across the channel. The dikes shall be so constructed to allow continuous river flow and prevent ponding behind the dikes.

3.4 Concrete conduit: After completion of the grout curtain in the cutoff trench and after the outlet works conduit has been constructed, foundation grouting beneath and adjacent to the conduit shall be performed as shown on the drawings and as directed.

4. EQUIPMENT:

4.1 General: All drilling and grouting equipment used shall be of a type, capacity and mechanical condition suitable for doing the work. Equipment shall be replaced or modified as the work progresses should it prove unsatisfactory. The power supply, equipment, and the layout thereof shall meet all applicable requirements of local, State, and Federal regulations and codes. Sufficient stand-by drilling equipment and grouting equipment shall be provided to avoid delays due to equipment malfunctions. No time adjustments will be made for any delays caused by failure of the Contractor's equipment.

4.2 Drilling equipment: Rotary type drilling equipment with circulating water shall be used for both grout hole drilling and exploratory drilling. Bits for drilling grout holes may be either the coring or noncoring type, and shall provide a minimum hole diameter of 1-3/8 inches at point of maximum penetration. Exploratory holes shall be drilled using NQ or larger size diamond bits and either a double tube core barrel equal to the Diamond Core Drilling Manufacturer's Association "M" Series standards or a wire line core barrel similar in construction and equal in performance to a Longyear Series "10" core barrel. In both grout and exploratory hole drilling, all bits and reamers employed must cut sufficient outside clearance to assure such unrestricted flow of returning drilling fluid that no excessive pressures will be generated (generally not exceeding the maximum allowed in grouting) which could cause jacking of materials drilled. A pressure gage shall be installed on the drill to give accurate indication of drilling fluid pressure being applied at the drill bit.

4.3 Grouting equipment: The grout plant shall be capable of supplying, mixing, stirring, and pumping the grout. The plant shall have a minimum capacity of injecting 30 gpm of grout at a pressure not greater than 150 psi. It shall be maintained in first-class operating condition at all times and any grout hole that is lost or damaged or plugged due to mechanical failure of equipment or inadequacy of grout supply shall be replaced by another grouted hole. The minimum equipment furnished shall include the following:

4.3.1 Grout pump: An air or gasoline-driven, progressing-cavity-type pump capable of delivering grout slurries at a minimum capacity of 30 gpm at a pressure up to 150 psi shall be provided. The pump shall be Robins and Meyers' "Moyno," or approved equal.

4.3.2 Grout mixer: A mechanical grout mixer of not less than 20 cubic feet capacity, capable of effectively mixing and stirring grout having water/cement ratios ranging from 0.6 to 8.0 measured by volume, shall be provided. The mixer shall be equipped with a disc type water meter as described herein.

4.3.3 Bentonite mixer: The bentonite mixer shall be designed and have sufficient capacity to mix an uninterrupted supply of bentonite slurry in order to maintain the pumping rate by the grout plant. Design of the plant is not specified. It is suggested that the Contractor obtain for guidance the mixing directions presented in the following publications of the American Colloid Company, Skokie, Illinois; Volclay, Wyoming Bentonite (Data No. 100) and Effective Water Stoppage (Data No. 229). The Bentonite mixer shall be supplied with an accurate scale and a water meter of identical design as the meter specified herein. It must be capable of completely dispersing and hydrating the bentonite to form a fluid free of lumps.

4.3.4 Sump: A mechanically agitated sump, designed to be capable of effectively stirring and holding in suspension all solid matter contained in the grout, shall be provided. It shall have a minimum capacity of 20 cubic feet.

4.3.5 Header: A circulating grout header shall be used.

4.3.6. Water tank: A tank for auxiliary water supply to be used in pressure testing, flushing, and washing operations.

4.3.7. Water meters: Four suitable water meters (one for the grout mixer, one for the bentonite mixer, one for pressure testing, and one for standby). Each shall be a disk type water mater having a threaded connection for a 1-1/2-inch or 2-inch diameter pipe. Each water meter shall be calibrated to read in cubic feet and tenths, shall include a direct reading totalizer, shall be designed so that after each delivery the hands can be conveniently set back to zero, and shall have a minimum size 6-inch vertical dial.

4.3.8 Pressure gages: A minimum of four pressure gages, in good operating condition, shall be available at all times. The gages shall be graduated in pounds-per-square inch (psi) capable of zero reading adjustment. Gradation intervals shall not exceed 5 psi except that for gages used in grouting at depths less than 20 feet, gradation intervals shall not exceed 1 psi.

4.3.9 Screen: A suitable 1/4-inch mesh for screening the grout before injection.

4.3.10 Expansion packers: Inflatable packers of a type which can be precisely seated at required elevations and which will remain seated and prevent leakage at depths and pressures specified. Minimum air pressure of 100 psi will be required to seat packers. At least 20 rubber expanders shall be available at all times. At least six packers in good repair shall be available at all times.

4.3.11 Fittings and tools: Such valves, pressure gages, pressure hose, supply lines, and small tools as may be necessary to provide a continuous supply of grout and accurate pressure control. The inside diameter of all lines, valves, and other connections starting at the pump head discharge and ending at the base of the header shall not be less than 1-1/2 inch. The inside diameter of all lines and connections made to the packer or casing collar, from the header, and other connections starting at the base of the header and extending through the packer, when used, shall not be less than 3/4-inch. Valves shall be so placed in the header and piping so that all or part of the grout can be injected into the hole or all or part returned to the sump. A suitable pressure gage shall be installed at the header and another gage between the header and hole being pressure tested or grouted in order to indicate the pressure during the injection of water or grout. Miscellaneous calking tools, hammers, wooden wedges, oakum, cotton waste, and lead wool used for calking leaks and the necessary labor and materials for calking shall also be furnished.

4.3.12 Compressors, water pumps, and other required auxiliary equipment with suitable capacity shall be provided.

4.4 Temporary steel casing shall be installed in the collar of the holes drilled from the cutoff trench floor when necessary to permit packer setting at collar. Temporary casing shall also be installed in holes drilled through overburden. The size of the casing shall be such as to permit free passage of the unexpanded packer. The casing shall be tightly seated in bedrock so there is no loss or return of drilling fluid along the outside of the casing. Upon completion of grouting in a hole, the holes shall be backfilled with grout and the casing removed. Packers, nipples or temporary casing for Zone 1 grouting shall not extend more than 1 foot below bedrock surfaces.

5. MATERIALS:

5.1 Grout shall be composed of water, bentonite and cement. The grout mixes will be designed by the Contracting Officer and will be varied to meet conditions encountered.

5.2 Water used in the grout shall be fresh and free from injurious amounts of oil, acid, salt, alkali, organic matter, or other deleterious substances. Normally river water will be satisfactory.

5.3 Cement used in grout shall conform to ASTM Standard C 150, type I or type II. Immediately upon receipt at the site of the work, cement shall be stored in a dry weathertight, and properly ventilated structure. All storage facilities shall be subject to approval and shall be such as to permit easy access for inspection and identification. Only cement furnished in bags will be accepted for use in the work. A sufficient quantity of cement shall be stored at or near the site of work to insure that grouting operations will not be delayed by shortage of cement. Cement containing lumps or foreign matter in amounts considered objectionable by the Contracting Officer shall not be used for grouting.

5.4 <u>Bentonite</u> shall be added to the mixing water and fully dispersed and hydrated before being added to the cement. The addition of bentonite tends to make grout appear to be considerably stiffer than it would be without the bentonite; this may, in effect, reduce the quantity of cement required. Since the bentonite is a fluidifier, the grout is pumpable even though it is stiffer. The amount of bentonite to be used shall vary from 1 percent to 6 percent by weight of the cement. However, past experience has indicated approximately 4 percent bentonite to be optimum. This percentage shall be increased or decreased if so directed by the Contracting Officer. The bentonite shall be handled and stored on as to avoid absorption of moisture, damage, or waste. Bentonite which has become caked due to moisture absorption will be rejected. The bentonite shall be sodium type and equal to grade KWK Volclay, manufactured by the American Colloid Company of Skokie, Illinois. A sufficient quantity of bentonite shall be stored at or near the site of the work to insure that grouting operations will not be delayed by shortage of bentonite.

6. DRILLING:

6.1 <u>Holes for grouting</u> shall be drilled at the locations, in the direction, and to the depths shown on the drawings or as directed. Grout holes shall not deviate more than 3 degrees from angle or direction specified or directed. Only clear water shall be used as drilling fluid. Water pressure during drilling shall not exceed allowable grouting pressures. The use of drilling mud, grease, rod dope, or other lubricant on rotary drill rods will not be permitted. Each hole drilled shall be protected by means of a cap or other suitable device at the collar. Any hole that becomes clogged or obstructed before completion of operations shall be cleaned in a satisfactory manner or another hole provided by and at the expense of the Contractor. Water for drilling shall not be allowed to discharge uncontrolled on the surface of earth backfill, embankment or bedrock foundation. Grout holes will generally be drilled at an angle of 30 degrees from vertical to depths from 7 feet to 150 feet. Horizontal holes will be required in abutments. Holes at angles as low as 30 degrees from horizontal will be required adjacent to conduit structure. Grout holes shall generally be drilled to total depth in one operation. In the event that severe loss or gain of drill water occurs, drilling shall be stopped and the hole washed, pressure tested and grouted prior to deepening the hole to required depth. Where holes for grouting are drilled through overburden, temporary casing shall be installed and sealed into approximately 1 foot of firm bedrock prior to advancing the hole further into bedrock.

6.2 Exploratory holes:

6.2.1 Drilling exploratory core holes: The Contracting Officer may require exploratory holes to be drilled at locations anywhere within the work area during construction operations and may include holes drilled through the embankment or overburden into the underlying bedrock. Exploratory holes shall be drilled at any angle from vertical to horizontal, and shall not be in excess of 200 feet in depth, measured from the collar of the hole. The locations, directions, and degree of inclination will be determined in the field. Only clear water shall be used as drilling fluid. Since the maximum recovery of unpredictable soft or friable materials is of prime importance, the Contractor shall make every effort to recover 100 percent of the core. Care shall be exercised to obtain cores in good condition. The core barrel shall be pulled whenever necessary to prevent loss or damage to the core. When the core barrel becomes blocked, whether intentionally or not, it shall be pulled, regardless of the interval drilled.

6.2.2 Records and supplementary information: The Contractor shall keep in a satisfactory manner an accurate driller's log of all exploratory holes drilled. The log shall include a nontechnical description of all materials encountered in drilling, their location in the holes, and the location of special features such as seams, open cracks, soft or broken rock, points where abnormal loss or gain of drill water occurred, amount of water loss or gain, drill action, penetration rate, bit record, drilling RPM, hydraulic pressure, and other items considered pertinent. Cores shall be fitted together and placed in core boxes in the correct sequence, with each run separated accurately by wooden blocks marked according to distances measured by tape in the holes. Core losses shall be marked on blocks of the end of the runs in which they occur. Core boxes shall be furnished by the Contractor and shall conform to the details shown on the drawings. Each box shall be marked clearly for identification and no box shall contain cores from more than one hole. Records, core, and core boxes shall become the property of the Government.

6.2.3 Exploratory holes in bedrock shall be pressure tested and stop grouted under pressure as directed. In the event open holes drilled by others are uncovered during required excavation, they shall be cleaned out and grouted in the same manner as exploratory holes drilled under this contract.

7. DEFINITIONS:

7.1 Zone is a predetermined partial depth of the grout curtain. Zones are shown on the drawings. The first zone is the uppermost and deeper zones are successively numbered.

7.2 Section is a reach along the grout curtain, not more than 300 feet in length. A section is further defined as a portion of the grout curtain, as determined by the Contracting Officer that may be grouted from a single setup of the grout pump.

7.3 Split spacing is the procedure of locating an additional grout hole midway between two previously drilled grout holes. The number of grout holes is increased, progressively, by this method as deemed necessary by the Contracting Officer until the amount of grout used, or water pressure testing, indicates that the foundation is tight.

7.4 Primary holes are the first set of grout holes drilled at regular spacings along the grout curtain and the first set of holes to be completely drilled and grouted in a given section. Within the cutoff trench limits, Grout Line "C" (centerline of cutoff trench), primary spacings shall be 10 feet. Primary spacings for Grout Lines "A" and "B" shall be 20 feet. Beyond the cutoff trench limits on each abutment, primary holes drilled through overburden shall be on 40-foot spacings or as directed.

7.5 Secondary holes are the grout holes drilled at the midpoint between primary holes, and are the second set of holes to be completely drilled and grouted in a given section. Within the cutoff trench limits, secondary holes shall be required.

7.6 Tertiary holes are the grout holes drilled at the midpoint between primary and secondary holes, and are the third set of holes to be completely drilled and grouted in a given section.

7.7 Quaternary holes are the fourth set of grout holes and may be drilled at the midpoint between secondary and tertiary holes or at selected locations adjacent to other holes. They may include all, or only a part of a given section and/or zone.

8. GROUTING PROCEDURES:

8.1 General: Grouting shall be performed immediately after pressure testing, unless otherwise directed.

8.2 Washing and pressure testing: Immediately before pressure grouting of each hole is begun, the hole shall be thoroughly washed under pressure and pressure tested. Holes in which the allowable pressure cannot be maintained shall be washed for a period of 10 minutes, with the pump running at full capacity, or for such period of time as fracture-filling is being removed, as evidenced by the escape of muddy water through surface openings or other grout holes. Each zone shall be pressure tested separately by setting a packer at the top of each zone. In holes where large water takes occur, additional packer settings shall be required to determine the zone of water take. In all holes that show an increasing rate of water take during a pressure test, the testing shall be continued until there is no longer any increase in the rate of take. All pressure tests shall be continued for at least 10 minutes. Pressures to be used for washing and pressure testing shall be as directed.

8.3 Grouting method:

8.3.1 General: Generally, each hole shall be drilled to the final depth and washed. Then, by means of setting a packer at various depths in the hole, the hole is pressure washed, pressure tested as specified hereinbefore, and grouted at successively shallower depths. The packer shall be left in place after each grouting until the pressure on the newly placed grout has dropped to or below the maximum pressure contemplated for the next higher zone. An exception to the general rule of initially drilling of such holes to final depth may be made by the Contracting Officer in instances of significant water loss or gain. In the event lost circulation or artesian pressures occur, the hole shall be grouted prior to drilling to final depth. Grouting pressures are generally reduced with each succeeding setting of the packer.

8.3.2 Limitations: Holes shall be drilled and grouted in sections commencing at one end of the valley portion of the grout curtain continuing in uninterrupted sequence in one direction across the valley. Abutment holes shall be drilled and grouted proceeding up the slope for each spacing sequence. At least two holes in the set in advance of the hole being grouted shall be drilled. Grouting of holes of any one set (primary, secondary, etc.) shall be completed for at least 24 hours before drilling of holes for the next set is commenced. It may be necessary to set packers in holes other than the one being grouted if grout communication between holes occurs.

9. GROUTING REQUIREMENTS:

9.1 Grouting pressures directed to be used in the work will vary with conditions encountered in the respective holes. It is anticipated that pressures will range from 2 psi to 100 psi.

9.2 Grout mixes: The water-cement ratio by volume will be modified to meet the varying characteristics of each hole as revealed by grouting operation and will range between 8.0 and 0.6.

9.3 Grout injection: In general, if pressure tests indicate a tight hole, grouting shall be started with a thin mix. If an open hole condition exists, as determined by loss of drill water or inability to build up pressure during washing operations, then grouting shall be started with a thicker mix but, for the first batch, not less than a 5.0 water-cement ratio. The grout pump shall operate as nearly as practicable at a constant speed at all times. If the hole is open, the mix ratio shall be decreased as directed until the required pressure has been reached. When pressure tends to rise too high, the grout mix shall be changed, if so directed, to produce the desired results. If necessary to relieve premature stoppage, periodic applications of water under pressure shall be made. Under no conditions shall the pressure or rate of pumping be increased suddenly, as either may produce a water-hammer effect which may promote stoppage. Should grout leaks develop, the leaks shall be calked with lead wool, oakum, wooden wedges, cotton waste, or other approved material, when and as directed. After grouting of any hole, the pressure shall be maintained by use of a stopcock or other suitable device until the grout has set to the extent that it will be retained in the hole.

9.4 Refusal: Grouting of any hole is considered to have reached refusal when the grout take at maximum allowable grouting pressure is less than 1 cubic foot in 10 minutes.

9.5 Open holes: If, due to size and continuity of fractures, it is found impossible to reach the required pressure after pumping a reasonable volume of grout at the minimum workable water-cement ratio, the speed of the pumping shall be reduced or the grout bypassed temporarily and intermittent grouting shall be performed allowing sufficient time between grout injections for the grout to stiffen. Following such reduction in pumping speed, if the desired result is not obtained, grouting in the hole shall be discontinued when directed. In such event, the grout shall be allowed to set and the hole shall be cleaned. Additional drilling and grouting shall then be done in this hole or in the adjacent area as directed, until the desired resistance is built up.

9.6 Backfilling grout holes: At the end of pressure grouting each section, all holes shall be backfilled with grout having a water-cement ratio of 0.7, or as directed. The backfill grout shall be pumped through a 1-inch (minimum) I.D. delivery line which shall extend to the bottom of the drill hole or to the top of "set up" grout. A section of steel pipe of 3/4-inch (minimum) I.D. and 6 feet (minimum) in length shall be attached to the end of the delivery line extending down the hole. The depth to which the delivery tube is inserted shall be measured and recorded. The delivery tube shall remain at maximum depth until the grout has reached the surface and begins flowing from the hole. Then the delivery tube shall be withdrawn with flow through the tube continuing until backfill is completed. After the backfill grout has set, and again prior to placing the embankment, all holes shall be rebackfilled in the event that settlement of the grout has occurred.

9.7 Regrouting: After the drilling and grouting of any section or sections has been deemed completed, it may develop that conditions are such that all or parts of the foundation already grouted require additional grouting. In such event, the equipment shall be returned and additional holes for grouting shall be drilled and grouted as directed.

9.8 Waste: Grout that cannot be placed, for any reason, within 2 hours after mixing shall be wasted as directed.

9.9 Equipment arrangement and operation: The arrangement of the grouting equipment shall be such as to provide a continuous circulation of grout throughout the system and to permit accurate pressure control by operation of a valve on the grout return line, regardless of how small the grout take may be. The equipment and lines shall be prevented from becoming fouled by the constant circulation of grout and by the periodic flushing out of the system with water. Flushing shall be done with the grout intake valve closed, the water supply valve open, and the pump running at full speed.

9.10 Records: The Contracting Officer will keep records of all grouting operations, such as a log of the grout holes, results of washing and pressure testing operations, time of each change of grouting operation, pressure, rate of pumping, amount of cement for each change in water-cement ratio, percentage of bentonite, and other data deemed by him to be necessary. The Contractor shall furnish all necessary assistance and cooperation to this end.

9.11 Communications: A satisfactory means of communication such as telephones or radios shall be provided for communicating between various elements of the plant.

9.12 Cleanup: During grouting operations, the Contractor shall take such precautions as may be necessary to prevent drill cuttings, loose and semi-detached rock, weathered and decomposed rock, soil, equipment exhaust, oil, wash and drainage water, and grout, from defacing or damaging the permanent structure or from remaining on the foundation. The foundation shall be maintained in a clean condition throughout the grouting operations. A continuing effort will be necessary to reclean and maintain a clean foundation. Such effort may require daily handwork and washing operations. The Contractor shall furnish such pumps as may be necessary to care for waste water and grout from his operations and shall not allow either waste water or natural drainage to pond in the cutoff trench. The Contractor shall, upon completion of his operations, clean up all waste resulting from his operations that is unsightly or would interfere with the efficient completion of other work in this Contract.

10. DRILLING AND GROUTING LOG: A complete log shall be made for submission to the Contracting Officer. The log shall contain all information necessary for computation of quantities including: linear feet of drilled grout holes, number of connections to grout holes, cubic feet of dry portland cement and pounds of bentonite used in grout mixtures and linear feet of drilled exploratory core holes. The log shall contain a complete description of the drilling and grouting equipment used.

11. MEASUREMENT AND COMPUTATION OF QUANTITIES:

11.1 Measurement for foundation drilling and grouting items: The information contained in the Government's drilling and grouting log shall be the basis of measurement for drilling holes, connections to grout holes, placing grout, portland cement and bentonite used in exploratory and grout holes.

11.2 Computation of quantities:

11.2.1 Drilling of grout holes: Quantities of drilling of grout holes will be computed in linear feet of drilling actually performed. The computations will be based on information contained in the Government's drilling and grouting record and the following controls:

(1) Fifty percent allowance for drilling holes for grouting through overburden.

(2) Fifty percent allowance for redrilled holes where grout has been allowed to set by direction of the Contracting Officer.

(3) No allowance for redrilling of holes rendered unsatisfactory if the condition resulted through fault of the Contractor.

11.2.2 Connection to grout holes: An allowance of one connection will be made for each hook-up to temporary casing or for each setting of packer for the purpose of injecting grout. No allowance will be made for connections to grout holes for other purposes.

11.2.3 Placing grout: Quantities of grout placement will be computed in cubic feet. The computation will be based on information contained in the Government's drilling and grouting log for the amount of dry cement in the grout mixtures actually injected into the grout holes and backfilling cased holes and exploratory holes at the direction of the Contracting Officer.

11.2.4 Portland cement: Quantities of portland cement will be computed in cubic feet. The computation will be based on information contained in the Government's drilling and grouting log for the cement used in the grout mixtures actually injected into grout holes and backfilling grout holes and exploratory holes or wasted at the direction of the Contracting Officer. One bag of 94 pounds will be considered as 1 cubic foot. No allowance will be made for wasted portland cement as a result of faulty or improper procedure of the Contractor.

11.2.5 Bentonite will be computed in pounds actually used in grout mixtures. No allowance will be made for wasted bentonite as a result of faulty or improper procedure of the Contractor.

11.2.6 Drilling of exploratory core holes: Quantities of drilling of exploratory core holes will be computed in linear feet. The computation will be based on holes satisfactorily drilled as directed.

11.3 The lump sum item "Mobilization and Demobilization" shall include the cost of assembling all plant and equipment at the site preparatory to initiating the work and for removing it therefrom when the drilling and grouting program has been completed. Sixty percent of the lump sum price will be paid following completion of moving onto the site, including the complete assembly in working order of all equipment necessary to perform the required drilling and grouting operations. The remaining 40 percent of the lump sum price will be paid when all equipment has been removed from the site. No allowances above the contract prices will be made for drilling and grouting in areas previously grouted or for the expense of any movement of equipment necessary to the performance of such work. No allowance will be made for temporary casing and fittings.

12. BIDDING SCHEDULE ITEMS applicable to the work covered by this section are as follows:

Item	Unit
Foundation Drilling and Grouting	
a. Mobilization and Demobilization	lump sum
b. Drilling Grout Holes	lin ft
c. Connection to Grout Holes	each
d. Placing Grout	cu ft
e. Portland Cement	cu ft
f. Drilling Exploratory Core Holes	lin ft
g. Bentonite	pounds