MISCELLANEOUS PAPER C-69-4

LABORATORY AND FIELD GROUTING SUPPORT FOR PROJECT SCROLL

by

D. M. Walley
T. L. Ellis

April 1969

Sponsored by

U. S. Atomic Energy Commission

and

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Conducted by

U. S. Army Engineer Waterways Experiment Station
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ARMY-MRC VICKSBURG, MISS.

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Foreword

The work performed by the U. S. Army Engineer Waterways Experiment Station (WES) in connection with Project Scroll was accomplished during the first half of 1968 for the U. S. Atomic Energy Commission (AEC) and the Advanced Research Projects Agency (ARPA) under the technical direction of the University of California's Lawrence Radiation Laboratory (LRL) at the Nevada Test Site. AEC, ARPA, LRL, Fenix and Scisson, and Reynolds' Electrical and Engineering Co. provided excellent cooperation, logistic support, and assistance to WES during this investigation.

WES's participation in the Project was under the direction of Mr. Bryant Mather, Chief, Concrete Division, and under the supervision of Messrs. J. M. Polatty and R. A. Bendinelli. The laboratory and field work was performed under the direct supervision of Messrs. W. L. Burnett, J. A. Boa, Jr., D. M. Walley, and T. L. Ellis. Messrs. Walley and Ellis prepared this report.

COL John R. Oswalt, Jr., CE, and COL Levi A. Brown, CE, were Directors of the WES during the conduct of the work and the preparation and publication of this report. Mr. J. B. Tiffany and Mr. F. R. Brown were Technical Directors.

Contents

Conversion Factors, British to Metric Units of Measurement

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
cubic feet	0.0283168	cubic meters
gallons (U. S.)	3.785412	cubic decimeters
pounds	0.45359237	kilograms
pounds per square inch	0.070307	kilograms per square centimeter
pounds per cubic foot	16.0185	kilograms per cubic meter
feet per second	0.3048	meters per second
Fahrenheit degrees	5/9	Celsius or Kelvin degrees*

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = (5/9)(F - 32). To obtain Kelvin (K) readings, use: K = (5/9)(F - 32) + 273.15.

Summary

In Project Scroll, a nuclear device was detonated at a depth of 750 ft in a vertical hole drilled in Area 19 of the U. S. Atomic Energy Commission's Nevada Test Site. The U. S. Army Engineer Waterways Experiment Station (WES) was responsible for (a) development of instrument-to-formation coupling grout mixtures embodying specified physical properties matching as closely as possible those of the formation at the Project site, (b) development of an emplacement hole stemming grout, (c) supervision of the mixing and placement of the grout mixtures, and (d) determining, on detonation date, the pertinent physical properties of field-cast grout specimens representing the field-placed grout. In general, it is believed that the physical properties of the grout mixed and emplaced in the field closely matched those set forth in the design criteria.

LABORATORY AND FIELD GROUTING SUPPORT FOR PROJECT SCROLL

Introduction

Overall objectives

1. Project Scroll, a research project of the Vela-Uniform Program, sponsored jointly by the U. S. Atomic Energy Commission (AEC) and the Advanced Research Projects Agency (ARPA), under the Technical Direction of the University of California's Lawrence Radiation Laboratory (LRL), Livermore, Calif., was primarily concerned with the seismic coupling of a dry, low-density, highly porous medium in conjunction with an underground nuclear explosion.

Objective and scope of WES participation

2. The U. S. Army Engineer Waterways Experiment Station (WES) was given the primary mission of developing an emplacement hole stemming grout and formation-matching grouts for formation coupling of instruments in three adjacent instrument holes. These four holes were drilled to various depths through strata of several geologic ages. Consequently, the physical properties of the formations required that formation-matching grouts be specifically developed embodying the physical properties of the different formations encountered.

Grout Mixtures

Design criteria submitted by LRL

3. The following is a résumé of the grout criteria furnished by LRL:

a. An instrument grout for use at a depth of 735 ft,* simulating low-density ashfall. The following ranges of physical properties are desirable: density, 84-93.5 pcf; pulse velocity, 6450-6950 fps; heat of hydration temperature, ≤150 F.

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* A table of factors for converting British units of measurement to metric units is presented on page ix.

b. An instrument grout for use at a depth of 1200 ft, simulating zeolitized tuff. Criteria are: density, 109-115 pcf; pulse velocity, 8250-8750 fps; heat of hydration temperature, ≤150 F.

c. An instrument grout for use at a depth of 2000 ft, simulating rhyolite. Criteria are: density, 121.5-127 pcf; pulse velocity, 10,000-10,500 fps; heat of hydration temperature, ≤150 F.

d. An emplacement hole stemming grout with a density of 120 pcf and an unconfined compressive strength of 400 psi at 2 days age. Heat of hydration temperature should not exceed 135 F.

Materials and laboratory mixtures

4. WES procured grouting materials from the Nevada Test Site stocks. These materials were a silica sand from a source in California and a class "G" cement produced by the Southwestern Portland Cement Company of Victorville, Calif. Other materials used in the WES-proportioned grouts included fly ash, bentonite, hydrated lime, and an air-entraining admixture.

5. Grouts developed by WES for use in Project Scroll were: mixture S-10A for the device hole; mixture S-2BB for holes 1 and 2 and stage 3 of hole 3; mixture S-8A for stage 1 of hole 3; and mixture S-6GG for stage 2 of hole 3.

6. Mixture S-2BB was found to be suitable for use as a lead-lubricating grout, the purpose of which is to lubricate mixers, pumps, tubing, and formations downhole prior to the emplacement of the formation or stemming grout.

7. As previously noted, LRL requested that all grouts other than those used in the emplacement hole be proportioned to match as closely as possible, when hardened, certain in situ physical properties of the various geological formations encountered in the drilled holes where instruments were to be placed. Formations encountered from the surface to a depth in excess of 2000 ft were: partially to densely welded tuff from 0 to 500 ft; low-density ashfall from 500 to 970 ft; zeolitized tuff from 970 to 1380 ft; and rhyolite from 1380 to 2000+ ft.

8. The mixtures proportioned to meet project criteria are presented in the tabulation on the following page.

Material	Solid Volume cu ft	Dry Batch Weight, lb (SSD)*
Mixture S-8A, for Stage 1 of Hole 3		
Cement, "G"	0.263	51.6
Fly ash	0.216	33.0
Gel (bentonite)	0.011	1.7
Monterey silica sand (20-40 gradation)	0.909	150.0
Hydrated lime	0.058	8.5
Water	0.815	50.8
CFR-2 (friction reducer)	--	0.34
NVX (air-entraining agent)	--	0.1875
Mixture S-6GG, for Stage 2 of Hole 3		
Cement, "G"	0.335	65.7
Fly ash	0.144	22.0
Monterey silica sand (20-40 gradation)	0.545	90.0
Gel (bentonite)	0.024	3.5
Hydrated lime	0.072	10.5
Water	1.056	65.8
NVX (air-entraining agent)	--	0.25
Mixture S-10A, for the Device Hole		
Cement, "G"	0.239	46.9
Fly ash	0.239	36.5
Gel (bentonite)	0.011	1.7
Monterey silica sand (20-40 gradation)	1.060	175.0
Hydrated lime	0.057	8.3
Water	1.058	65.9
NVX (air-entraining agent)	--	0.1875
Mixture S-2BB, for Holes 1 and 2 and Stage 3 of Hole 3		
Cement, "G"	0.192	37.7
Fly ash	0.287	43.8
Gel (bentonite)	0.033	4.9
Hydrated lime	0.067	9.8
Water	1.047	65.2
NVX (air-entraining agent)	--	0.25

* Saturated surface dry.

Laboratory-simulated downhole conditions

9. A model was designed to simulate the worst conditions that might be experienced in a stratum of highly permeable, low-density ashfall. Photograph 1 depicts the sequential formation of a model, and photograph 2

shows a general view of the completed model setup. The main objective was to gain an indication of how much mixture water would be lost to the surrounding medium prior to hardening of the grout and how this moisture loss would affect computed volumes and hardened physical properties of the grout. Mixture S-2BB was used. The simulated model was an 18-in.-diam by 34-in.-deep, 1-in.-mesh wire cylinder covered with cotton muslin. This central core cylinder was placed inside a 55-gal drum, forming an annulus of 4 in. between the drum and the core. The annulus was filled with a mixture consisting of, by weight, 80% vermiculite, 10% rocklite sand, and 10% bentonite gel. This procedure resulted in a highly permeable and insulated area around the grout core. After the central core had been filled with grout, two thermocouples, attached to a recording potentiometer, were positioned at the center of the mass, and the temperature rise resulting from heat of hydration of the cement was monitored for 24 hr past the time of peak temperature, which occurred 19 hr after placement (plate 1).

Physical tests of laboratory mixtures

10. Laboratory specimens cast from mixtures S-2BB, S-6GG, S-8A, and S-10A were tested for the physical properties listed at the ages indicated in the following tabulation. Each value represents the average of three specimens.

Mixture	1 Day	2 Days	7 Days	14 Days	28 Days
		Pulse Velocity, fps, at Ages Shown			
S-2BB	--	--	6,040	6,220	6,835
S-6GG	--	--	7,985	8,265	8,590
S-8A	--	--	10,170	10,615	10,920
		Density, pcf, at Ages Shown			
S-2BB	--	--	91.3	90.0	89.9
S-6GG	--	--	104.2	104.1	104.1
S-8A	--	--	124.4	124.1	124.0
S-10A	120.0	119.8	119.0	119.4	120.4
		Compressive Strength, psi, at Ages Shown			
S-10A	240	360	740	1,180	1,685

11. Test data on 4-in. specimens cored from a simulated downhole grout plug are listed below.

Mixture	Age days	Pulse Velocity fps	Density pcf
S-2BB	14	7,530	95.3

These values are judged to be somewhat higher than those of the grout actually emplaced downhole. This judgment is based on the probability that considerably less permeability existed in the ashfall areas downhole than was simulated in the laboratory tests. Values of approximately 7000 fps and 92 pcf are felt to be more representative of the sonic pulse velocity and density of the emplaced grout on detonation date.

12. Plastic-state grout data compiled on laboratory mixtures utilizing standard laboratory procedures, including "Method of Test for Water Retentivity of Grout Mixtures, CRD-C 80,"* are as follows:

Mixture	Bleeding With Air and Lime %	Bleeding Without Air or Lime, %	Bleeding With Lime but Without Air, %	Bleeding With Air but Without Lime, %	Time Required to Extract 60 ml of Water from Sample, sec	
					With Lime	Without Lime
S-2BB	0.7	4.2	0.9	2.0	83	51
S-6GG	0.6	2.9	1.3	2.9	145	128
S-8A	0.0	2.0	0.9	1.5	582	161
S-10A	2.2	3.3	3.3	3.1	130	78

Field Grouting

Grouting operations

13. The first field operation performed at the Project site was grouting of instrument hole U19N No. 3. This hole was located 750 ft directly south of the emplacement hole. It was drilled to a total depth of

* U. S. Army Engineer Waterways Experiment Station, CE, "Handbook for Concrete and Cement," Aug 1949 (with quarterly supplements), Vicksburg, Miss.

2050 ft through 500 ft of partially to densely welded tuff, 470 ft of low-density ashfall, 410 ft of zeolitized tuff, and 620+ ft of rhyolite (see paragraph 7).

14. Hole U19N No. 3 required three stages. The grout mixture used for the first stage was S-8A. Two hundred cubic feet of this grout mixture was pumped downhole by means of 1.55-in.-ID steel tubing run downhole inside 3.5-in.-diam perforated fiberglass tubing (see photographs 3-5). Subsequent tagging showed the top of the grout at a depth of 1944 ft. The ambient air temperature at the surface was 65 F; the mixture water temperature, iced, was 40 F; and the grout temperature after mixing was 56 F. Air content, determined at the surface after all materials had been mixed, was 9.5% by volume. Subsequent to the completion of first stage grouting operations, the hole was stemmed with Overton sand to the 1225-ft level.

15. A significant rise in temperature occurred during the downhole pumping operation, probably resulting from the effects of friction in such a relatively small-bore injection tubing (1.55-in.-ID). Grout temperature at the bottom of the hole was 25 deg F higher than the temperature at which the grout was introduced into the tubing. Pumping pressure was approximately 1300 psi, indicating a high degree of friction. The pumping rate was approximately 9.8 cu ft per min.

16. Hole U19N No. 2, a 15-in.-diam instrument hole, was drilled to a total depth of 785 ft through partially to densely welded tuff and low-density ashfall. Subsequently, perforated 3.5-in.-ID fiberglass tubing was run downhole and grouted in place. A 60-ft column of grout mixture S-2BB was then pumped downhole to couple the instrument package, located near the bottom of the hole, to the surrounding medium. U19N No. 2 was located 450 ft directly south of the emplacement hole U19N and 200 ft directly south of the U19N No. 1 hole. Tagging after completion showed the top of the grout at the 707-ft depth. Subsequently, the hole was stemmed to the surface with Overton sand. All grouting operations on hole U19N No. 2 were completed on 11 April 1968. The ambient air temperature was 62 F. Temperature of the grout at the surface, before introduction into the downhole tubing, was 66 F, which increased to 71 F at the bottom of the hole, according to the thermistors monitored by LRL personnel. A total

volume of 135 cu ft of grout was pumped downhole through the injection tubing (photograph 6).

17. The mobile derrick and traveling block were then moved back over U19N No. 3 for emplacement of the second grout plug at a depth of 1225 ft. This stage, composed of mixture S-6GG, was a 50-ft plug, filling the interval between the 1225- and 1175-ft levels. The inside of the perforated fiberglass tubing was filled with a lead-lubricating grout, consisting of fly ash, bentonite, lime, and an air-entraining admixture. Instrument package No. 2, to be grouted in place, was located in a stratum of zeolitized tuff. The rotary action of the drill had increased the planned diameter of the hole somewhat during drilling operations due primarily to the relative incompetence of the rock material.

18. On 12 April 1968, approximately 179 cu ft of grout was emplaced, as stage No. 2, at a surface temperature (after mixing) of 53 F. Temperature of the iced mixing water was 40 F. The mixing water for all the grout mixtures was iced with locally procured block ice to retard heat buildup downhole resulting from hydration of the cement. Depressed mixing water temperatures are one means by which the maximum hydration temperature of a portland cement grout mixture placed downhole can be significantly lowered. After completion of operations on 12 April 1968, the top of the grout plug was tagged at a depth of 1158 ft. The hole was subsequently stemmed with Overton sand to the 775-ft level.

19. Grout mixture S-2BB was used in the third and final stage of hole U19N No. 3. The peak temperature measured in that stage was 155 F, which is 5 deg higher than criteria allowed. This increase in temperature is attributed to the hole's being drilled to a 29-in. diameter instead of a 15-in. diameter. The grout mixture was developed for a 15-in.-diam hole. The appreciable decrease in surface-to-volume ratio of the grout mass resulted in an impedance of the conduction of the heat to the formation. Five hundred cubic feet of mixture S-2BB was mixed and placed downhole on 15 April 1968. Mixing water temperature was 40 F, ambient air temperature was 43 F, and the grout temperature at the surface was 56 F. Placing of the third stage of hole U19N No. 3 was finished at midnight on 15 April 1968. The top of the grout plug was tagged at a depth of approximately

725 ft. The remainder of the open hole was stemmed to the surface with Overton sand. Grouting of the third stage of U19N No. 3 followed the usual procedure of using perforated fiberglass tubing, which remained in place after completion of grouting operations. Steel tubing, 1.55 in. in diameter, was run downhole inside the fiberglass tubing for actual grout transport.

20. The derrick was then moved over hole U19N No. 1 for emplacement of instrument grout. U19N No. 1 was located 100 ft directly north of U19N No. 2. The diameter of the hole was originally planned to be 17.5 in. However, widening of the hole did occur during drilling operations due to the relative incompetence of the strata penetrated, particularly the weak, low-density ashfall. One of the two grout stages scheduled for placement in this hole occupied the interval between the 750- and 670-ft depths. Tagging after emplacement of the grout indicated that the top of the stage was at the 670-ft level. The ambient air temperature at the time of mixing and emplacement was 50 F, and the mixing water temperature was 40 F. Grout temperature at the surface was 55 F. Emplacement was accomplished during the afternoon of 15 April 1968. The pumping rate was approximately 27.2 cu ft per min down 1.55-in.-ID steel tubing. Pumping continued until 150 cu ft of mixture S-2BB had been placed downhole. Overton sand was used to stem the hole from the 670-ft level to the 450-ft level.

21. The second stage of grout for U19N No. 1 was placed on 16 April 1968. No problems occurred during placement. The top of the grout was subsequently tagged at a depth of 410 ft. Vertical height of the plug was 40 ft. Overton sand was used to stem the hole from a depth of 410 ft to the surface. Grout mixture S-2BB was used for the second stage of the hole.

22. The rig was next moved over the emplacement hole. This hole, a 30-in.-diam open hole drilled to a depth of 775 ft, penetrated the partially to densely welded tuff stratum (0 to 500 ft) and was terminated in low-density ashfall. The geological competence of these two formations was not good, especially that of the low-density ashfall, with the end result being a considerable variance in specified hole diameter. Caliper logs confirmed the irregularity of the hole sidewall. The emplacement hole was

stemmed from the 775-ft level to the 450-ft level with Overton sand. A 40-ft grout plug, composed of 400 cu ft of grout, was pumped downhole to fill the interval between the 450- and 410-ft levels on 18 April 1968. Subsequent to the termination of grouting activities, the remainder of the hole was stemmed from the 410-ft level to the surface with Overton sand.

Tests on field-cast specimens

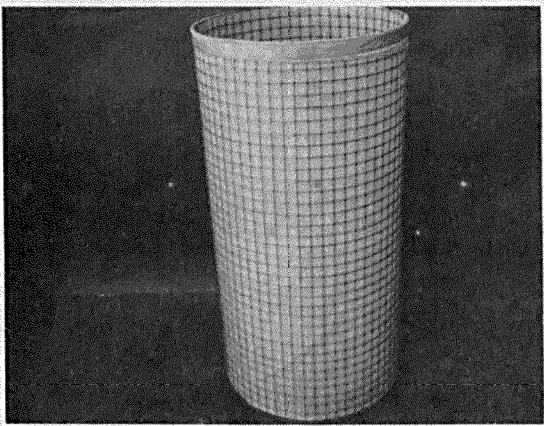
23. Density, sonic pulse velocity, and compressive strength tests were conducted on field-cast 6- by 12-in. cylinders on detonation date. Test results are shown in the following tabulation:

Hole	Stage	Density pcf	Sonic Velocity fps	Compressive Strength psi
Emplacement	1	122.1	8,275	465
1	1	94.0	6,290	500
1	2	--	--	--
2	1	93.8	6,565	580
3	1	119.7	10,685	1,510
3	2	112.5	9,320	1,620
3	3	93.7	5,975	530

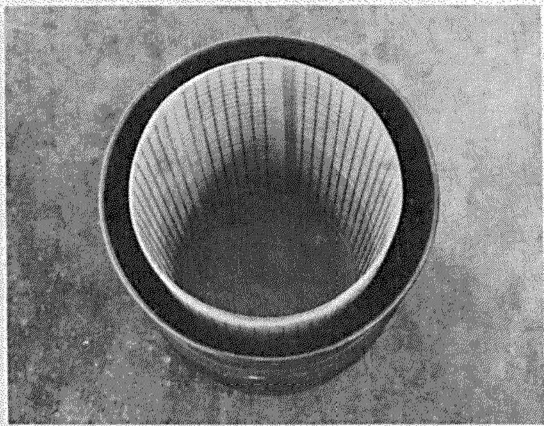
Note: Because no instruments were embedded in the stage 2 grout of hole No. 1, no field data were obtained.

Conclusions

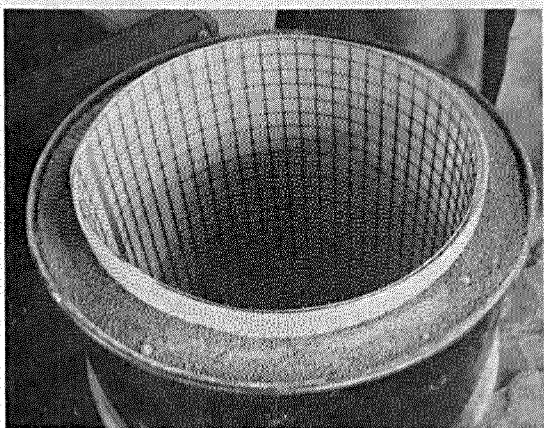
24. The grouting operations conducted for Project Scroll are judged to have been generally successful. The various grout mixtures closely met the design criteria. The excessive temperature experienced in stage 3 of hole 3 (155 F, whereas criteria stipulated a maximum of 150 F) is attributed to the hole's diameter being 29 in. instead of 15 in., which appreciably reduced the surface-to-volume ratio of the grout mass and impeded heat conduction to the formation. Although the sonic values of the ashfall grout are at the upper limits, they do meet Project requirements.



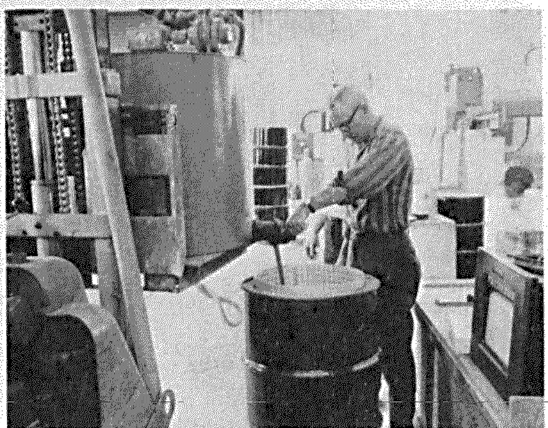
a. Core form



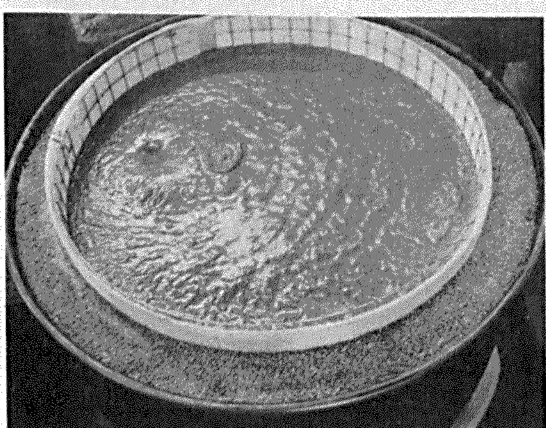
b. Core form positioned in drum



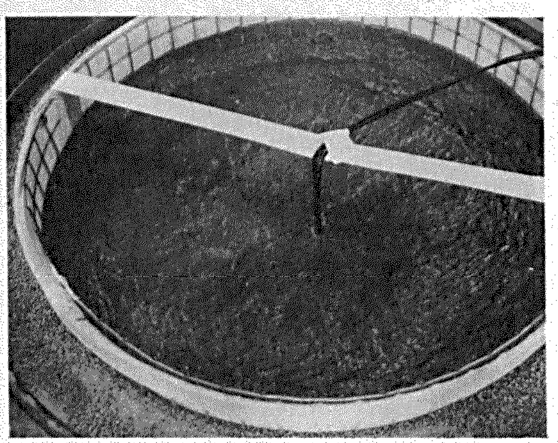
c. Annulus filled with permeable material



d. Filling core with grout

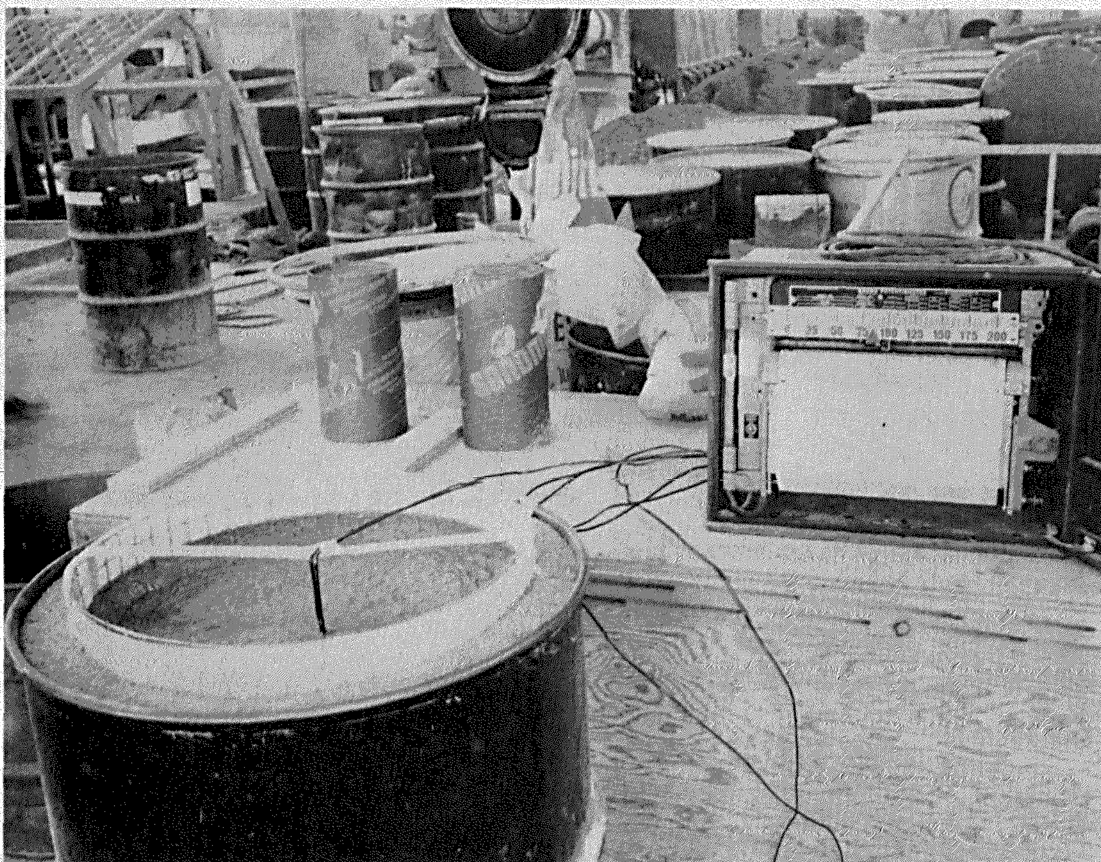


e. Close-up of top of core

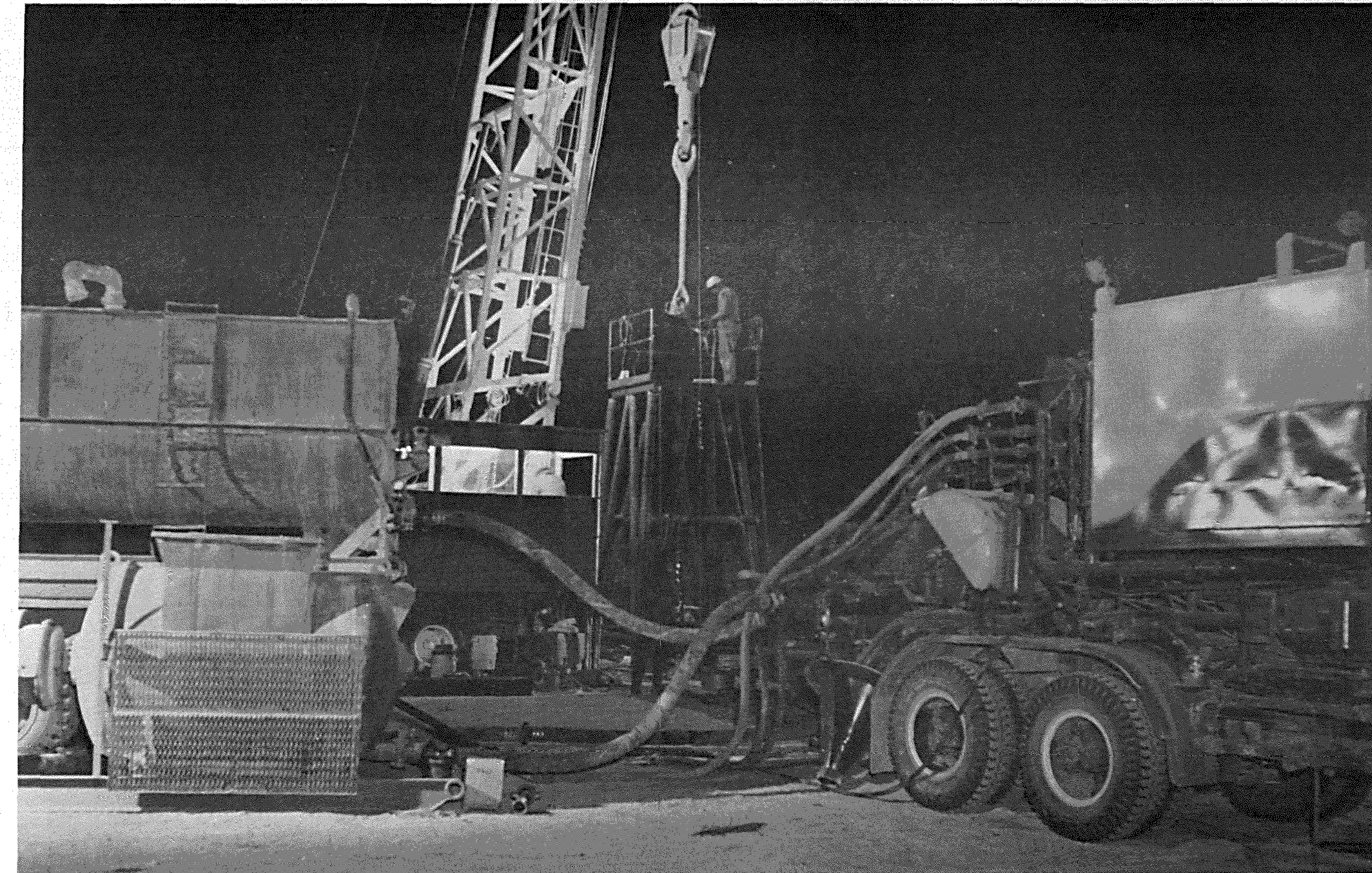


f. Thermocouple located in center of grout core

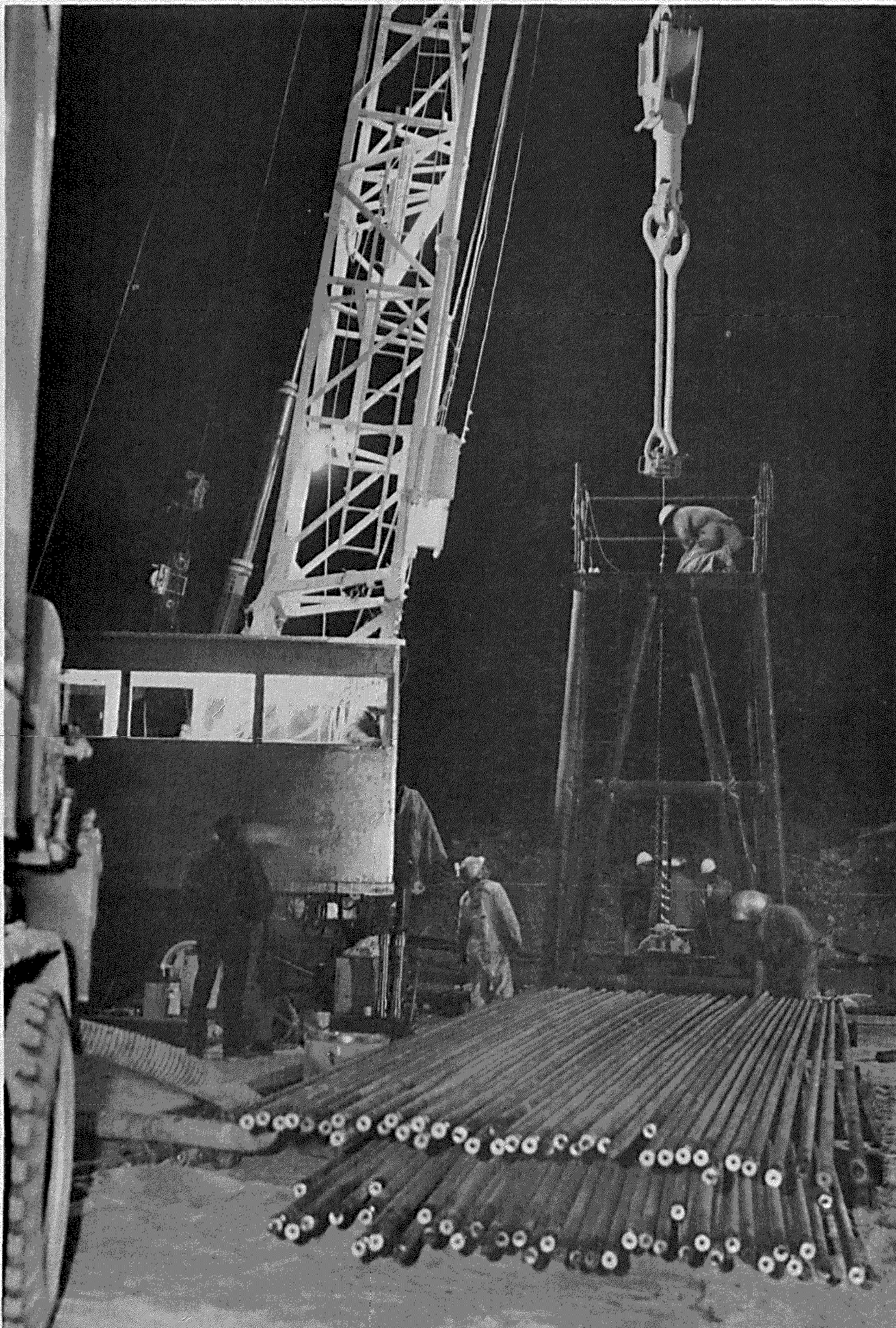
Photograph 1. Sequential formation of a model setup



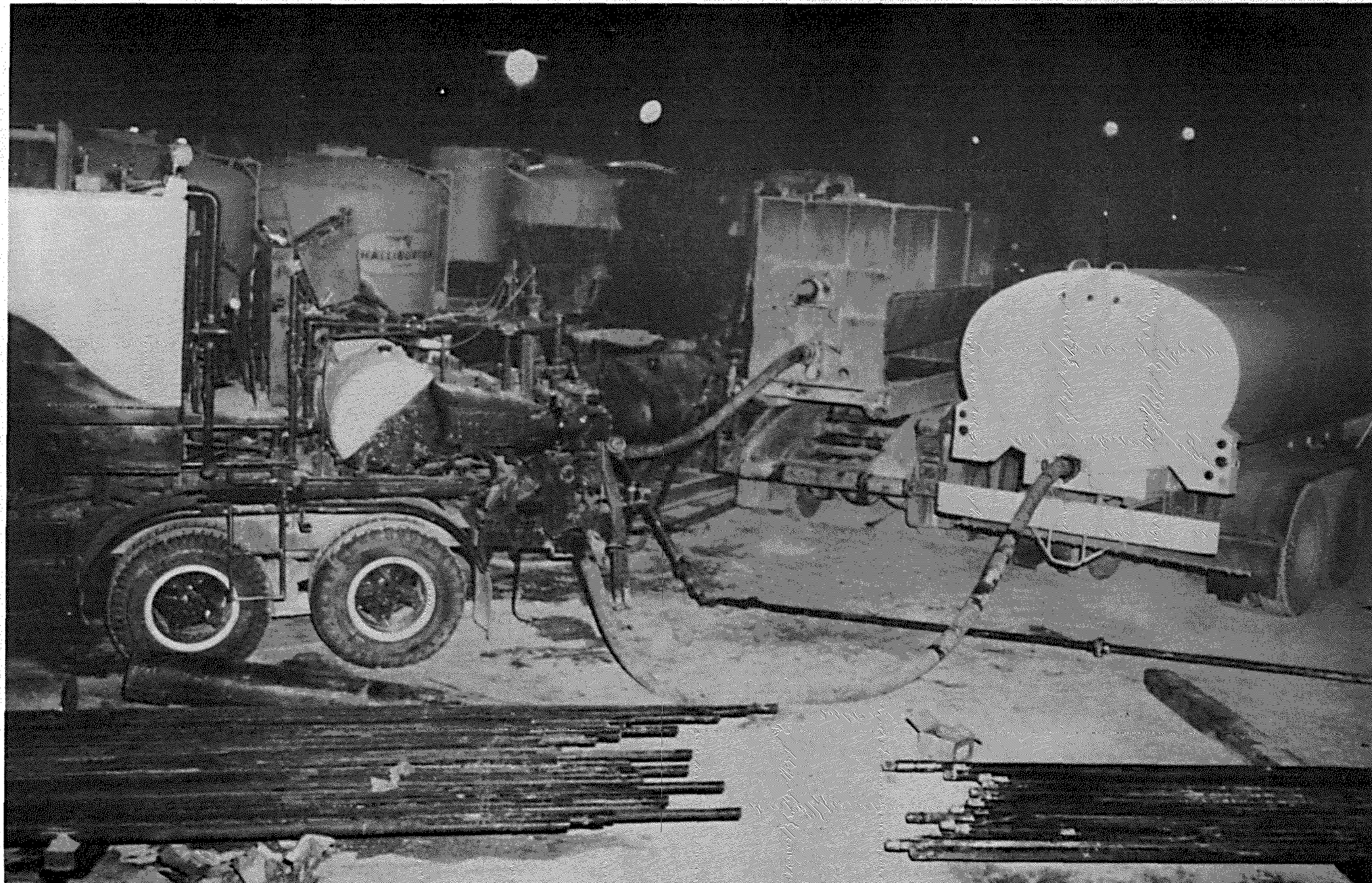
Photograph 2. General view of model setup



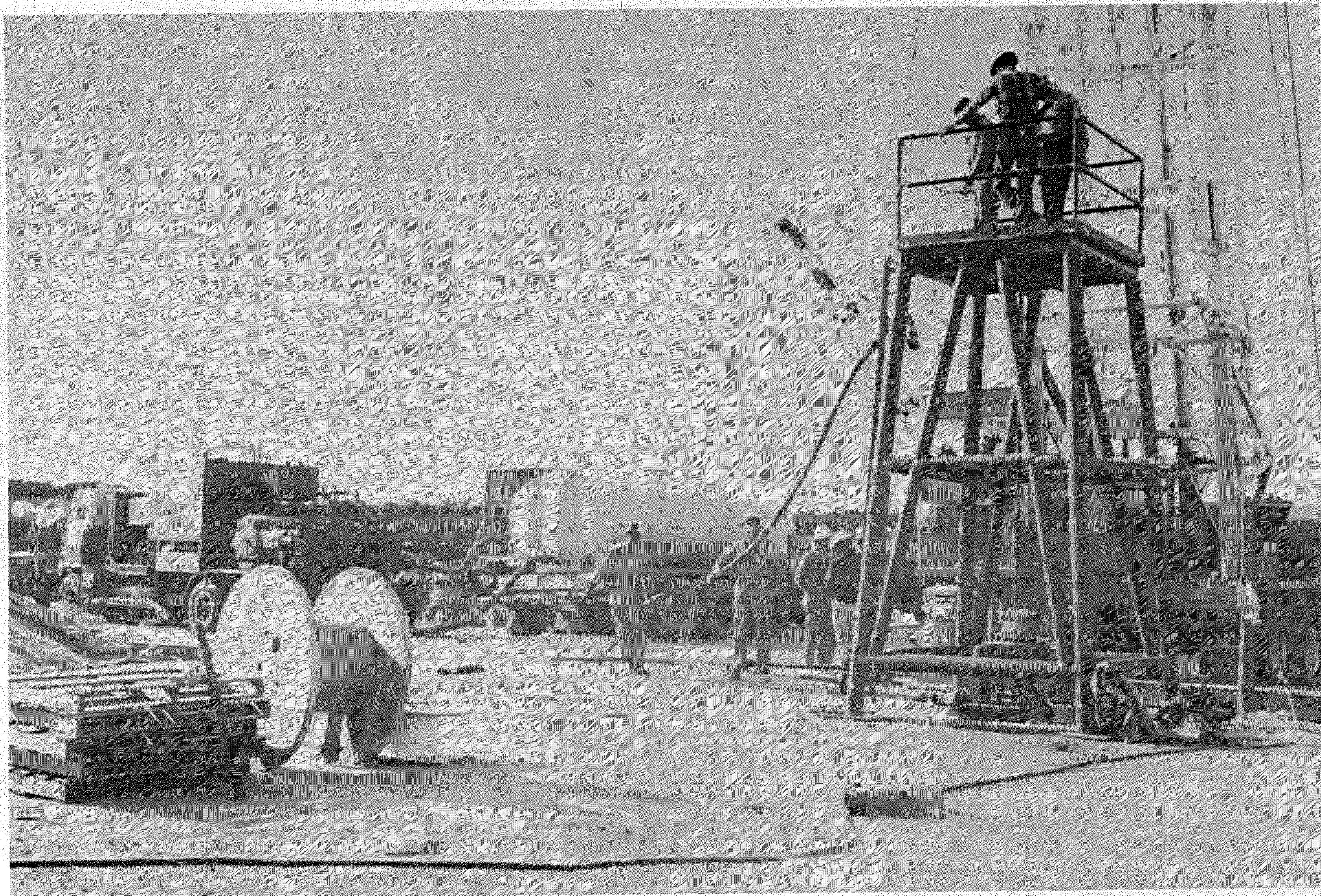
Photograph 3. Typical grouting equipment setup



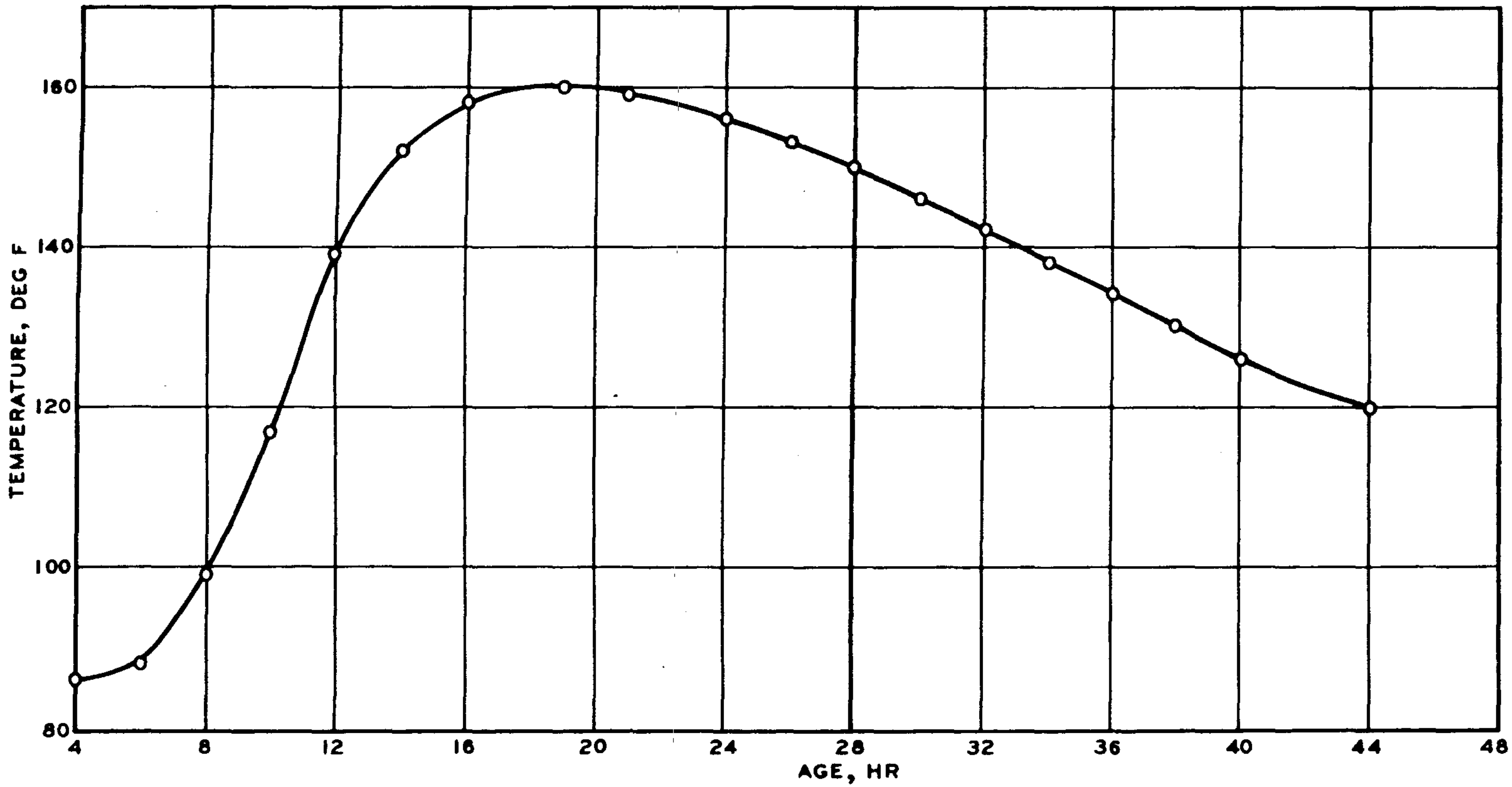
Photograph 4. Pulling grout tubing



Photograph 5. Pumping grout downhole through injection tubing



Photograph 6. Rigging up to pump grout downhole



NOTE: CURVE BASED ON 18-IN.-DIAM HOLE UNDER SIMULATED DOWNHOLE CONDITIONS.

AGE VERSUS TEMPERATURE
MIXTURE S-2BB

Plate 1

69196

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13. ABSTRACT

In Project Scroll, a nuclear device was detonated at a depth of 750 ft in a vertical hole drilled in Area 19 of the U. S. Atomic Energy Commission's Nevada Test Site. The U. S. Army Engineer Waterways Experiment Station (WES) was responsible for (a) development of instrument-to-formation coupling grout mixtures embodying specified physical properties matching as closely as possible those of the formation at the Project site, (b) development of an emplacement hole stemming grout, (c) supervision of the mixing and placement of the grout mixtures, and (d) determining, on detonation date, the pertinent physical properties of field-cast grout specimens representing the field-placed grout. In general, it is believed that the physical properties of the grout mixed and emplaced in the field closely matched those set forth in the design criteria.

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Grouting						
Nuclear explosions						
Scroll (Project)						

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