Graham

87

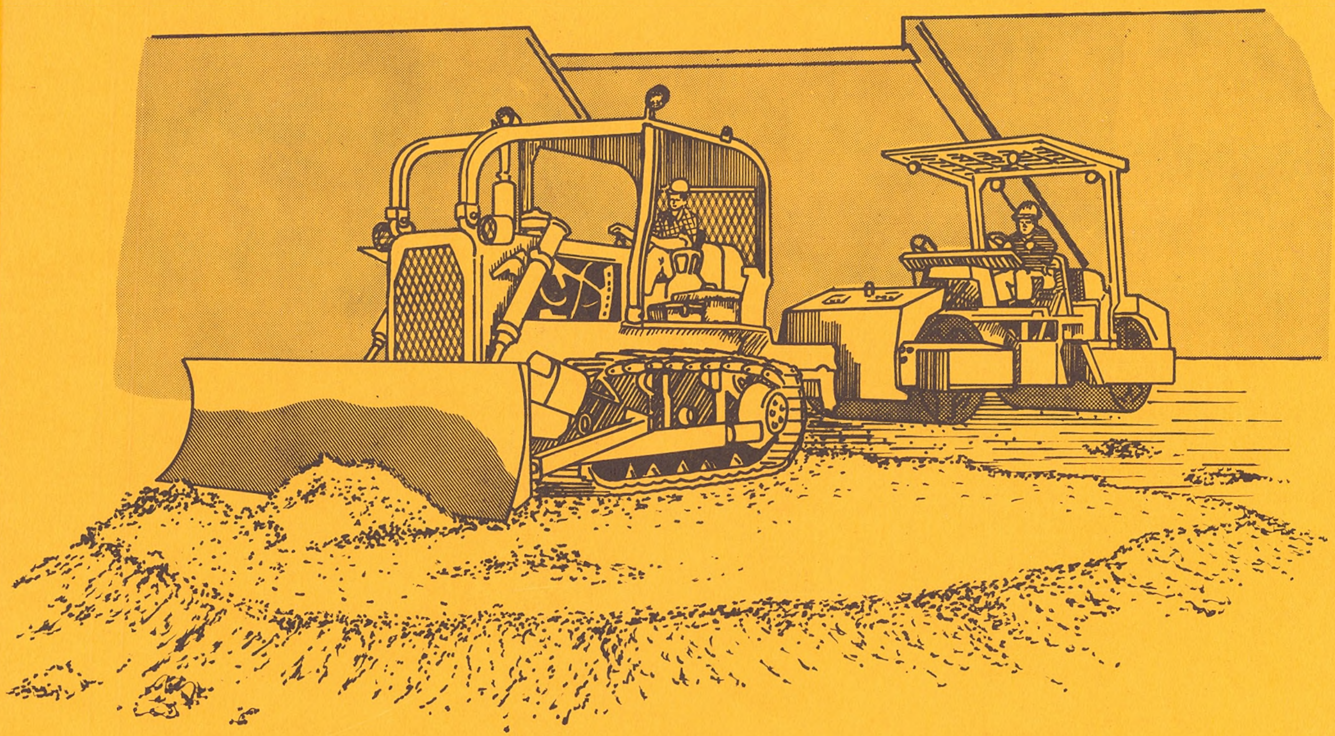
US Army Corps
of Engineers
Walla Walla District

Concrete Report

Willow Creek Dam

World's First All Roller Compacted Concrete Dam

July 1983



WILLOW CREEK DAM

CONCRETE REPORT

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont.)

TABLES

PLATES

TABLE OF CONTENTS (Cont.)

PLATES (Cont.)

PLATES (Cont.)

TABLE OF CONTENTS (Cont.)

PLATES (Cont.)

EXHIBITS

TABLE OF CONTENTS (Cont.)

EXHIBITS (Cont.)

PREFACE

This report has been written with laboratory strength data that was available as of February 1983. Long-term strength data, long-term thermal behavior, and future evaluation of data from cores to be taken from the dam will be included in a supplement to the report.

The report has been prepared by topic. Each chapter (topic) can be excerpted and stand on its own for technical content with little or no cross-referencing to other chapters. Photographs, graphs, tables, and exhibits pertinent to each chapter follow at the end of each chapter. The report is not intended to duplicate discussion and data from the initial aggregate investigations, crusher studies, cavitation/erosion studies, design test fill, thermal analysis, and preliminary mix studies contained in the project design memorandum (Supplement 1 to GDM 2 - Phase II).

This report was prepared by Ernest Schrader, Walla Walla District U.S. Army Corps of Engineers. Laboratory data contained in the report were obtained from testing at the North Pacific Division Laboratory (Jim Hinds and Jim Paxton) and from the resident field laboratory (Dennis Baird). Additional information was provided by the contractor (Rick McKinnon). Colonel H. Thayer was District Engineer during design and the start of construction. Colonel R. Williams was District Engineer during most of the construction and during reservoir filling.

Special thanks go to the District's Service Branch, Drafting Section, and photography laboratory. With their cooperation and effort, timely publication of this report has been accomplished concurrent with the main dam contract reaching its formal completion date.

WILLOW CREEK LAKE
HEPPNER, OREGON

PERTINENT DATA

PROJECT FUNCTIONS

Flood Control
Recreation
Fish and Wildlife
Provision has been made in design for future irrigation.

LAKE

Drainage area above damsite, square miles	96
Standard project thunderstorm flood:	
Peak flow, cfs	45,000
Volume, acre-feet	11,500
Probable maximum thunderstorm flood:	
Peak flow, cfs	107,000
Volume, acre-feet	28,000
Standard project general winter rain and snowmelt flood:	
Peak flow, cfs	9,000
Volume, acre-feet	25,000
Probable maximum general winter rain and snowmelt flood:	
Peak flow, cfs	18,000
Volume, acre-feet	51,000
Project design flood:	
Volume, acre-feet	9,500
Design flood recurrence interval, years (Composite)	100
Maximum controlled lake elevation	2,113.5
Average minimum lake elevation	2,047
Lake length at spillway crest elevation, miles:	
Willow Creek	1.8
Balm Fork	1.3
Lake length at average minimum elevation, miles:	
Willow Creek	0.7
Balm Fork	0.4
Lake surface area, acres:	
Maximum controlled elevation 2113.5 (spillway crest)	265
Average minimum lake elevation 2047	88
Gross storage capacity, acre-feet:	
Exclusive flood control:	
Initial	11,250
Future	7,750
Future irrigation storage:	
Exclusive	1,750
Joint	1,750
Fish, wildlife, recreation, and esthetics	600
Sediment accumulation	1,400
Total	13,250

DAM-RCC

Top elevation	2,130
Height above streambed, feet	169
Length, feet	1,700
Width, top, feet	16
Volume, C.Y.	435,000

SPILLWAY, OVER DAM

Crest elevation	2,113.5
Crest length, feet	380
Design capacity, cfs	91,700

OUTLET WORKS

Regulating outlet capacity at low pool, elevation 2047, cfs	500
Water quality outlet capacity, cfs	
at low pool elevation 2047	80
at normal high pool elevation 2076.5	95

PROJECT ECONOMICS

Total Project Cost (May 1983)	$36,100,000
Dam Contract (May 1983)	$14,900,000

CHAPTER 1

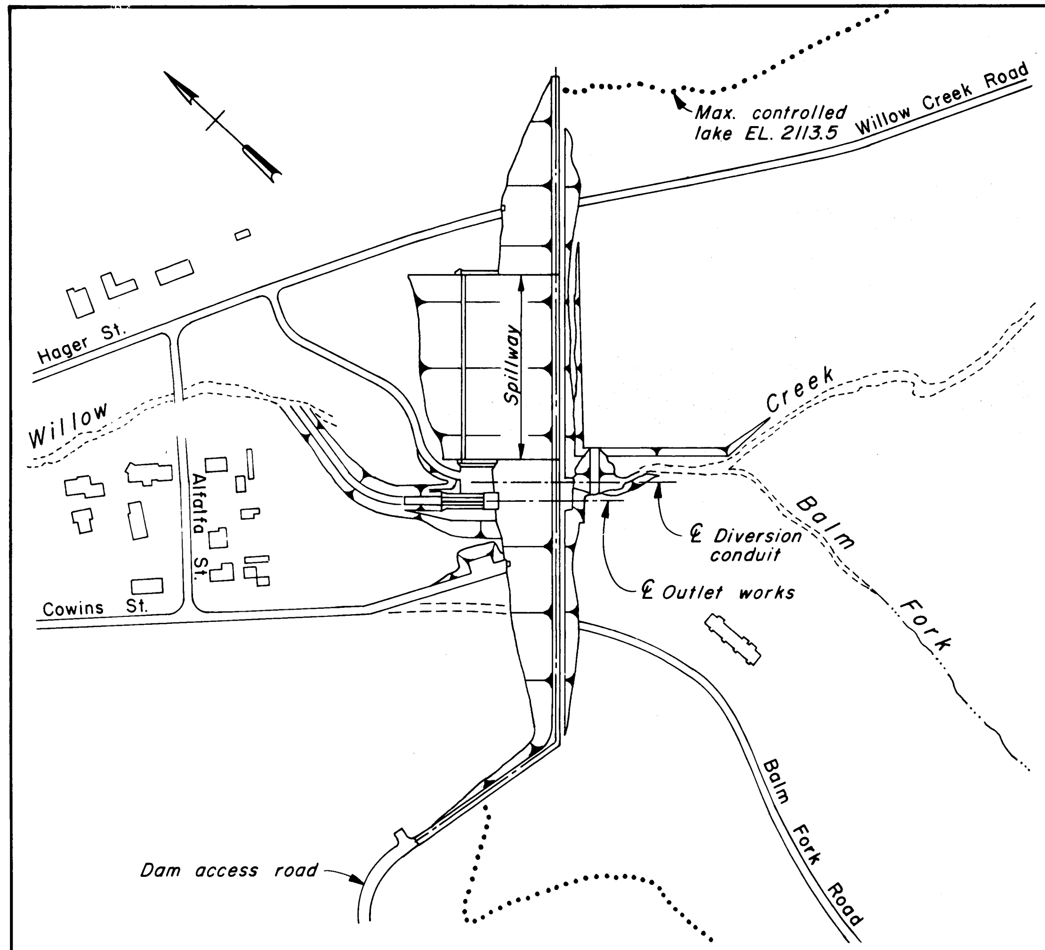
INTRODUCTION

Willow Creek Dam was the world's first all rolled concrete structure designed and built specifically with the no-slump rolled mix. The design intent, assumptions, procedures, and studies are described in the appropriate Corps of Engineers design memoranda. Articles published in Civil Engineering (April 1982), Concrete International (October 1982), Engineering News Record (October 1982), and elsewhere contain summaries of design and initial construction plans. This report specifically addresses concrete and related operations during construction, results of routine construction testing, special testing during construction, and initial reservoir and dam performance. It also includes recommendations for future roller-compacted concrete (RCC) construction. A construction history covering all phases of the project is under preparation.

Initial estimates for a dam at Willow Creek were on the order of $32 million for a rockfill structure. This was later refined down to $25 million with less conservative design adjustments. The construction period would have been 3 years. The rolled concrete dam design was then developed, found to be competitive, and was estimated to take a construction time of 1 to 2 years. As design progressed and contingencies were eliminated through tests and further study, the estimated cost decreased. The ultimate low bid price of $14 million saved an estimated $11 million off the rockfill estimate. Also, the dam was functional in about 1 year and the contract was complete in about 1-1/2 years.

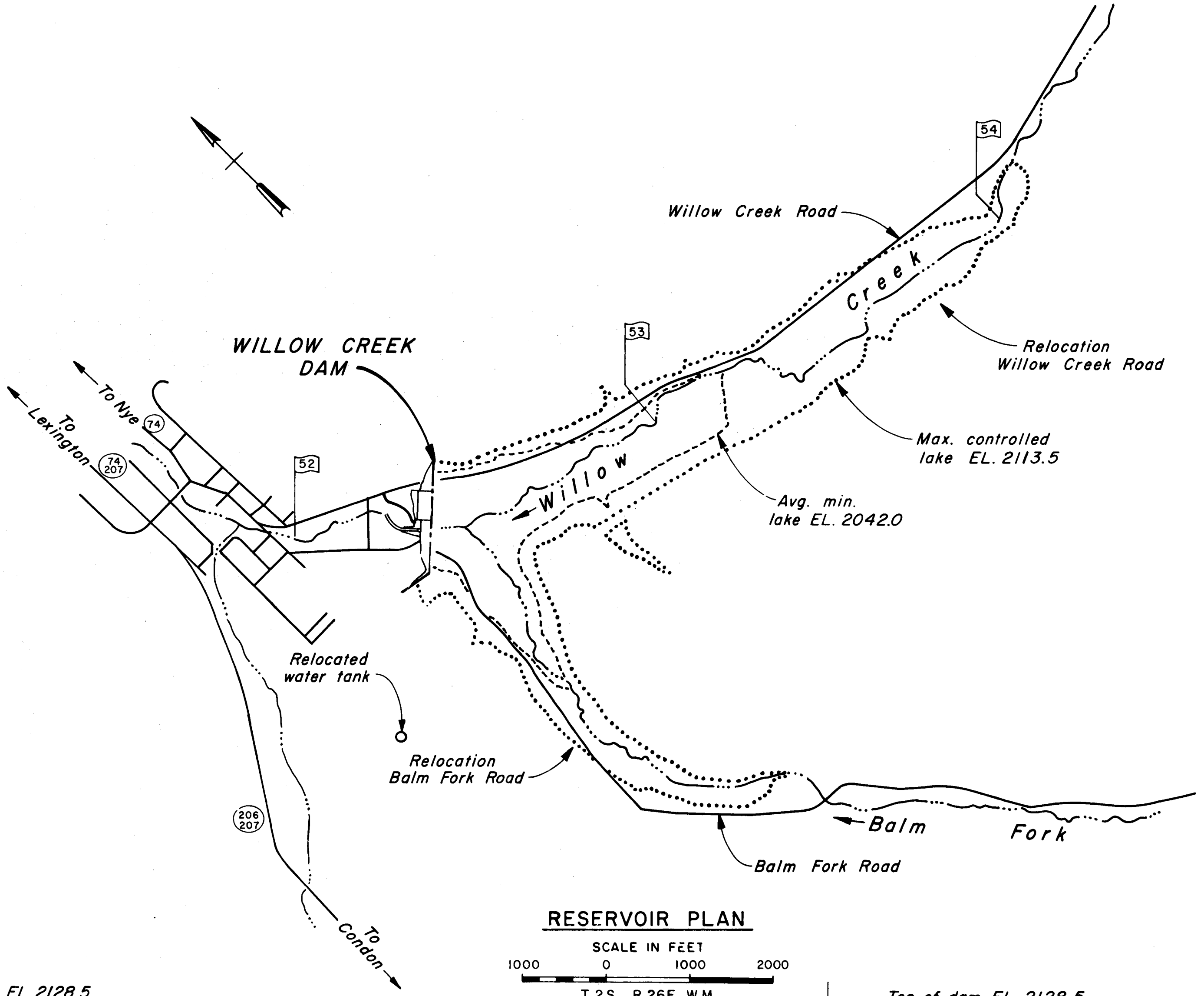
Plate 1.1 shows the project location and typical sections. Plate 1.2 shows the envisioned and completed structure. Plates 1.3 and 1.4 show a sequence of progress photographs taken from the same location on a monthly basis. They clearly indicate the speed with which the dam was constructed. Plates 1.5 through 1.11 are aerial views which also show monthly progress.

Plate 1.12 shows progress of the total project and percent complete as a function of calendar date starting with initial advertising. Plates 1.13 and 1.14 show the rate of construction of the dam once RCC placement began. Plate 1.12 includes the value of the contract and its value as overruns and change orders (modifications) developed. The project cost stayed remarkably close to the original bid, especially when considering the unprecedented nature of the project. A major contract modification because of significant added excavation was directed just prior to the start of RCC placement because of unforeseen foundation conditions. There were very few changes because of the RCC and none of significance.



PLAN

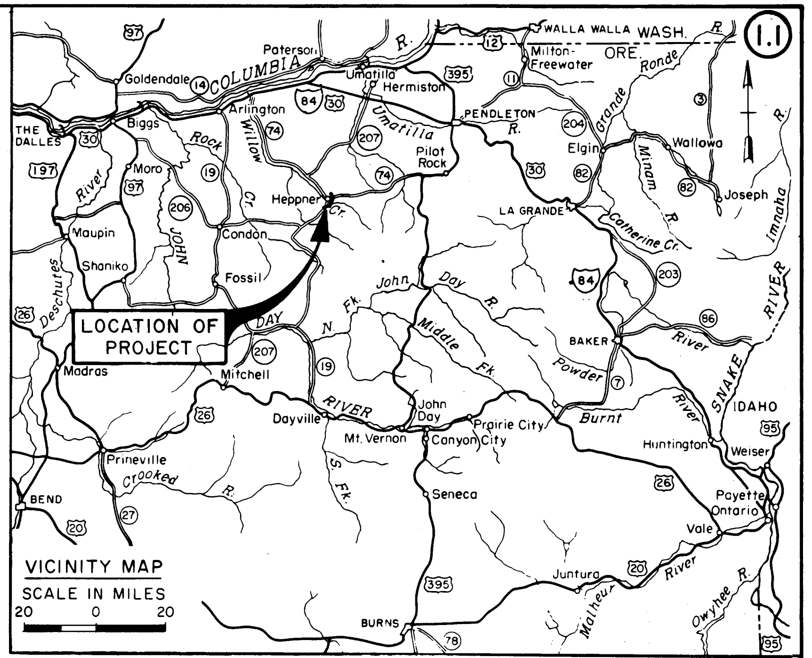
SCALE IN FEET 200 0 200 400 600



RESERVOIR PLAN

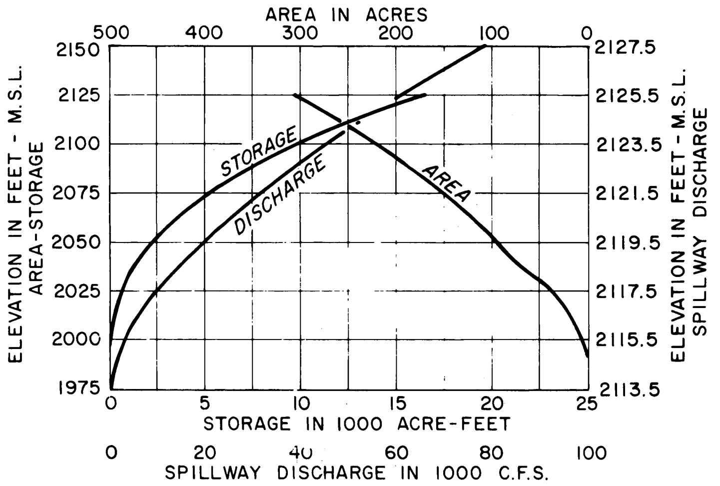
SCALE IN FEET 1000 0 1000 2000

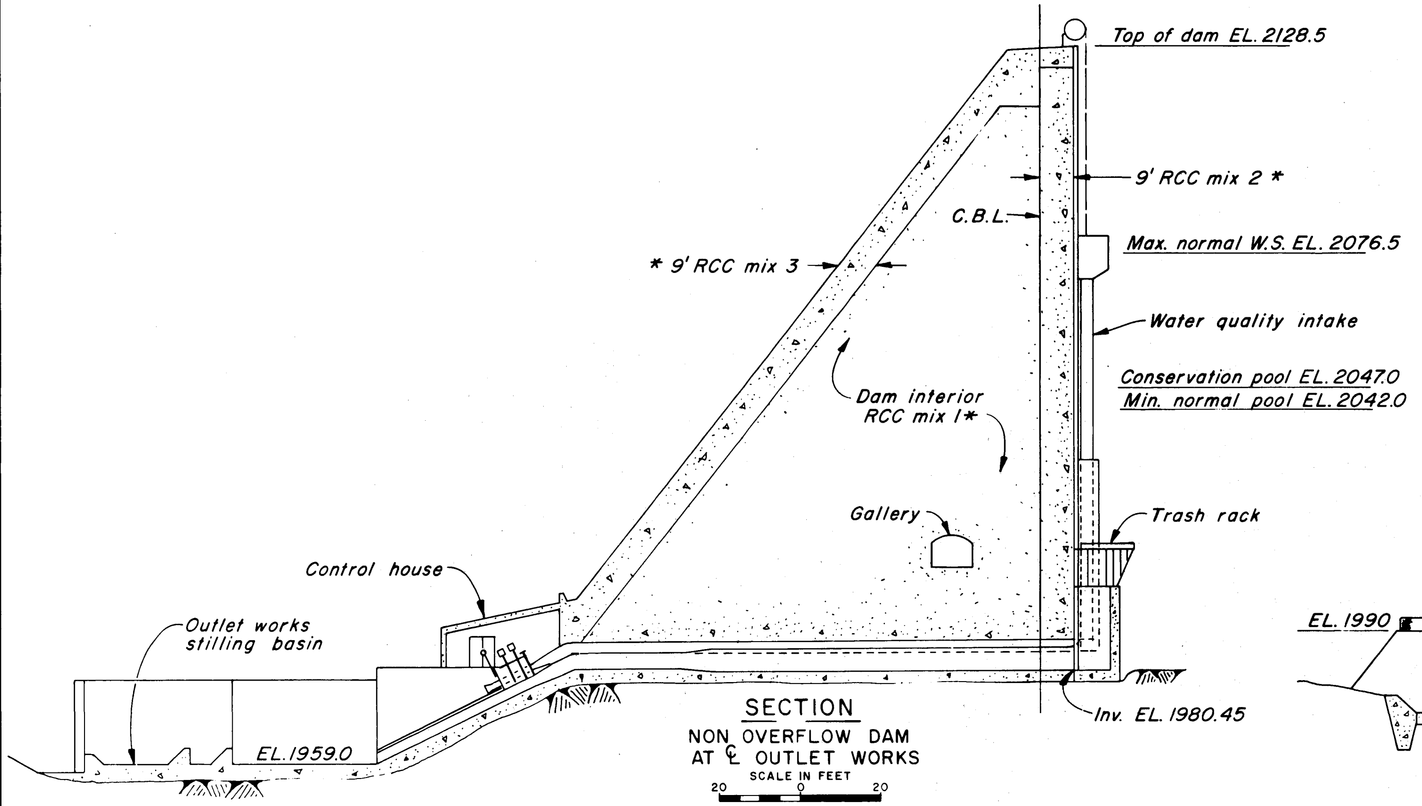
T.2S., R.26E., W.M. MORROW COUNTY



LEGEND

Highway relocation





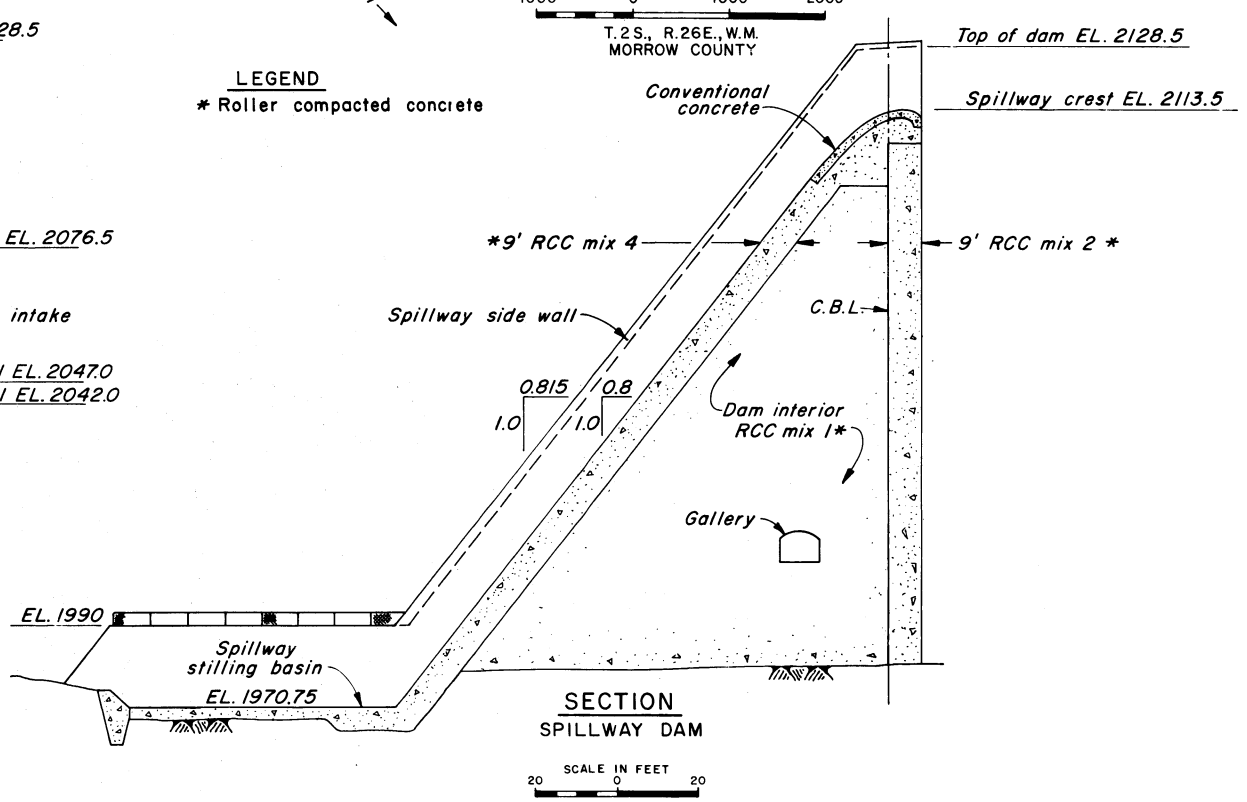
SECTION

NON OVERFLOW DAM AT ℄ OUTLET WORKS

SCALE IN FEET 20 0 20

LEGEND

* Roller compacted concrete



SECTION

SPILLWAY DAM

SCALE IN FEET 20 0 20

PROJECT PLAN AND TYPICAL SECTION

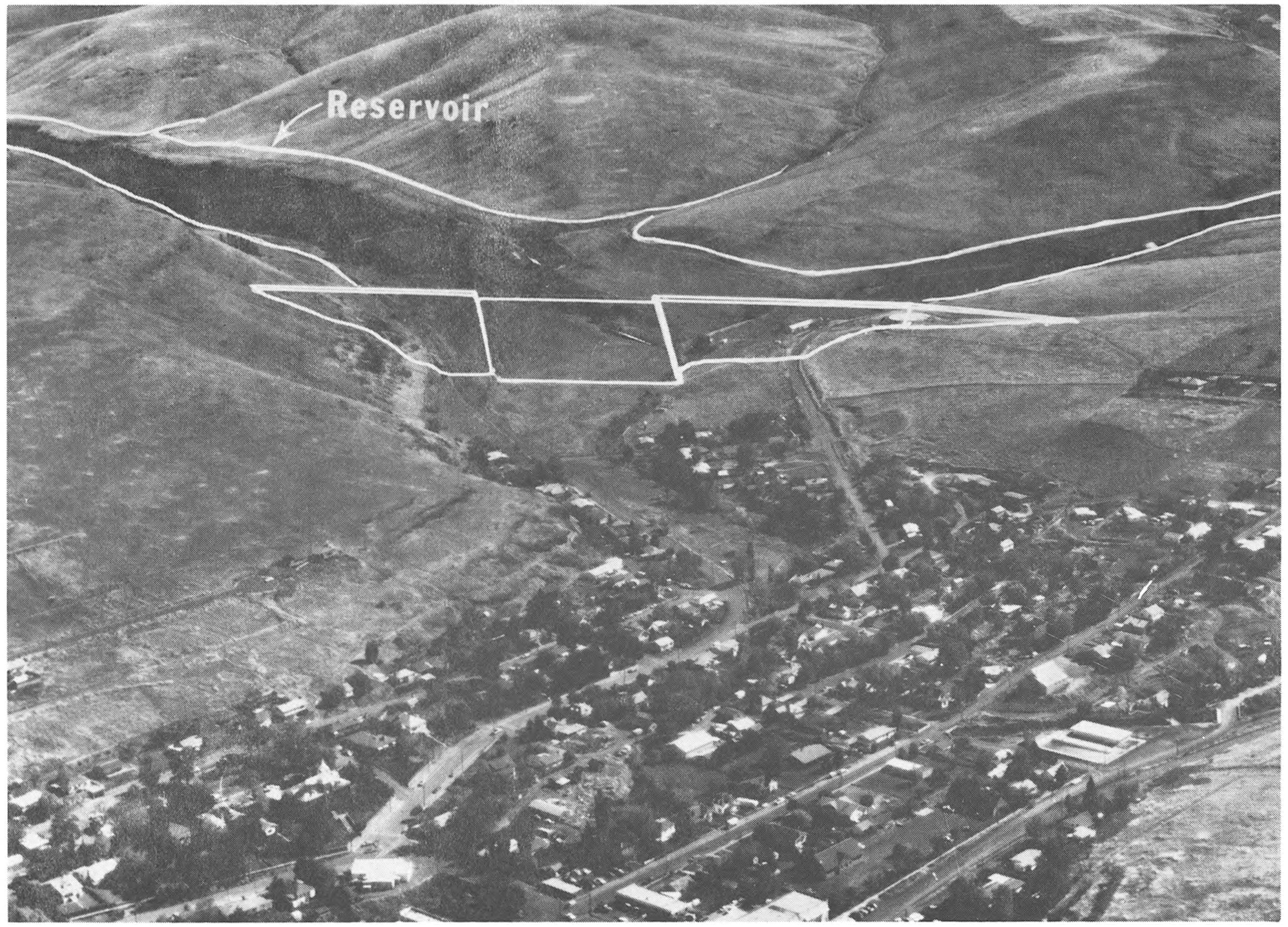
WILLOW CREEK LAKE

HEPPNER, OREGON

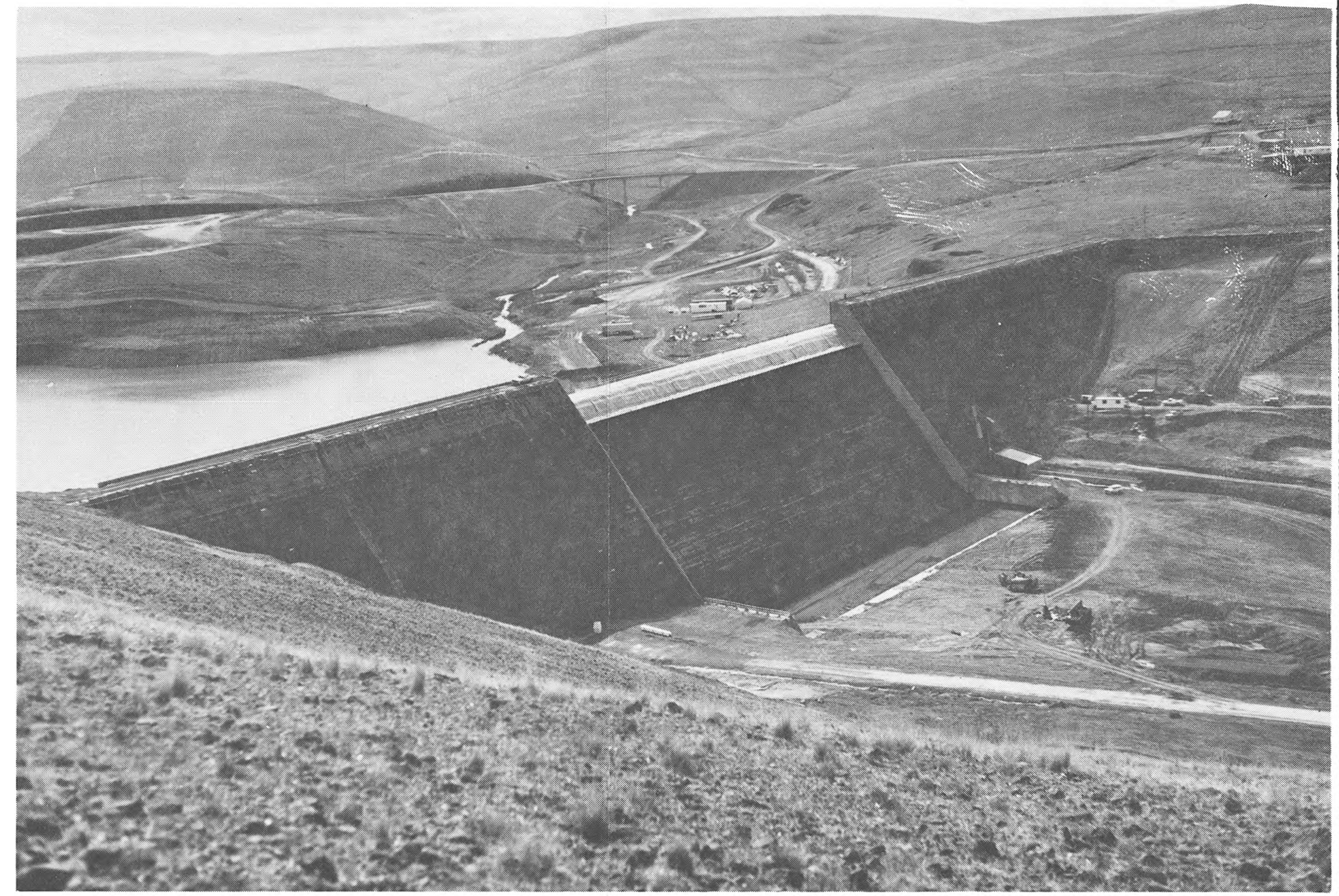
U. S. ARMY ENGINEER DISTRICT, WALLA WALLA

30 SEPTEMBER 1981

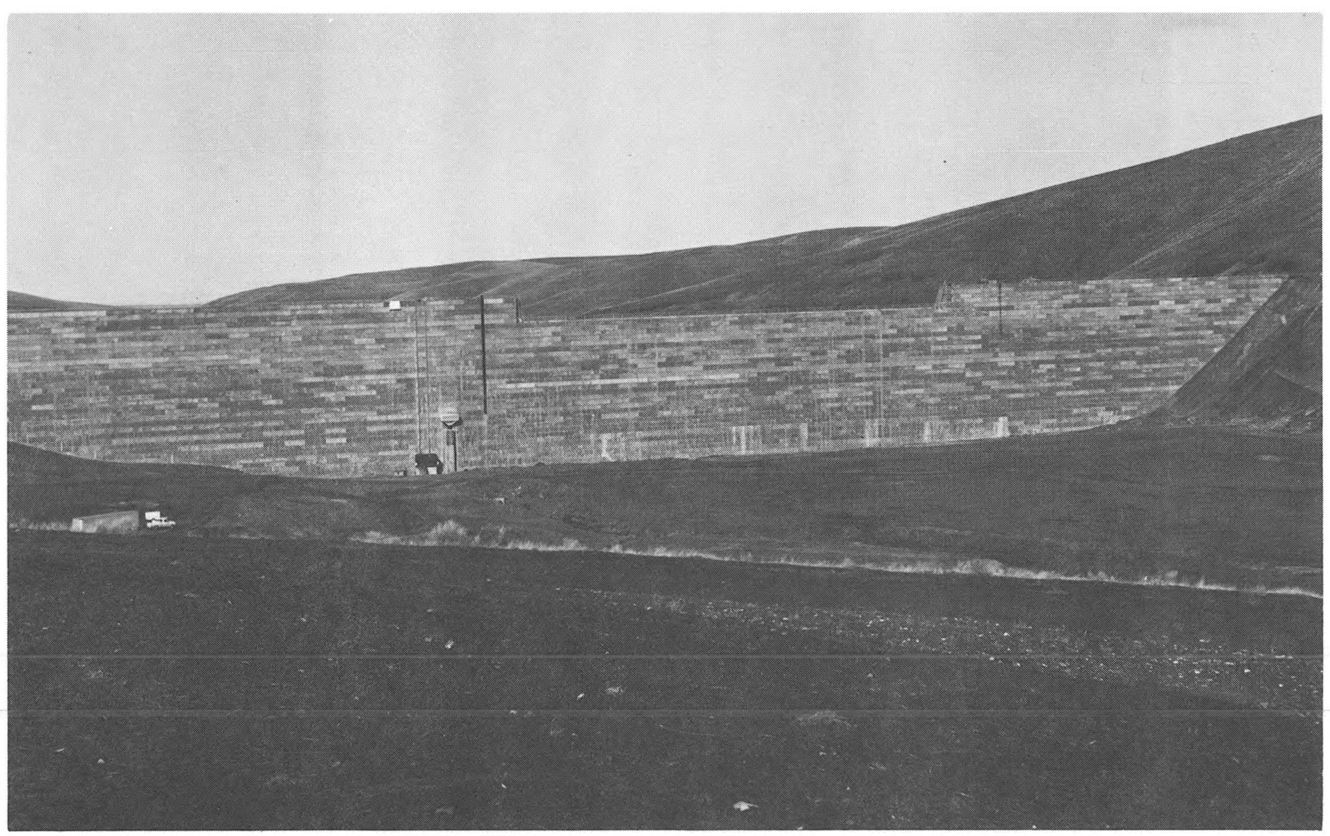
PLATE 1



AS ENVISIONED PRIOR TO CONSTRUCTION.



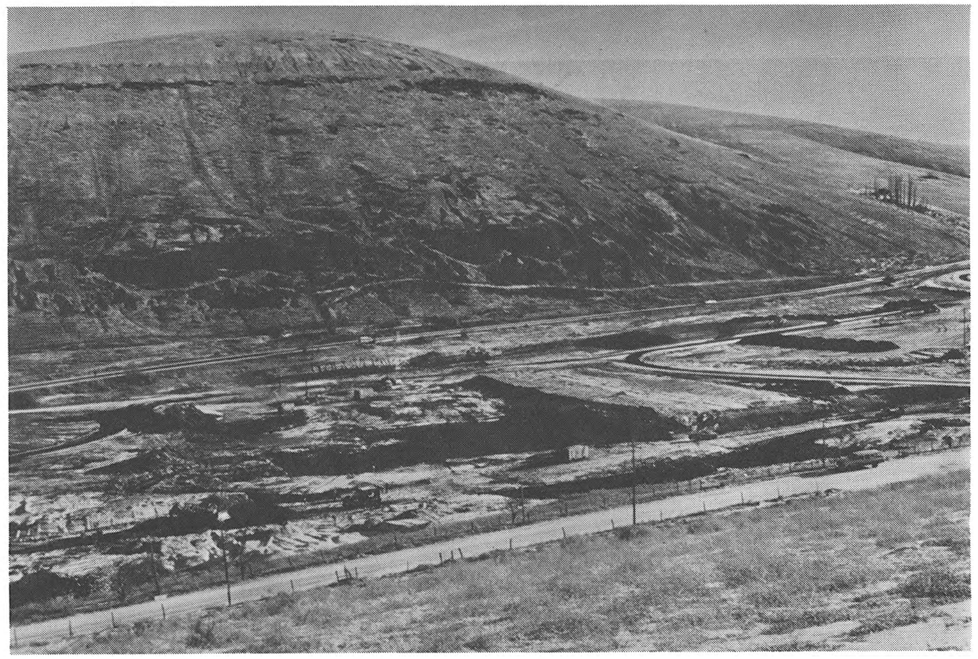
FALL OF 1982.



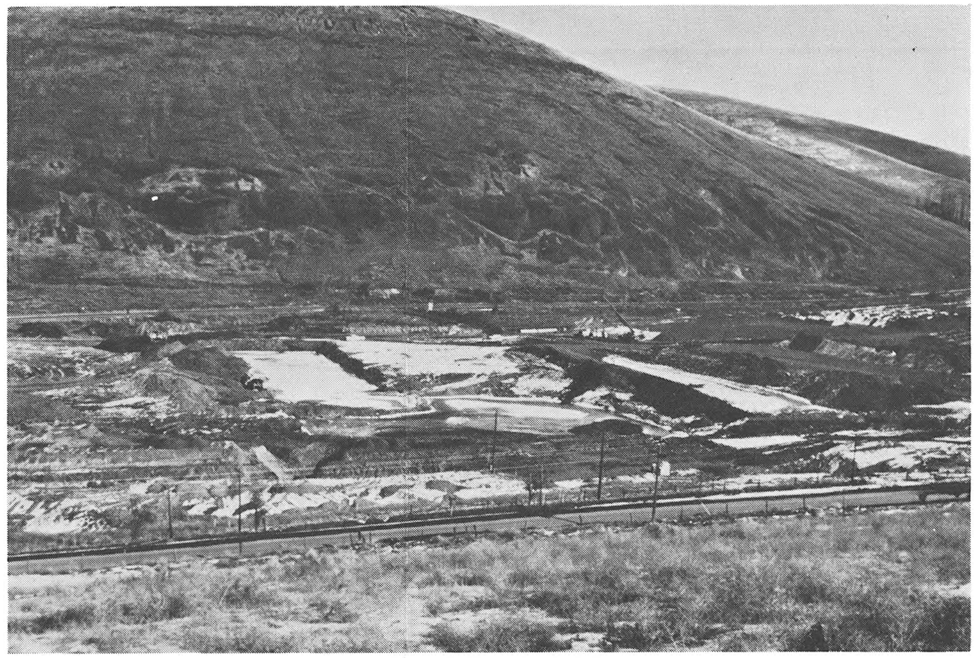
UPSTREAM FACE PRIOR TO POOL RAISE.

WILLOW CREEK DAM

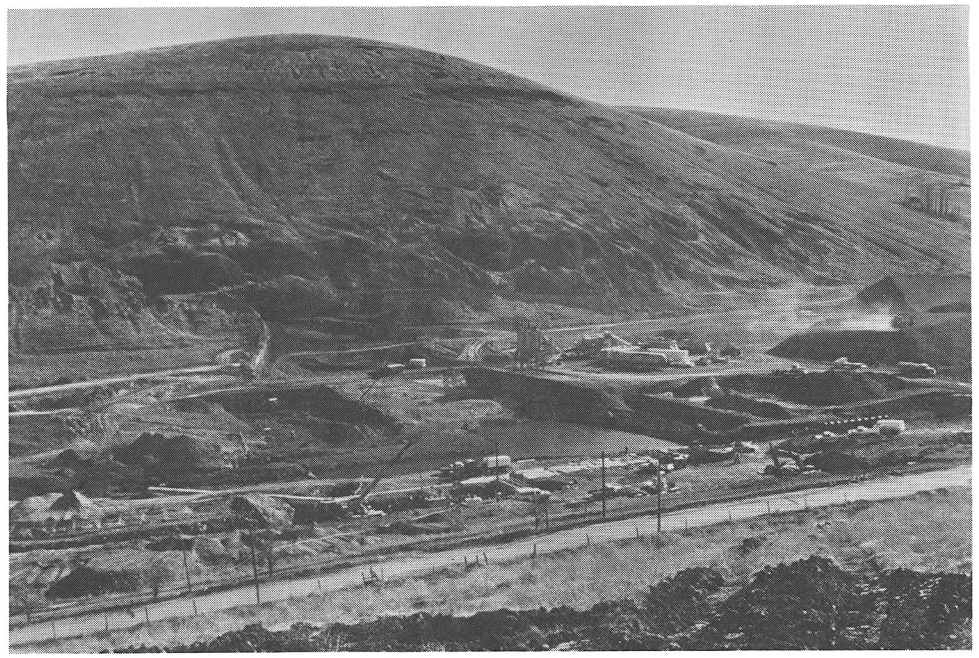
PLATE 1.2



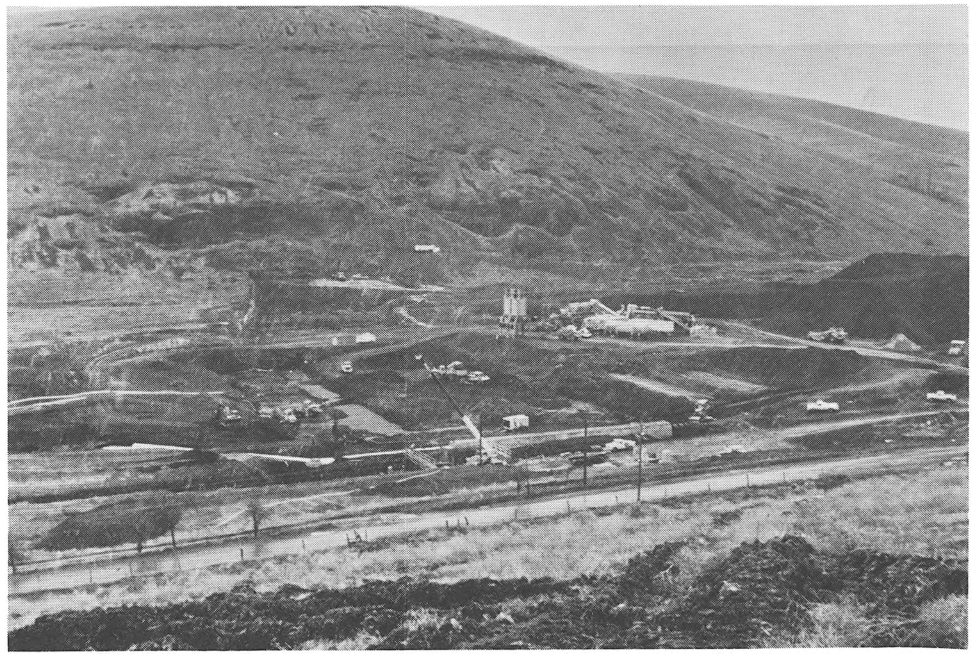
12 JANUARY 1982



10 FEBRUARY 1982



12 MARCH 1982

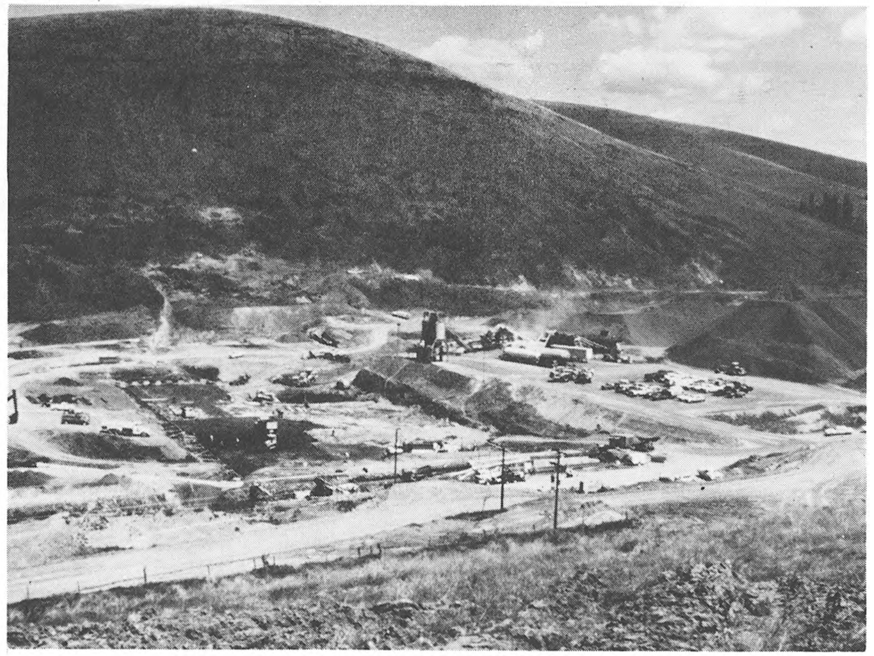


15 APRIL 1982

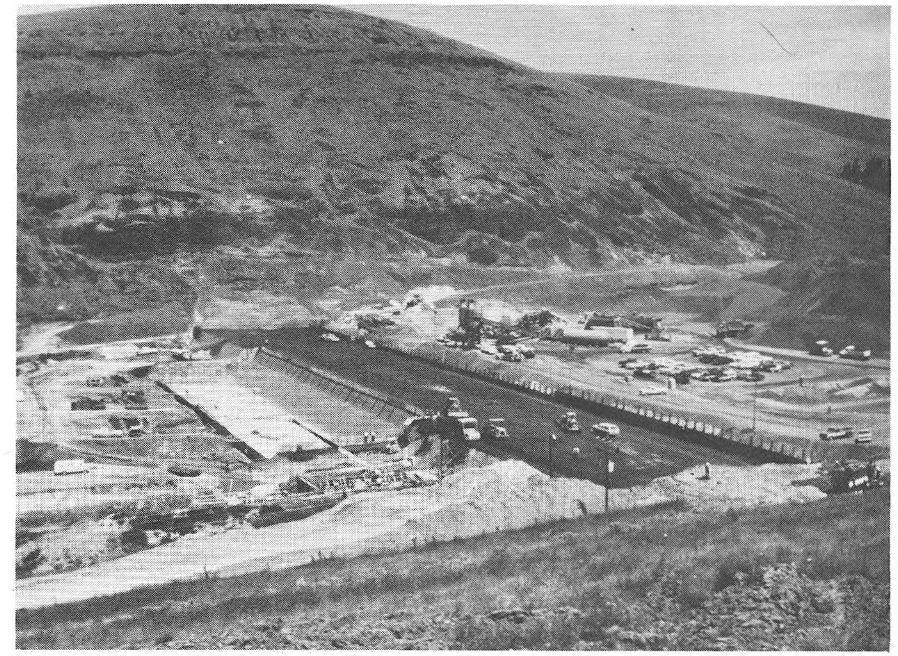
FOUNDATION EXCAVATION AND
AGGREGATE STOCKPILING

PROGRESS PHOTOS

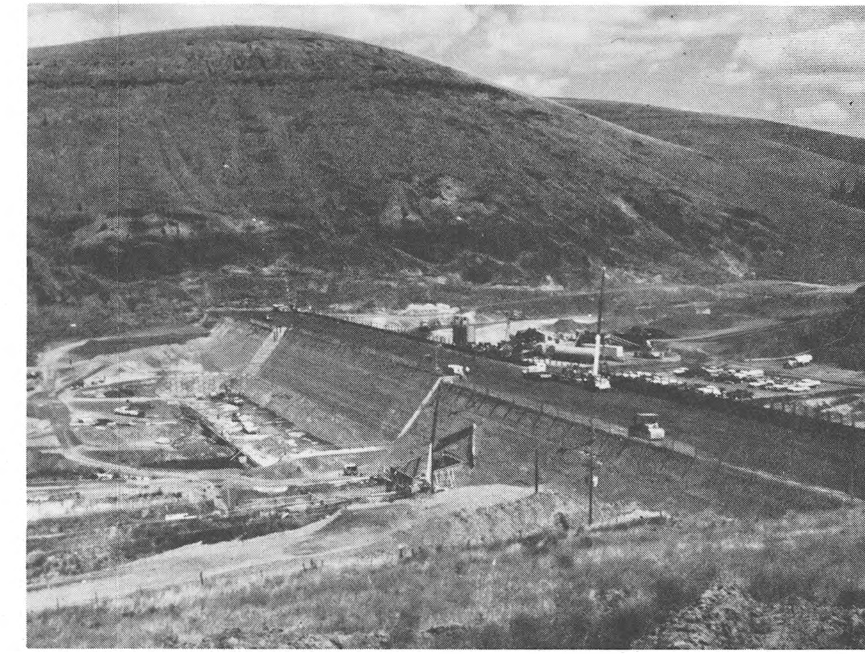
PLATE 1.3



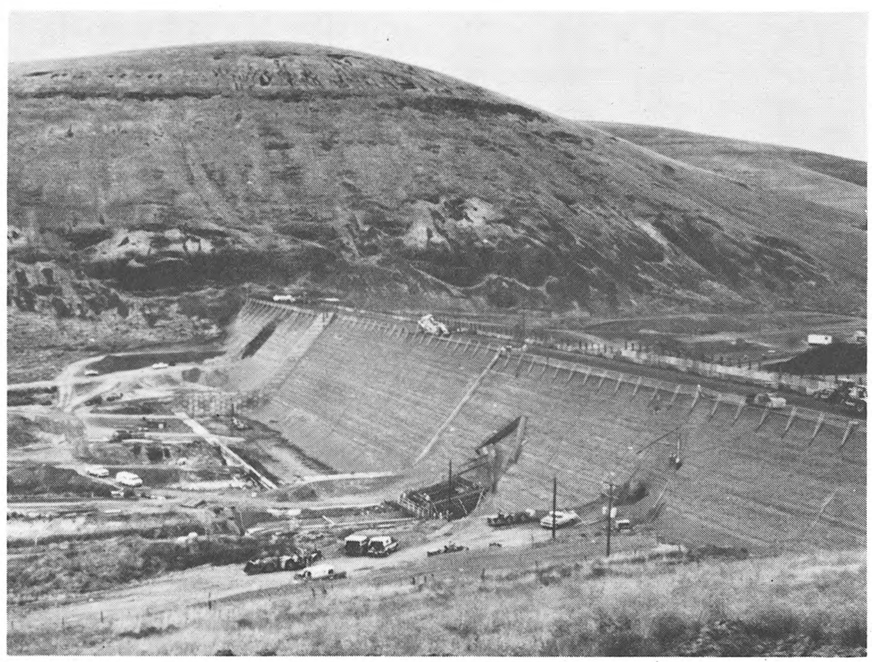
12 MAY 1982



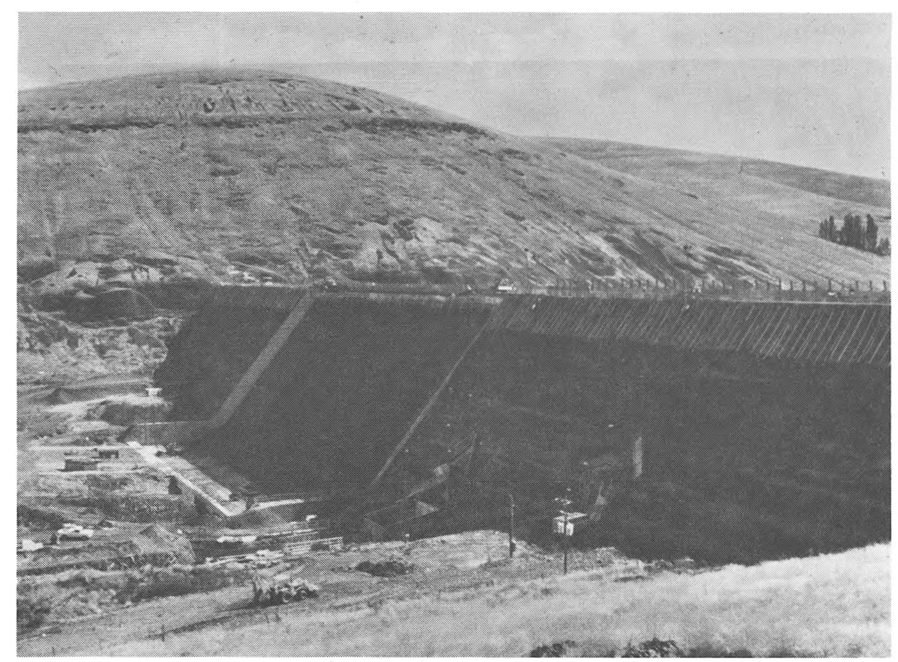
11 JUNE 1982



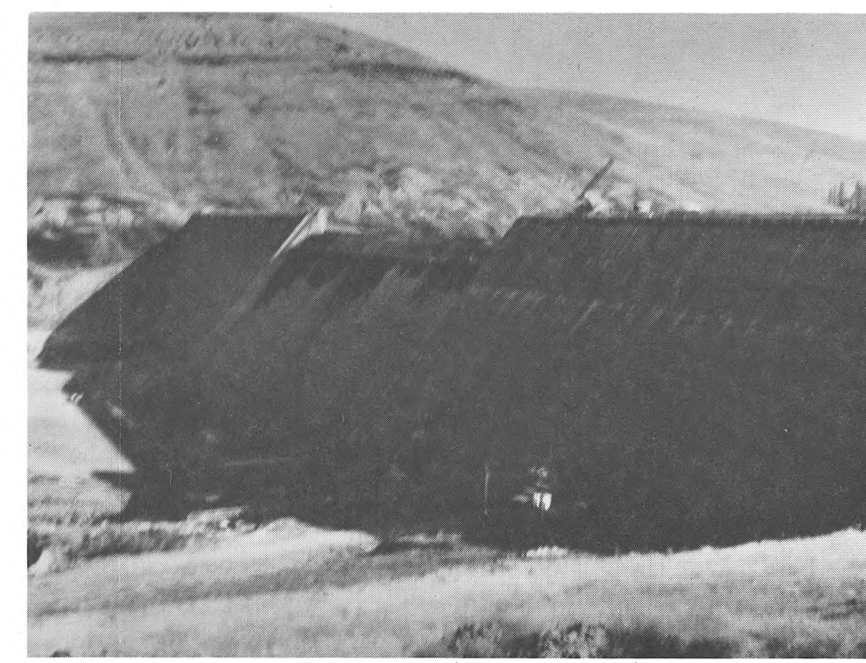
14 JULY 1982



10 AUGUST 1982



13 SEPTEMBER 1982



24 SEPTEMBER 1982

ROLLED CONCRETE

PROGRESS PHOTOS

PLATE 1.4

MARCH 6, 1982

AERIAL PHOTO

PLATE 1.5

APRIL 16, 1982

AERIAL PHOTO

PLATE 1.6

NOTE: PHOTO WAS TAKEN JUST AFTER THE START OF RCC PLACEMENT. BOTTOM ELEVATION 1963.

MAY 4, 1982

AERIAL PHOTO

PLATE 1.7

NOTE THE FOLLOWING CONSTRUCTION VIOLATIONS:

1. FOUR LIFT SURFACES SIMULTANEOUSLY EXPOSED.
2. VERTICAL JOINTS DO NOT FOLLOW THE PATTERN ALLOWED IN THE RCC SPEC.
3. TIRE TRACKS LEFT FROM VEHICLE THAT MADE A TIGHT TURN SCARRING THE SURFACE.
4. NONUNIFORM MOISTURE ON THE EXPOSED SURFACE.

JUNE 3, 1982

AERIAL PHOTO

PLATE 1.8

STILLING BASIN

SPILLWAY FACE

NOTE TRACKING OF DEBRIS ONTO THE PLACEMENT FROM THE HAUL ROAD.

CONCRETE PLANT

3/4 INCH AGGREGATE

1 1/2 INCH AGGREGATE

3 INCH AGGREGATE

AGGREGATE FILL IN THE GALLERY ZONE.

NOTE TIGHT TURN BY TRUCK DAMAGING THE RCC SURFACE. ALSO, TRACKING OF MATERIAL ONTO THE RCC SURFACE FROM THE HAUL ROAD.

HEPPNER RESIDENCE IMMEDIATELY DOWNSTREAM OF THE DAM.

JULY 3, 1982

AERIAL PHOTO

PLATE 1.9

CONVEYOR FEED FOR 3/4 INCH AGGREGATE

3/4 INCH AGGREGATE

SPRINKLING 1 1/2 INCH AND 3 INCH AGGREGATE

AGGREGATE CRUSHING AND SCREENING.

RCC AT APPROXIMATE ELEVATION 2098.

PERMANENT OUTLET CHANNEL CONTROL HOUSE.

AUGUST 3, 1982

AERIAL PHOTO

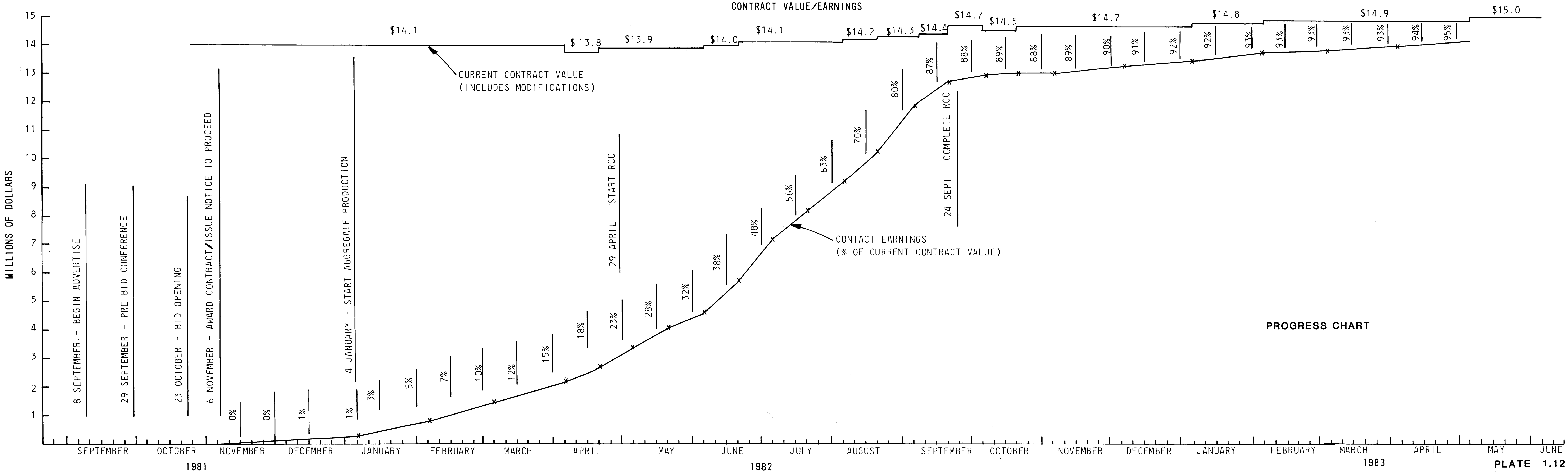
PLATE 1.10

APPROXIMATE ELEVATION 2118. EIGHT DAYS AND 11 FEET BEFORE COMPLETION OF RCC AT THE TOP OF THE DAM.

SEPTEMBER 16, 1982

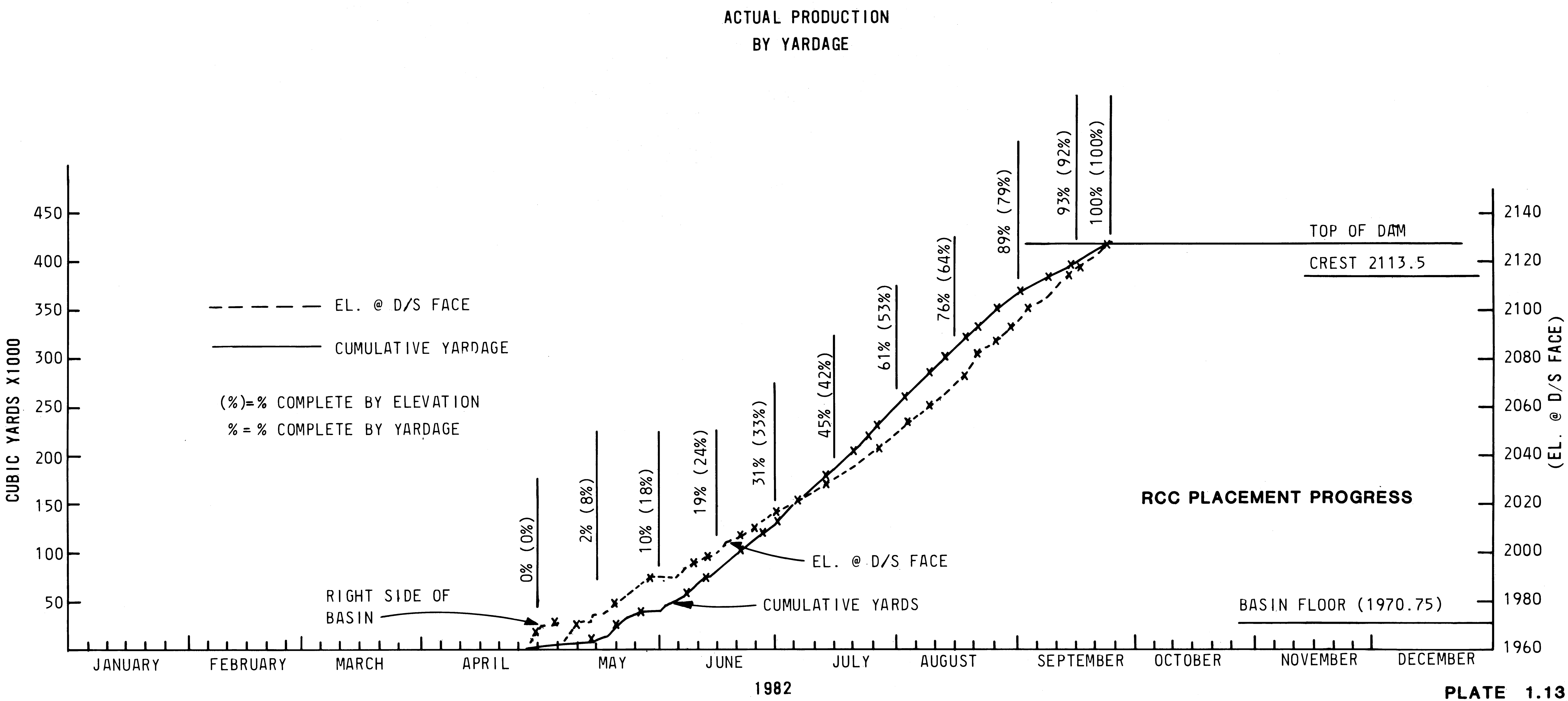
AERIAL PHOTO

PLATE 1.11



PROGRESS CHART

PLATE 1.12



ACTUAL PRODUCTION
BY YARDAGE
EL. @ D/S FACE
CUMULATIVE YARDAGE
(%)=% COMPLETE BY ELEVATION
% = % COMPLETE BY YARDAGE
CUBIC YARDS X1000
450
400
350
300
250
200
150
100
50
0% (0%)
2% (8%)
10% (18%)
19% (24%)
31% (33%)
45% (42%)
61% (53%)
76% (64%)
89% (79%)
93% (92%)
100% (100%)
TOP OF DAM
CREST 2113.5
RIGHT SIDE OF
BASIN
EL. @ D/S FACE
CUMULATIVE YARDS
BASIN FLOOR (1970.75)
RCC PLACEMENT PROGRESS
2140
2120
2100
2080
2060
2040
2020
2000
1980
1960
(EL. @ D/S FACE)
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
1982

PLATE 1.13

WILLOW CREEK LAKE

R.C.C. LIFT DRAWING

SCALE: 1 INCH = 5 FEET

PLOTTED BY CDPS - 23 MAY 83

NOTES:

1. GALLERY FLOOR ELEVATION VARIES.
2. STILLING BASIN RCC LIFTS ARE HORIZONTAL PLAINS IN 1 FOOT INCREMENTS WITH TOP AT ELEVATION 1970.75.
3. TRAINING WALL RCC LIFTS ARE IN 1 FOOT VERTICAL INCREMENTS STARTING AT ELEVATION 1970.75 THRU LIFT ELEVATION 1974.75. CONTROL ELEVATIONS THEN HELD AT CBL WITH HINGE AT SPILLWAY FACE.
4. RCC LIFTS IN MAIN DAM BELOW LIFT CONTROL AT CBL ELEVATION 1970.0 ARE BASED ON LIFT ELEVATIONS ESTABLISHED IN NOTES 2 & 3 AND HINGE AT D/S FACE OF SPILLWAY WITH A SLOPE RATIO OF -20:1 TO EITHER INTERCEPT WITH ROCK OR U/S FACE OF DAM.
5. RCC LIFTS WITH CONTROL AT CBL ARE IN 1 FOOT VERTICAL INCREMENTS STARTING WITH LIFT ELEVATION 1970.0 THRU LIFT AT ELEVATION 1990.0 AND SLOPING TO THE D/S FACE AT A HORIZONTAL SLOPE RATIO OF -20:1 AND A -20:1 TO THE U/S FACE.
6. RCC LIFTS ABOVE CBL CONTROLED LIFT AT ELEVATION 1990.0 ARE IN 1 FOOT VERTICAL INCREMENTS ON THE U/S FACE STARTING AT ELEVATION 1990.75 AND SLOPING TO THE D/S FACE AT A HORIZONTAL SLOPE RATIO OF -20:1
7. SEE DETAIL CONTROL OF DAM CREST ON SHEET 13 OF CONTRACT DRAWINGS FOR LIFTS ABOVE U/S FACE CONTROLED LIFT AT ELEVATION 2118.75.

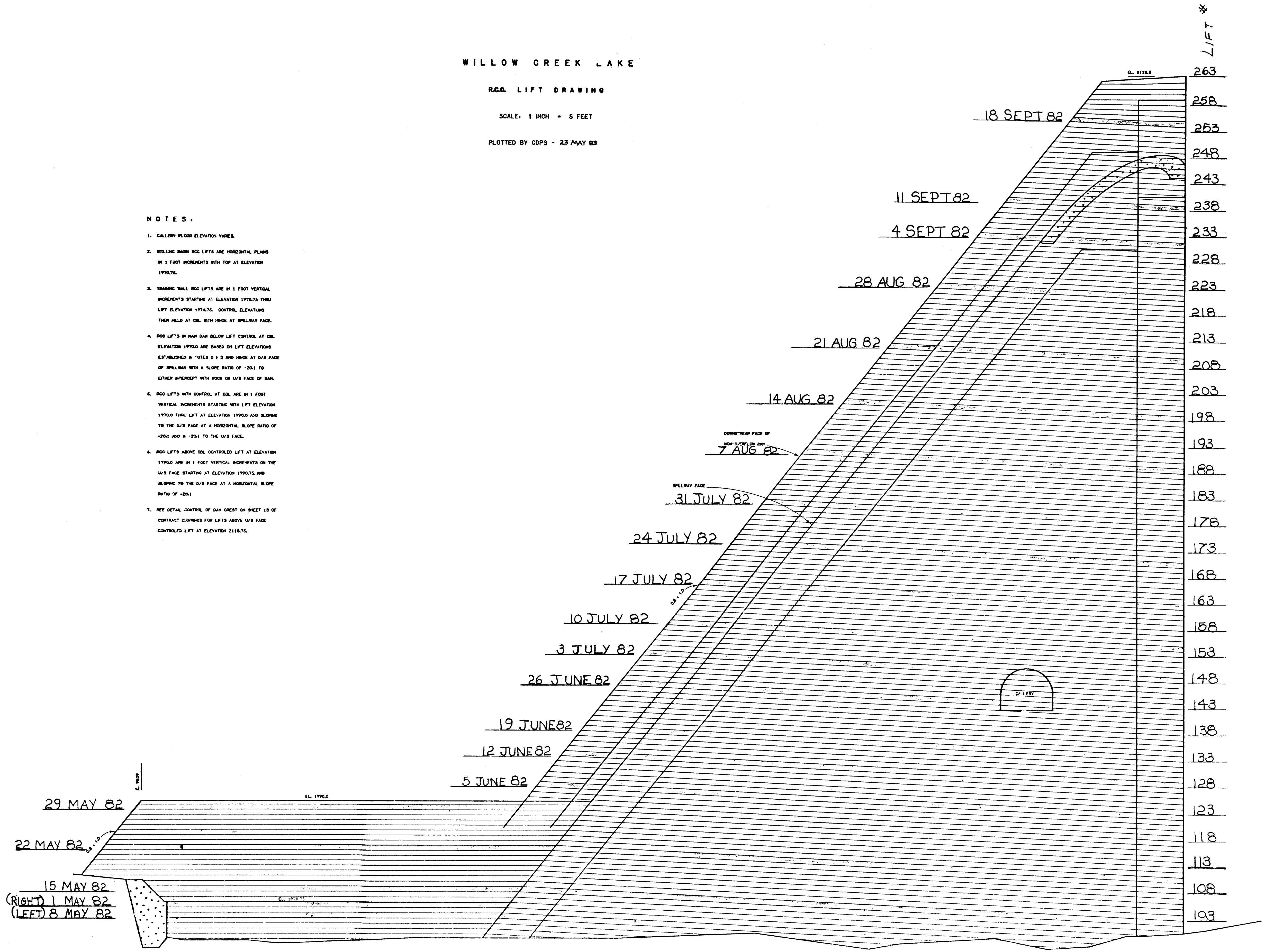


PLATE 1.14

AUG 19 1982

CHAPTER 2

CEMENT AND FLY ASH

CEMENT

Cement for all roller concrete was Type II low-alkali with the optional requirement limiting the heat of hydration at 7 days to 70 calories per gram. It was required to meet ASTM C 150 standards. The supplier of all cement for RCC was LeHigh Cement Company. It was all produced at their Metaline Falls, Washington, facility; shipped by rail to Pasco, Washington, where it was put into temporary storage; and then shipped by truck to the project. Approximately 1,000 tons of cement per week were used during most of the RCC construction.

LeHigh met Corps requirements for being listed as a prequalified cement source, so cement was accepted on that basis. The old procedure (still in effect for nonqualified cement sources) of placing cement in sealed bins and holding it until acceptable results from tests of that material are received was not used. Instead, the plant provided a record of the results of its own analyses, and occasional check samples were taken by the Corps for verification and record purposes. As long as the cement routinely and consistently met specification requirements, its use was approved without holding it in sealed bins. The supplier agreed to use sealed bins at his transfer point in Pasco, Washington, to preclude the possibility of contamination with other cements stored there.

Cement certificates representing material used in the RCC follow this section in Exhibit 2.1.

FLY ASH

Fly ash was ASTM C 618, Class F, except that a small amount of RCC was placed using Class C ash for comparison. The specifications required the ash to meet Class F requirements and allowed Class C if the amount of heat produced by a blend of 65-percent cement with 35-percent ash produced less than 90 percent of the heat generated by use of the cement with no ash substitution.

The Class F ash was produced at the Jim Bridger plant in Rock Springs, Wyoming. It was shipped by rail in sealed cars to Heppner, Oregon, and brought by truck for the short haul from the rail siding to the jobsite. The Class C ash was produced and trucked directly from the Boardman, Oregon, plant. Pozzolanic Northwest was the distributor for both ash sources.

Ash was not released for use in RCC until chemical and physical tests on the samples representing each shipment were satisfactorily completed at the Corps' Waterways Experiment Station. An exception to this was when the small amounts of Class C ash were used on short notice and the supplier had furnished acceptable certificates of his own. Results of fly ash testing follow this section.

During design, tests were performed to try to determine the optimum amount of fly ash and to determine if going to very high ash contents would result in marked increases in strength as had previously been reported in studies for Milton Brook Dam in England. The laboratory work showed only a marginal improvement in strength when adding ash, and showed that at later ages very high ash contents would be harmful. Results are shown graphically on Plates 2.1 through 2.2.

Although laboratory tests did not show a major strength benefit by using fly ash, it was included in the design for several reasons:

(1) To verify if, in fact, under production conditions and with many test results, the ash would still show little strength benefit in RCC. This did turn out to be the case.

(2) To allow a comparison between Class F and Class C ash in RCC under production conditions. Class C ash significantly improved later strength as discussed below.

(3) To provide additional fines into the mix and a method of increasing it further without cement if needed during construction. This did not turn out to be necessary.

(4) To help keep down the heat of hydration of the total mix. There was very little benefit since the ash did not appear to give similar later age strengths when substituted for cement, and similar cement factors were necessary for similar strengths, regardless of the ash content.

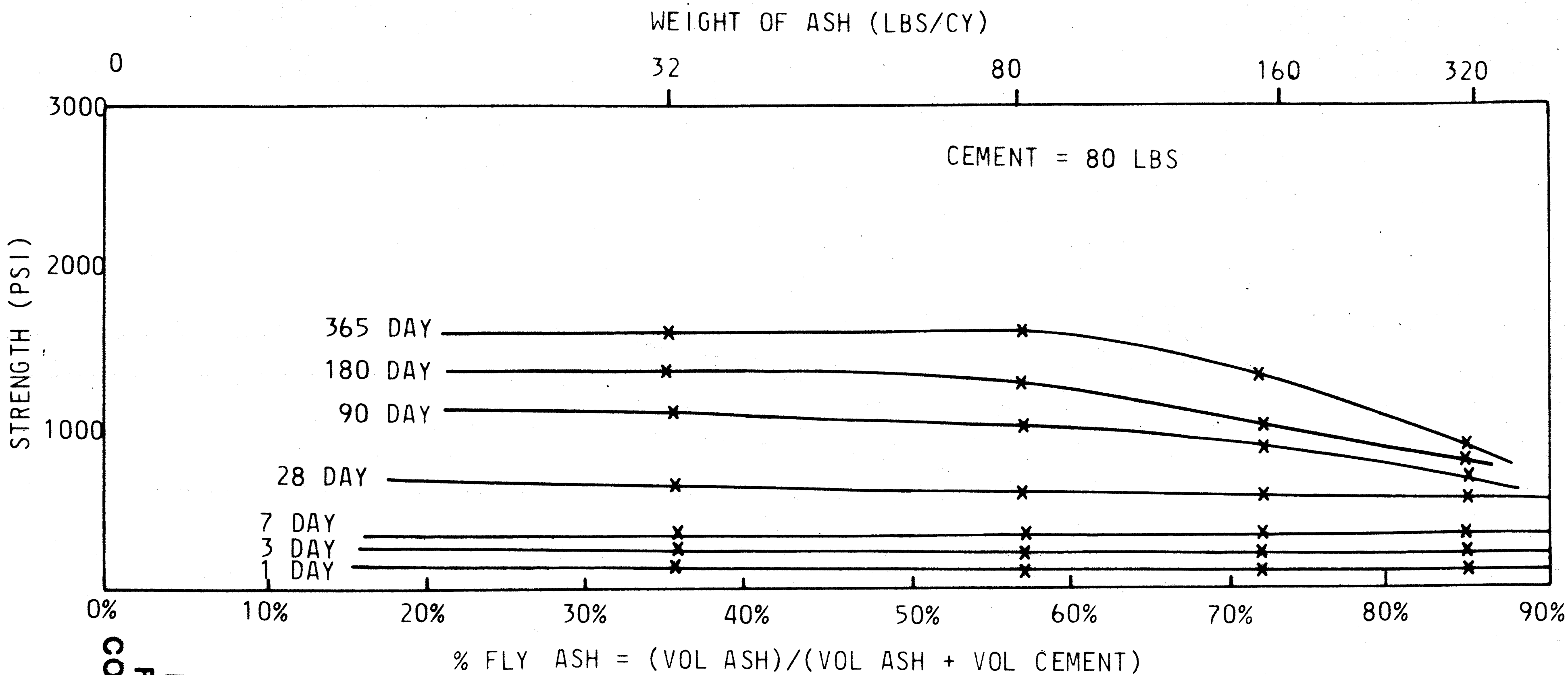
(5) To help long-term impermeability and provide a mechanism for long-term improvement of integrity across the lift line between RCC layers through chemical cementing action. This is difficult to evaluate, but theoretically should be occurring.

(6) To help control potential alkali-silica gel in the potentially reactive aggregate.

Mixes made with Class C ash showed no difference in mixability, placeability, handling, compactibility, or appearance when compared to mixes made with Class F ash. The Class C ash had a higher specific gravity (2.67) than Class F ash (2.32), but for simplicity during construction no adjustment was made in batch weights to compensate for the corresponding 13-percent reduction in volume of ash. Because the amount of ash used per cubic yard was so small, the effect on yield was negligible (less than 0.5 percent).

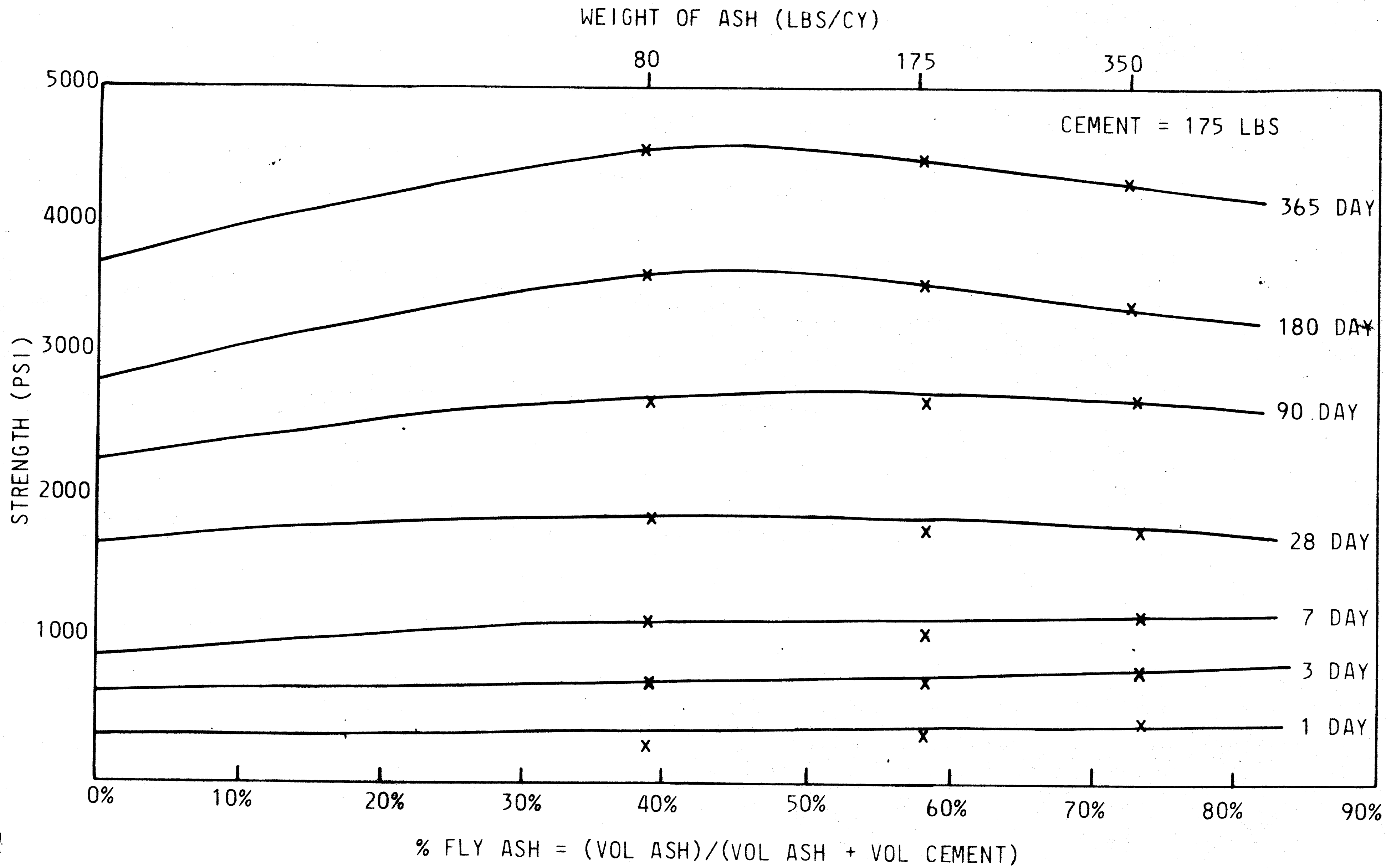
During the design stage a series of tests was made comparing compressive strengths and the rates of strength gain for mixes made with the two classes of fly ash. The 80+32, 175+80, and 315+135 mixes were compared with test ages of 1, 3, 7, 14, 28, 60, 90, 180, and 365 days. At that time there was no significant and consistent difference for any mix at any age, although there was a tendency for the Class F ash to be 1- to 7-percent stronger.

During construction the lifts placed with Class C ash used a pound-for-pound substitution of Class C ash for Class F ash. Everything else remained the same. Both 6- x 12-inch and 9- x 18-inch cylinders were made for the 80+32, 175+80, and 315+135 mixes which used the Class C ash. Strength results are shown on Plates 9.4 through 9.8. The leaner mixes had lower strengths until an age of about 2 to 3 months, at which time the rate of strength gain increased dramatically. From then on the data indicates that the mix with Class C ash will be considerably stronger. The mix with higher cement content (315 pounds) showed significantly higher strengths at all ages, and a similar dramatic increase in the rate of strength gain after 2 to 3 months. The graphed data is the average of all field-cast cylinders available as of 1 February 1983.



EFFECT OF INCREASING FLY ASH CONTENT AT A CONSTANT CEMENT FACTOR OF 80 POUNDS PER CUBIC YARD

PLATE 2.1



EFFECT OF INCREASING FLY ASH CONTENT AT A CONSTANT CEMENT FACTOR OF 175 POUNDS PER CUBIC YARD

PLATE 2.2

EXHIBIT 2.1

TYPICAL CEMENT ANALYSES

Reports of analysis from both the supplier
and from Government check tests.

LABORATORY TEST REPORT

LEHIGH PORTLAND CEMENT COMPANY

Consignee Eucon Corp. Destination Heppner, Oregon

Date March 10, 1982 Car/Truck Plant Metaline Falls, Wn.

TYPE AND SPECIFICATION No. II ASTM-C 150

RESULTS OF TESTS—BIN No. 43 4-82

		SPECIFICATION LIMITS					
		NORMAL PORTLAND CEMENT TYPE I		MODERATE SULFATE RESISTING CEMENT TYPE II		HIGH EARLY STRENGTH PORTLAND CEMENT TYPE III	
CHEMICAL		A.S.T.M. C150	FEDERAL SS-C-1960/3	A.S.T.M. C150	FEDERAL SS-C-1960/3	A.S.T.M. C150	FEDERAL SS-C-1960/3
Silica (SiO_2)	22.1	Min.%		21.0	21.0		
Alumina (Al_2O_3)	4.1	Max.%	7.5	6.0	6.0		7.5
Ferric Oxide (Fe_2O_3)	3.8	Max.%	6.0	6.0	6.0		6.0
Calcium Oxide (CaO)	62.7						
Magnesia (MgO)	2.0	Max.% 6.0	6.0	6.0	6.0	6.0	6.0
Sulfuric Anhydride (SO_3)							
When $3CaO.Al_2O_3$ is 8% or less	2.6	Max.% 3.0	3.0	3.0	3.0	3.5	3.5
When $3CaO.Al_2O_3$ is over 8%		Max.% 3.5	3.5			4.5	4.5
Ignition Loss	1.1	Max.% 3.0	3.0	3.0	3.0	3.0	3.0
Insoluble Residue	0.21	Max.% 0.75	0.75	0.75	0.75	0.75	0.75
Potential Compounds							
Tricalcium Silicate ($3CaO.SiO_2$)	47						
Tricalcium Aluminate ($3CaO.Al_2O_3$)	4.4	Max.%	15.0	8	8	15	15
Dicalcium Silicate	28						
PHYSICAL							
Fineness, Specific Surface, (Wagner)		Min. 1600	1600	1600	1600		
(Blaine)	3370	Min. 2800	2800	2800	2800		
Soundness, Autoclave Expansion	0.06	Max.% 0.80	0.80	0.80	0.80	0.80	0.80
Time of Set (Gillmore)							
Initial (Hr. : Min.)	3:40	Min. 1:0	1:0	1:0	1:0	1:0	1:0
Final (Hr. : Min.)	5:45	Max. 10:0	10:0	10:0	10:0	10:0	10:0
Compressive Strength, psi.							
1-day		Min.				1800	1800
3-day 1000	2200	Min. 1800	1800	~~1500~~	1500	3500	3500
7-day 1700	3170	Min. 2800	2800	~~2500~~	2500		(a) (b)
Total Equivalent Alkalies	0.50			.60			
Heat of Hydration @ 7 days	68			70			

(a) Effective only when so specified by purchaser. (b) Strengths at any age higher than strengths at next preceding specification age.

NOTE.—All test specimens were made and stored under strictly controlled temperature conditions. All testing equipment used complies with the requirements of A.S.T.M. and Federal Specifications for Portland Cement.

For Willow Creek Dam Job # DACW 68-82-C-0018

Date March 10, 1982

David M. Watson
Quality Control Supervisor

EXHIBIT 2.1
Sheet 1 of 12

LABORATORY TEST REPORT

LEHIGH PORTLAND CEMENT COMPANY

Consignee: Eucon Corp. Destination: Heppner, Oregon

Date: May 12, 1982 Car/Truck: Plant: Metaline Falls, Wa.

TYPE AND SPECIFICATION No. II ASTM C-150

RESULTS OF TESTS—BIN No. 44 3-82

SPECIFICATION LIMITS

	Results		Normal Portland Cement Type I A.S.T.M. C150	Normal Portland Cement Type I Federal SS-C-1960/3	Moderate Sulfate Resisting Cement Type II A.S.T.M. C150	Moderate Sulfate Resisting Cement Type II Federal SS-C-1960/3	High Early Strength Portland Cement Type III A.S.T.M. C150	High Early Strength Portland Cement Type III Federal SS-C-1960/3
CHEMICAL								
Silica (SiO_2)	21.9	Min.%			21.0	21.0		
Alumina (Al_2O_3)	4.6	Max.%		7.5	6.0	6.0		7.5
Ferric Oxide (Fe_2O_3)	3.8	Max.%		6.0	6.0	6.0		6.0
Calcium Oxide (CaO)	63.2							
Magnesia (MgO)	2.0	Max.%	6.0	6.0	6.0	6.0	6.0	6.0
Sulfuric Anhydride (SO_3)								
When $3CaO.Al_2O_3$ is 8% or less	2.5	Max.%	3.0	3.0	3.0	3.0	3.5	3.5
When $3CaO.Al_2O_3$ is over 8%		Max.%	3.5	3.5			4.5	4.5
Ignition Loss	1.7	Max.%	3.0	3.0	3.0	3.0	3.0	3.0
Insoluble Residue	0.22	Max.%	0.75	0.75	0.75	0.75	0.75	0.75
Potential Compounds								
Tricalcium Silicate ($3CaO.SiO_2$)	47							
Tricalcium Aluminate ($3CaO.Al_2O_3$)	5.8	Max.%		15.0	8	8	15	15
Dicalcium Silicate	27							
PHYSICAL								
Fineness, Specific Surface, (Wagner)		Min.	1600	1600	1600	1600		
(Blaine)	3430	Min.	2800	2800	2800	2800		
Soundness, Autoclave Expansion	0.09	Max.%	0.80	0.80	0.80	0.80	0.80	0.80
Time of Set (Gillmore)								
Initial (Hr. : Min.)	3:25	Min.	1:0	1:0	1:0	1:0	1:0	1:0
Final (Hr. : Min.)	5:25	Max.	10:0	10:0	10:0	10:0	10:0	10:0
Compressive Strength, psi.								
1-day		Min.					1800	1800
3-day	2010	Min.	1800	1800	1500	1500	3500	3500
7-day	3020	Min.	2800	2800	2500	2500		(a) (b)
Total Equivalent Alkalies	0.44			Max.	0.60			
Heat of Hydration @ 7 days	70			Max.	70			

(a) Effective only when so specified by purchaser. (b) Strengths at any age higher than strengths at next preceding specification age.

NOTE.—All test specimens were made and stored under strictly controlled temperature conditions. All testing equipment used complies with the requirements of A.S.T.M. and Federal Specifications for Portland Cement.

For Willow Creek Dam Job # DACW 68-82-C-0018

Date: May 12, 1982

David M. Watson

Quality Control Supervisor

EXHIBIT 2.1
Sheet 2 of 12

FORM CHEM 4 B

LABORATORY TEST REPORT RECEIVED JUN 4 1982

LEHIGH PORTLAND CEMENT COMPANY

Consignee Eucon Corp. **Destination** Heppner, Oregon

Date May 28, 1982 **Car/Truck** **Plant** Metaline Falls, Wn.

TYPE AND SPECIFICATION No. II L.A. HH @ 7days

RESULTS OF TESTS—BIN No. 51 15-82

		SPECIFICATION LIMITS						
			NORMAL PORTLAND CEMENT TYPE I		MODERATE SULFATE RESISTING CEMENT TYPE II		HIGH EARLY STRENGTH PORTLAND CEMENT TYPE III	
			A.S.T.M. C150	FEDERAL SS-C-1960/3	A.S.T.M. C150	FEDERAL SS-C-1960/3	A.S.T.M. C150	FEDERAL SS-C-1960/3
CHEMICAL								
Silica (SiO_2)	22.9	Min.%			21.0	21.0		
Alumina (Al_2O_3)	4.1	Max.%		7.5	6.0	6.0		7.5
Ferric Oxide (Fe_2O_3)	4.2	Max.%		6.0	6.0	6.0		6.0
Calcium Oxide (CaO)	62.3							
Magnesia (MgO)	2.2	Max.%	6.0	6.0	6.0	6.0	6.0	6.0
Sulfuric Anhydride (SO_3)								
When $3CaO.Al_2O_3$ is 8% or less	2.1	Max.%	3.0	3.0	3.0	3.0	3.5	3.5
When $3CaO.Al_2O_3$ is over 8%		Max.%	3.5	3.5			4.5	4.5
Ignition Loss	1.3	Max.%	3.0	3.0	3.0	3.0	3.0	3.0
Insoluble Residue		Max.%	0.75	0.75	0.75	0.75	0.75	0.75
Potential Compounds								
Tricalcium Silicate ($3CaO.SiO_2$)	40							
Tricalcium Aluminate ($3CaO.Al_2O_3$)	3.8	Max.%		15.0	8	8	15	15
Dicalcium Silicate	36							
PHYSICAL								
Fineness, Specific Surface, (Wagner)		Min.	1600	1600	1600	1600		
(Blaine)	3340	Min.	2800	2800	2800	2800		
Soundness, Autoclave Expansion	0.04	Max.%	0.80	0.80	0.80	0.80	0.80	0.80
Time of Set (Gillmore)								
Initial (Hr. : Min.)	2:50	Min.	1:0	1:0	1:0	1:0	1:0	1:0
Final (Hr. : Min.)	5:00	Max.	10:0	10:0	10:0	10:0	10:0	10:0
Compressive Strength, psi.								
1-day		Min.					1800	1800
3-day 1000	1760	Min.	1800	1800	~~1500~~	1500	3500	3500
7-day 1700		Min.	2800	2800	~~2500~~	2500		(a) (b)
Total Equivalent Alkalies	0.53				0.60			
Heat of Hydration @ 7 days	62				70			

(a) Effective only when so specified by purchaser. (b) Strengths at any age higher than strengths at next preceding specification age.

NOTE.—All test specimens were made and stored under strictly controlled temperature conditions. All testing equipment used complies with the requirements of A.S.T.M. and Federal Specifications for Portland Cement.

Willow Creek Dam Job #DACW 68-82-C-0018

Date May 28, 1982

David M. Watson
Quality Control Supervisor

RECEIVED JUN 2 5 1982

LABORATORY TEST REPORT

LEHIGH PORTLAND CEMENT COMPANY

Consignee Eucon Corp. Destination Heppner, Oregon

Date June 23, 1982 Car/Truck Plant Metaline Falls, Wn.

TYPE AND SPECIFICATION No. II ASTM C-150

RESULTS OF TESTS—BIN No. 33 15-82

		SPECIFICATION LIMITS					
		NORMAL PORTLAND CEMENT TYPE I		MODERATE SULFATE RESISTING CEMENT TYPE II		HIGH EARLY STRENGTH PORTLAND CEMENT TYPE III	
		A.S.T.M. C150	FEDERAL SS-C-1960/3	A.S.T.M. C150	FEDERAL SS-C-1960/3	A.S.T.M. C150	FEDERAL SS-C-1960/3
CHEMICAL							
Silica (SiO_2)	23.1	Min.%		21.0	21.0		
Alumina (Al_2O_3)	4.3	Max.%	7.5	6.0	6.0		7.5
Ferric Oxide (Fe_2O_3)	3.9	Max.%	6.0	6.0	6.0		6.0
Calcium Oxide (CaO)	63.3						
Magnesia (MgO)	1.7	Max.% 6.0	6.0	6.0	6.0	6.0	6.0
Sulfuric Anhydride (SO_3)							
When $3CaO.Al_2O_3$ is 8% or less	2.0	Max.% 3.0	3.0	3.0	3.0	3.5	3.5
When $3CaO.Al_2O_3$ is over 8%		Max.% 3.5	3.5			4.5	4.5
Ignition Loss	1.3	Max.% 3.0	3.0	3.0	3.0	3.0	3.0
Insoluble Residue	0.29	Max.% 0.75	0.75	0.75	0.75	0.75	0.75
Potential Compounds							
Tricalcium Silicate ($3CaO.SiO_2$)	42						
Tricalcium Aluminate ($3CaO.Al_2O_3$)	4.8	Max.%	15.0	8	8	15	15
	35						
PHYSICAL							
Fineness, Specific Surface, (Wagner)		Min. 1600	1600	1600	1600		
(Blaine)	3380	Min. 2800	2800	2800	2800		
Soundness, Autoclave Expansion	0.04	Max.% 0.80	0.80	0.80	0.80	0.80	0.80
Time of Set (Gillmore)							
Initial (Hr. : Min.)	2:55	Min. 1:0	1:0	1:0	1:0	1:0	1:0
Final (Hr. : Min.)	5:05	Max. 10:0	10:0	10:0	10:0	10:0	10:0
Compressive Strength, psi.							
1-day		Min.				1800	1800
3-day 1000	1820	Min. 1800	1800	XXXXXX	1500	3500	3500
7-day 1700	2580	Min. 2800	2800	XXXXXX	2500		(a) (b)
Total Equivalent Alk.	0.50		Max.	0.60			
Heat of Hydration @ 7 days	66		Max.	70			

(a) Effective only when so specified by purchaser. (b) Strengths at any age higher than strengths at next preceding specification age.

NOTE.—All test specimens were made and stored under strictly controlled temperature conditions. All testing equipment used complies with the requirements of A.S.T.M. and Federal Specifications for Portland Cement.

For Willow Creek Dam Job #DACW 68-82-C-0018

Date June 22, 1982

David M. Watson
Quality Control Supervisor

USAE District, Walla Walla
ATTN: Mr. Ernie Schrader,
NPWEN-FM
Bldg. 602, City-County Airport
Walla Walla, WA 99362

REPORT OF TESTS OF PORTLAND CEMENT

FROM: CORPS OF ENGINEERS
U.S. ARMY
Structures Laboratory
Waterways Exp Station
ATTN: Cem & Pozz Unit
P O Box 631
Vicksburg, MS 39180

TEST REPORT NO. NPW-237-82 | BIN NO. | CWT REPRESENTED: CQMS | DATE: 30 June 82

SPECIFICATION: SS-C-1960/3, Type II, LA, HH | DATE SAMPLED: 14 June 82

COMPANY: Lehigh Cem Co., | LOCATION: Metaline Falls, WA | BRAND:

THIS CEMENT DOES X MEET SPECIFICATION REQUIREMENTS

SAMPLE NO.	1	Spec						
SiO_2, %	22.1							
Al_2O_3, %	4.0							
Fe_2O_3, %	4.0							
MgO, %	2.3							
SO_3, %	2.5							
LOSS ON IGNITION, %	1.5							
ALKALIES-TOTAL AS Na_2O, %	0.55	0.60 max						
Na_2O, %	0.13							
K_2O, %	0.64							
INSOLUBLE RESIDUE, %	0.33							
CaO, %	62.0							
C_3S, %	45							
C_3A, %	4	8 max						
C_2S, %	29							
$C_3A + C_3S$, %	49							
C_4AF, %	12							
$C_4AF + 2 C_3A$, %	20							
HEAT OF HYDRATION, 7D, CAL/G	67	70 max						
HEAT OF HYDRATION, 28D, CAL/G								
SURFACE AREA, SQ CM/G (A.P.)	3450	280[illegible]						
AIR CONTENT, %	7.7							
COMP. STRENGTH, 3 D, PSI	2270	1000						
COMP. STRENGTH, 7 D, PSI	3550	[illegible]						
COMP. STRENGTH, D, PSI								
FALSE SET-PEN. F/I, %								
SAMPLE NO.	1							
AUTOCLAVE EXP., %	0.06							
INITIAL SET, HR/MIN	2:40							
FINAL SET, HR/MIN	4:40							
SAMPLE NO.								
AUTOCLAVE EXP., %								
INITIAL SET, HR/MIN								
FINAL SET, HR/MIN								

REMARKS: Project Sample DACW68-82-C-0018

CC: Res Engr, Heppner, OR
Lehigh Cem Co., Metaline Falls, WA

THE INFORMATION GIVEN IN THIS REPORT SHALL NOT BE USED IN ADVERTISING OR SALES PROMOTION TO INDICATE EITHER EXPLICITLY OR IMPLICITLY ENDORSEMENT OF THIS PRODUCT BY THE U. S. GOVERNMENT.

R. E. Reinhold

R. E. REINHOLD
Chief, Cement & Pozzolan Unit

ENG FORM 1 MAR 72 6008-R

PREVIOUS EDITIONS OBSOLETE

TO:	REPORT OF TESTS OF PORTLAND CEMENT	FROM: CORPS OF ENGINEERS U. S. ARMY
USAE District, Walla Walla ATTN: Mr. Ernie Schrader NPWEN-FM Bldg. 602, City-Co. Airport Walla Walla, WA 99362		Structures Laboratory Waterways Exp Station ATTN: Cem & Pozz Unit P O Box 631

TEST REPORT NO. NPW-245-82 | BIN NO. | CWT REPRESENTED: CQMS | DATE: 6 July 82

SPECIFICATION: SS-C-1960/3, Type II, LA, HH | DATE SAMPLED: 22 June 82

COMPANY: Lehigh Cem Co., | LOCATION Metaline Falls, WA | BRAND:

THIS CEMENT DOES X MEET SPECIFICATION REQUIREMENTS

SAMPLE NO.	1	Spec							
SiO_2, %	22.9								
Al_2O_3, %	3.9								
Fe_2O_3, %	4.2								
MgO, %	2.1								
SO_3, %	2.3								
LOSS ON IGNITION, %	1.3								
ALKALIES-TOTAL AS Na_2O, %	0.56	0.60 max							
Na_2O, %	0.14								
K_2O, %	0.64								
INSOLUBLE RESIDUE, %	0.23								
CaO, %	62.0								
C_3S, %	40								
C_3A, %	3	8 max							
C_2S, %	35								
$C_3A + C_3S$, %	43								
C_4AF, %	13								
$C_4AF + 2 C_3A$, %	19								
HEAT OF HYDRATION, 7D, CAL/G	55	70 max							
HEAT OF HYDRATION, 28D, CAL/G									
SURFACE AREA, SQ CM/G (A.P.)	3460	2800							
AIR CONTENT, %	9.5								
COMP. STRENGTH, 3 D, PSI	1930	1000							
COMP. STRENGTH, 7 D, PSI	2900	1700							
COMP. STRENGTH, D, PSI									
FALSE SET-PEN. F/I, %									
SAMPLE NO.	1								
AUTOCLAVE EXP., %	0.02								
INITIAL SET, HR/MIN	2:30								
FINAL SET, HR/MIN	4:30								
SAMPLE NO.									
AUTOCLAVE EXP., %									
INITIAL SET, HR/MIN									
FINAL SET, HR/MIN									

REMARKS: Project Sample DACW68-82-C-0018

CC: Res Engr, Heppner, OR
Lehigh Cement Company. Metaline Falls, WA

THE INFORMATION GIVEN IN THIS REPORT SHALL NOT BE USED IN ADVERTISING OR SALES PROMOTION TO INDICATE EITHER EXPLICITLY OR IMPLICITLY ENDORSEMENT OF THIS PRODUCT BY THE U. S. GOVERNMENT.

R. E. Reinhold

R. E. REINHOLD
Chief, Cement & Pozzolan Unit

ENG FORM 1 MAR 72 6008-R

TO:		FROM: CORPS OF ENGINEERS U. S. ARMY
USAE District, Walla Walla ATTN: Mr. Ernie Schrader, Bldg. 602, City-Co. Airport Walla Walla, WA 99362	**REPORT OF TESTS OF PORTLAND CEMENT**	Structures Laboratory Waterways Exp Station ATTN: Cem & Pozz Unit P O Box 631 Vicksburg, MS 39180

TEST REPORT NO. NPW-254-82 | BIN NO. | CWT REPRESENTED: CQMS | DATE: 15 July 82

SPECIFICATION: SS-C-1960/3, Type II, LA, HH | DATE SAMPLED: 23 June 82

COMPANY: Lehigh Cem Co | LOCATION Metaline Falls, WA | BRAND:

THIS CEMENT DOES X MEET SPECIFICATION REQUIREMENTS

SAMPLE NO.	1							
SiO_2, %	22.9							
Al_2O_3, %	3.8							
Fe_2O_3, %	4.2							
MgO, %	2.1							
SO_3, %	2.4							
LOSS ON IGNITION, %	1.3							
ALKALIES-TOTAL AS Na_2O, %	0.57	*Ref Para 5. a. App C, ER 1110-1-2002, dated 11/11/77,						
Na_2O, %	0.14	exceeds critical limit for Total Alkali						
K_2O, %	0.66							
INSOLUBLE RESIDUE, %	0.29							
CaO, %	61.4							
C_3S, %	37							
C_3A, %	3							
C_2S, %	38							
$C_3A + C_3S$, %	19							
C_4AF, %	13							
$C_4AF + 2\,C_3A$, %	19							
HEAT OF HYDRATION, 7D, CAL/G	63							
HEAT OF HYDRATION, 28D, CAL/G								
SURFACE AREA, SQ CM/G (A.P.)	3460							
AIR CONTENT, %	8.0							
COMP. STRENGTH, 3 D, PSI	2270							
COMP. STRENGTH, 7 D, PSI	2900							
COMP. STRENGTH, D, PSI								
FALSE SET-PEN. F/I, %								
SAMPLE NO.	1							
AUTOCLAVE EXP., %	0.01							
INITIAL SET, HR/MIN	2:30							
FINAL SET, HR/MIN	4:35							
SAMPLE NO.								
AUTOCLAVE EXP., %								
INITIAL SET, HR/MIN								
FINAL SET, HR/MIN								

REMARKS: Project Sample DACW68-82-C-0018

CC: Res Engr, Heppner, OR
Lehigh, Metaline Falls, WA

R. E. Reinhold (signature)
R. E. REINHOLD
Chief, Cement & Pozzolan Unit

ENG FORM 1 MAR 72 6008-R

TO:
USAE Dist. Walla Walla
ATTN: Ernie Schrader,
NPWEN-FM
Bldg. 602, City-CO, A/port
Walla Walla, WA 99362

REPORT OF TESTS OF PORTLAND CEMENT

FROM: CORPS OF ENGINEERS
U. S. ARMY
Structures Laboratory
Waterways Exp Station
ATTN: Cem & Pozz Unit
P O Box 631
Vicksburg, MS 39180

TEST REPORT NO. NPW-270-82 | BIN NO. | CWT REPRESENTED: CQMS | DATE: 21 July 82

SPECIFICATION: SS-C-1960/3, Type II, LA, HH | DATE SAMPLED: 1 July 82

COMPANY: Lehigh Cement Co. | LOCATION: Metaline Falls, WA | BRAND:

THIS CEMENT DOES X MEET SPECIFICATION REQUIREMENTS

SAMPLE NO.	1	4						
SiO_2, %	23.1	22.8						
Al_2O_3, %	4.2	4.2						
Fe_2O_3, %	3.9	4.0						
MgO, %	1.9	2.0						
SO_3, %	2.5	2.1						
LOSS ON IGNITION, %	1.2	1.5						
ALKALIES-TOTAL AS Na_2O, %	0.58	0.60*	*Ref Para 5.a. App C, ER 1110-1-2002, dated 11/11/					
Na_2O, %	0.15	0.14	exceeds critical limit for Total Alkalies.					
K_2O, %	0.66	0.70						
INSOLUBLE RESIDUE, %	0.16	0.12						
CaO, %	61.5	61.9						
C_3S, %	35	38						
C_3A, %	4	5						
C_2S, %	40	37						
$C_3A + C_3S$, %	40	43						
C_4AF, %	12	12						
$C_4AF + 2\ C_3A$, %	21	21						
HEAT OF HYDRATION, 7D, CAL/G	67							
HEAT OF HYDRATION, 28D, CAL/G								
SURFACE AREA, SQ CM/G (A.P.)	3920	3570						
AIR CONTENT, %	7.5	7.8						
COMP. STRENGTH, 3 D, PSI	1970	2270						
COMP. STRENGTH, 7 D, PSI	2750	3380						
COMP. STRENGTH, D, PSI								
FALSE SET-PEN. F/I, %								
SAMPLE NO.	1-2	3-4						
AUTOCLAVE EXP., %	0.08	0.02						
INITIAL SET, HR/MIN	2:40	2:40						
FINAL SET, HR/MIN	4:30	4:40						
SAMPLE NO.								
AUTOCLAVE EXP., %								
INITIAL SET, HR/MIN								
FINAL SET, HR/MIN								

REMARKS: Project Sample DACW68-82-C-0018

CC: Res Engr, Heppner, OR 97836
Lehigh Cem Co., Metaline Falls, WA

for Tony B. Husbands
R. E. REINHOLD
Chief, Cement & Pozzolan Unit

ENG FORM 1 MAR 72 6008-R

TO: USAE District, ATTN: Ernie Schrader, NPWEN-FM Bldg. 602, City-County Airport Walla Walla, WA 99362	**REPORT OF TESTS OF PORTLAND CEMENT**	FROM: CORPS OF ENGINEERS U. S. ARMY Structures Laboratory Waterways Exp Station ATTN: Cem & Pozz Unit P.O. Box 631 Vicksburg, MS 39180

TEST REPORT NO. NPW-310-82 | BIN NO. | CWT REPRESENTED: CQMS | DATE: 17 August 1982

SPECIFICATION: ASTM C150, Type II, LA, HH | DATE SAMPLED: 31 July 1982

COMPANY: Lehigh Portland Ce. | LOCATION: Metaline Falls, WA | BRAND:

THIS CEMENT DOES X MEET SPECIFICATION REQUIREMENTS

SAMPLE NO.	1							
SiO_2, %	22.0							
Al_2O_3, %	4.0							
Fe_2O_3, %	4.3							
MgO, %	2.2							
SO_3, %	2.2							
LOSS ON IGNITION, %	1.2							
ALKALIES-TOTAL AS Na_2O, %	0.55							
Na_2O, %	0.14							
K_2O, %	0.63							
INSOLUBLE RESIDUE, %	0.19							
CaO, %	62.4							
C_3S, %	47							
C_3A, %	3							
C_2S, %	28							
$C_3A + C_3S$, %	50							
C_4AF, %	13							
$C_4AF + 2 C_3A$, %	20							
HEAT OF HYDRATION, 7D, CAL/G	63							
HEAT OF HYDRATION, 28D, CAL/G								
SURFACE AREA, SQ CM/G (A.P.)	3660							
AIR CONTENT, %	8.8							
COMP. STRENGTH, 3 D, PSI	2560							
COMP. STRENGTH, 7 D, PSI	3590							
COMP. STRENGTH, D, PSI								
FALSE SET - PEN. F/I, %								
SAMPLE NO.	1							
AUTOCLAVE EXP., %	0.02							
INITIAL SET, HR/MIN	3:00							
FINAL SET, HR/MIN	4:40							
SAMPLE NO.								
AUTOCLAVE EXP., %								
INITIAL SET, HR/MIN								
FINAL SET, HR/MIN								

REMARKS: Project Sample DACW68-82-C-0018.

CC: Resident Engineer, Heppner, OR 97836
Lehigh Cement Company, Metaline Falls, WA

R.E. Reinhold
R.E. REINHOLD
Chief, Cement & Pozzolan Unit

ENG FORM 1 MAR 72 6008-R

TO: USAE District, Walla Walla ATTN: Ernie Schrader NPWEN-FM Bldg. 602, City County Airport Walla Walla, WA 99362	**REPORT OF TESTS OF PORTLAND CEMENT**	FROM: CORPS OF ENGINEERS U. S. ARMY Structures Laboratory Waterways Exp Station ATTN: Cem & Pozz Unit P.O. Box 631 Vicksburg, MS 39180

TEST REPORT NO. NPW-317-82 | BIN NO. | CWT REPRESENTED: CQMS | DATE: 24 August 1982

SPECIFICATION: ASTM C150, Type II, LA, HH | DATE SAMPLED: 11 August 1982

COMPANY: Lehigh Portland | LOCATION Metaline Falls, WA | BRAND:

THIS CEMENT DOES X MEET SPECIFICATION REQUIREMENTS

SAMPLE NO.	1							
SiO_2, %	21.4							
Al_2O_3, %	3.9							
Fe_2O_3, %	3.9							
MgO, %	2.2							
SO_3, %	2.3							
LOSS ON IGNITION, %	0.9							
ALKALIES-TOTAL AS Na_2O, %	0.35							
Na_2O, %	0.10							
K_2O, %	0.49							
INSOLUBLE RESIDUE, %	0.2							
CaO, %	62.4							
C_3S, %	49							
C_3A, %	4							
C_2S, %	27							
$C_3A + C_3S$, %	53							
C_4AF, %	12							
$C_4AF + 2C_3A$, %	19							
HEAT OF HYDRATION, 7D, CAL/G	70							
HEAT OF HYDRATION, 28D, CAL/G								
SURFACE AREA, SQ CM/G (A.P.)	3720							
AIR CONTENT, %	9.2							
COMP. STRENGTH, 3 D, PSI	2170							
COMP. STRENGTH, 7 D, PSI	3170							
COMP. STRENGTH, D, PSI								
FALSE SET-PEN. F/I, %								
SAMPLE NO.	1							
AUTOCLAVE EXP., %	0.03							
INITIAL SET, HR/MIN	3:10							
FINAL SET, HR/MIN	5:15							
SAMPLE NO.								
AUTOCLAVE EXP., %								
INITIAL SET, HR/MIN								
FINAL SET, HR/MIN								

REMARKS: Project Sample DACW68-82-C-0018.

CC: Resident Engineer, Heppner, OR
Lehigh Cement Company, Metaline Falls, WA

R.E. REINHOLD
Chief, Cement & Pozzolan Unit

ENG FORM 1 MAR 72 6008-R

PREVIOUS EDITIONS OBSOLETE

TO: USAE District, Walla Walla ATTN: Ernie Schrader, NPWEN-FM Bldg. 602, City-Co. Airport Walla Walla, WA 99362	**REPORT OF TESTS OF PORTLAND CEMENT**	FROM: CORPS OF ENGINEERS U. S. ARMY Structures Laboratory Waterways Exp Station ATTN: Cem & Pozz Unit P O Box 631 Vicksburg, MS 39180

TEST REPORT NO NPW-333-82 | BIN NO. | CWT REPRESENTED: COMS | DATE: 14 Sept 82

SPECIFICATION: ASTM C-150, Type II, LA, HH | DATE SAMPLED: 17 Aug 82

COMPANY: Lehigh Co. | LOCATION Metaline Falls, WA | BRAND:

THIS CEMENT DOES NOT MEET SPECIFICATION REQUIREMENTS *

SAMPLE NO.	1							
SiO_2, %	21.5							
Al_2O_3, %	4.0							
Fe_2O_3, %	4.2							
MgO, %	2.3							
SO_3, %	2.4							
LOSS ON IGNITION, %	1.0							
ALKALIES-TOTAL AS Na_2O, %	0.48							
Na_2O, %	0.13							
K_2O, %	0.53							
INSOLUBLE RESIDUE, %	0.13							
CaO, %	63.4							
C_3S, %	56							
C_3A, %	3							
C_2S, %	19							
$C_3A + C_3S$, %	59							
C_4AF, %	13							
$C_4AF + 2 C_3A$, %	19							
HEAT OF HYDRATION, 7D, CAL/G	73	*Fails Heat Hydration 7 day						
HEAT OF HYDRATION, 28D, CAL/G								
SURFACE AREA, SQ CM/G (A.P.)	3750							
AIR CONTENT, %	9							
COMP. STRENGTH, 3 D, PSI	2470							
COMP. STRENGTH, 7 D, PSI	3700							
COMP. STRENGTH, D, PSI								
FALSE SET-PEN. F/I. %								
SAMPLE NO.	1							
AUTOCLAVE EXP., %	0.05							
INITIAL SET, HR/MIN	3:00							
FINAL SET, HR/MIN	5:00							
SAMPLE NO.								
AUTOCLAVE EXP., %								
INITIAL SET, HR/MIN								
FINAL SET, HR/MIN								

REMARKS: Project sample DACW68-82-C-0018

CC: Resi. Eng., Heppner, OR 97836
Lehigh Cement Co., Metaline Falls, WA 99153

THE INFORMATION GIVEN IN THIS REPORT SHALL NOT BE USED IN ADVERTISING OR SALES PROMOTION TO INDICATE EITHER EXPLICITLY OR IMPLICITLY ENDORSEMENT OF THIS PRODUCT BY THE U. S. GOVERNMENT.

R. E. Reinhold

R. E. REINHOLD
Chief, Cement & Pozzolan Unit

ENG FORM 6008-R
1 MAR 72

TO: USAE District, Walla Walla ATTN: Ernie Schrader, NPWEN-FM Bldg. 602, City-Co. Airport Walla Walla, WA 99362	REPORT OF TESTS OF PORTLAND CEMENT	FROM: CORPS OF ENGINEERS U. S. ARMY Structures Laboratory Waterways Exp Station ATTN: Cem & Pozz Unit P O Box 631 Vicksburg, MS 39180

TEST REPORT NO. NPW-338-82 | BIN NO. | CWT REPRESENTED: CQMS | DATE: 9 Sept 82

SPECIFICATION: ASTM C150 , Type II, LA, HH | DATE SAMPLED: 24 Aug 82

COMPANY: Lehigh Cem Co. | LOCATION Metaline Falls, WA | BRAND:

THIS CEMENT DOES X MEET SPECIFICATION REQUIREMENTS

SAMPLE NO.	1							
SiO_2, %	22.2							
Al_2O_3, %	3.9							
Fe_2O_3, %	3.7							
MgO, %	2.5							
SO_3, %	2.2							
LOSS ON IGNITION, %	1.2							
ALKALIES-TOTAL AS Na_2O, %	0.45							
Na_2O, %	0.11							
K_2O, %	0.51							
INSOLUBLE RESIDUE, %	0.16							
CaO, %	63.0							
C_3S, %	50							
C_3A, %	4							
C_2S, %	26							
$C_3A + C_3S$, %	54							
C_4AF, %	11							
$C_4AF + 2C_3A$, %	19							
HEAT OF HYDRATION, 7D, CAL/G	64							
HEAT OF HYDRATION, 28D, CAL/G								
SURFACE AREA, SQ CM/G (A.P.)	3320							
AIR CONTENT, %	9							
COMP. STRENGTH, 3 D, PSI	2520							
COMP. STRENGTH, 7 D, PSI	3080							
COMP. STRENGTH, D, PSI								
FALSE SET-PEN. F/I. %								
SAMPLE NO.	1							
AUTOCLAVE EXP., %	0.05							
INITIAL SET, HR/MIN	3:35							
FINAL SET, HR/MIN	4:35							
SAMPLE NO.								
AUTOCLAVE EXP., %								
INITIAL SET, HR/MIN								
FINAL SET, HR/MIN								

REMARKS: Project Sample DACW68-82-C-0018

CC: Res Engr, Heppner, OR
Lehigh, Metaline Falls, WA

R. E. Reinhold

R. E. REINHOLD
Chief, Cement & Pozzolan Unit

ENG FORM 6008-R
1 MAR 72

EXHIBIT 2.2

TYPICAL FLY ASH ANALYSES

LABORATORY	REPORT OF TESTS ON POZZOLAN	REPORT NO.:
Structures Laboratory Waterways Exp Station ATTN: Cem & Pozz Group P.O. Box 631 Vicksburg, MS 39180	SS-C-1960/5	WES-10F-82 SHEET 1 OF 1 DATE: 22 Jan 82 10 Feb 82

CLASS (F) N — KIND OF POZZOLAN: Fly Ash

SOURCE: Pozzolanic Intl., Rock Springs, WY — BRAND:

TEST RESULTS OF THIS SAMPLE LOT [X] COMPLY [ ] DO NOT COMPLY WITH SPECIFICATION LIMITS (SEE REMARKS)

FOR USE AT:

CONTRACT NO.:

DISTRICT(S): Bureau of Reclamation

SAMPLED BY: PSP — DATE SAMPLED: 14-18 Dec 81

CAR NO.: — BIN NO.: 1 & 3-350 tons

FIELD SAMPLE NO.: — LAB SAMPLE NO.:

DATE RECEIVED: 7 Jan 82 — LAB JOB NO.:

TESTED BY: Cem & Pozz Group — CHECKED BY:

TESTS ON COMPOSITE OF THE 100-TON SAMPLES LISTED BELOW

$SiO_2 + Al_2O_3 + Fe_2O_3$ %	MgO %	SO_3 %	AVAILABLE ALKALIES %	POZZOLAN STRENGTH % CONTROL	INCREASE IN SHRINKAGE % (a)	AUTOCLAVE EXPANSION %	REDUCTION IN EXPANSION % (b)
REQUIREMENTS							
MIN 70.0	MAX 5.0	MAX 4.0		MIN 75	MAX 0.03	MAX 0.50	MIN 75
TEST RESULTS							
84.6	1.6	0.5		* 98		-0.04	

TESTS ON SAMPLES REPRESENTING 100 TONS OR LESS

SAMPLE NO.	MOISTURE CONTENT %	LOSS ON IGNITION %	Fineness 325 Mesh Sieve % Retained	% pts var from avg prev 10	LIME POZZOLAN STRENGTH PSI	WATER REQUIREMENT % of Control	SPECIFIC GRAVITY	SP GR VARIATION FROM AVERAGE OF PRECEDING 10, %
REQUIREMENTS								
—	MAX 3.0	MAX 10.0 (N) 6.0 (F)	MAX 34	MAX 5	MIN 900	MAX 105	—	MAX 5
TEST RESULTS								
1	0.0	0.4	22	0	1250		2.35	2
3	0.0	0.3	26	4	1250		2.35	2
				Bin Composite		93		
R Factor = 0.26								
CaO = 5.9								
AVERAGE	—	—		—	—	—	2.35	—

(a) APPLICABLE ONLY TO CLASS N — LABORATORY CEMENT USED Ideal, Tijeras, NM

(b) OPTIONAL REQUIREMENT — LABORATORY LIME USED Chemstone

REMARKS: Meets 7 day specification requirements. *28 day test results.

R. E. Reinhold

R. E. REINHOLD
Acting Chief, Cement & Pozzolan Group

NOTE: THE INFORMATION GIVEN IN THIS REPORT SHALL NOT BE USED IN ADVERTISING OR SALES PROMOTION TO INDICATE EITHER EXPLICITLY OR IMPLICITLY ENDORSEMENT OF THIS PRODUCT BY THE U. S. GOVERNMENT.

ENG FORM NO. 6000-R
1 AUG 67

POZZOLAN...

LABORATORY		REPORT NO.
Structures Laboratory Waterways Exp Station ATTN: Cem & Pozz Group P.O. Box 631 Vicksburg, MS 39180	REPORT OF TESTS ON POZZOLAN SS-C-1960/5	WES-111F-82 SHEET 1 OF 1 DATE 29 Mar 82

APR - 5 1982

CLASS (F) N — KIND OF POZZOLAN: Fly Ash

SOURCE: Pozzolanic International, Rock Springs, WY — BRAND:

TEST RESULTS OF THIS SAMPLE LOT [X] COMPLY [ ] DO NOT COMPLY WITH SPECIFICATION LIMITS (SEE REMARKS)

FOR USE AT: Willow Creek Dam

CONTRACT NO.: DACW62-82-C-0018

DISTRICT(S): Walla Walla

SAMPLED BY: PSP — DATE SAMPLED: 19 Mar 82

CAR NO.: See Remarks — BIN NO.: NA

FIELD SAMPLE NO.: — LAB SAMPLE NO.:

DATE RECEIVED: 3/22/82 — LAB JOB NO.:

TESTED BY: Cem & Pozz Group — CHECKED BY:

TESTS ON COMPOSITE OF THE 100-TON SAMPLES LISTED BELOW

$SiO_2 + Al_2O_3 + Fe_2O_3$ %	MgO %	SO_3 %	AVAILABLE ALKALIES %	POZZOLAN STRENGTH* % CONTROL	INCREASE IN SHRINKAGE % (a)	AUTOCLAVE EXPANSION %	REDUCTION IN EXPANSION % (b)
REQUIREMENTS							
MIN 70.0	MAX 5.0	MAX 4.0	MAX 1.50	MIN 75	MAX 0.03	MAX 0.50	MIN 75
TEST RESULTS							
85.6	1.8	0.4	*	*		-0.04	

TESTS ON SAMPLES REPRESENTING 100 TONS OR LESS

SAMPLE NO.	MOISTURE CONTENT %	LOSS ON IGNITION %	Fineness 325 Mesh Sieve % Retained	% pts var from avg prev 10	LIME POZZOLAN STRENGTH PSI	WATER REQUIREMENT % of Control	SPECIFIC GRAVITY	SP GR VARIATION FROM AVERAGE OF PRECEDING 10, %
REQUIREMENTS								
—	MAX 3.0	MAX 10.0 (N) 6.0 (F)	MAX 34	MAX 5	MIN 900	MAX 105	—	MAX 5
TEST RESULTS								
1	0.1	0.4	23	1	1180		2.35	1
2	0.0	0.4	26	4	1150		2.36	1
3	0.0	0.4	25	3	1410		2.36	1
4	0.1	0.4	24	1	1180		2.35	0
5	0.0	0.3	24	0	1390		2.36	0
				BIN COMPOSITE		92		
Meets 7 days specification requirements						*28 day test results		
					R. E. REINHOLD			
					Acting Chief, Cement & Pozzolan Grp			
AVERAGE	—	—		—	—	—	2.36	—

(a) APPLICABLE ONLY TO CLASS N
(b) OPTIONAL REQUIREMENT

LABORATORY CEMENT USED: Ideal, Tijeras, NM
LABORATORY LIME USED: Chemstone

REMARKS: Meets 7 day specification requirements. *28 day test results.

	Sample No. 1	Sample No. 2	Sample No. 3	Sample No. 4	Sample No. 5
RR Car No.	13225	13032	19349	13328	13109
" " "	13129	13148	19363	13130	19625
" " "	13030	13073	19804	13317	19879
" " "	13157	13366	19585	13152	13008

NOTE: THE INFORMATION GIVEN IN THIS REPORT SHALL NOT BE USED IN ADVERTISING OR SALES PROMOTION TO INDICATE EITHER EXPLICITLY OR IMPLICITLY ENDORSEMENT OF THIS PRODUCT BY THE U. S. GOVERNMENT.

ENG FORM NO. 6000-R
1 AUG 67

LABORATORY:	REPORT OF TESTS ON POZZOLAN	REPORT NO.: WES-179F-82
Structures Laboratory Waterways Exp Station ATTN: Cem & Pozz Unit P O Box 631 Vicksburg, MS 39180	SS-C-1960/5	SHEET 1 OF 1 DATE: 18 May 82 9 June 82

CLASS (F) N — KIND OF POZZOLAN: Fly Ash

SOURCE: Pozzolanic Northwest, Rock Springs, WY — BRAND:

TEST RESULTS OF THIS SAMPLE LOT [X] COMPLY [ ] DO NOT COMPLY WITH SPECIFICATION LIMITS (SEE REMARKS)

FOR USE AT:

CONTRACT NO.:

DISTRICT(S): Bureau of Reclamation & Walla Walla

SAMPLED BY: PSP — DATE SAMPLED: 4 May 82

CAR NO.: — BIN NO.: #3-160 tons + Railroad Cars 975 tons **

FIELD SAMPLE NO.: — LAB SAMPLE NO.:

DATE RECEIVED: 7 May 82 — LAB JOB NO.:

TESTED BY: Cement & Pozzolan Unit — CHECKED BY:

TESTS ON COMPOSITE OF THE 100-TON SAMPLES LISTED BELOW

	$SiO_2 + Al_2O_3 + Fe_2O_3$ %	MgO %	SO_3 %	AVAILABLE ALKALIES %	POZZOLAN STRENGTH % CONTROL	INCREASE IN SHRINKAGE % (a)	AUTOCLAVE EXPANSION %	REDUCTION IN EXPANSION % (b)
REQUIREMENTS	MIN 70.0	MAX 5.0	MAX 4.0	MAX 1.50	MIN 75	MAX 0.03	MAX 0.50	MIN 75
TEST RESULTS	87.2	2.0	0.6	* 1.68	* 90		0.02	

TESTS ON SAMPLES REPRESENTING 100 TONS OR LESS

SAMPLE NO.	MOISTURE CONTENT %	LOSS ON IGNITION %	Fineness 325 Mesh Sieve % Retained	% pts var from avg prev 10	LIME POZZOLAN STRENGTH PSI	WATER REQUIREMENT % of Control	SPECIFIC GRAVITY	SP GR VARIATION FROM AVERAGE OF PRECEDING 10, %
REQUIREMENTS								
—	MAX 3.0	MAX 10.0 (N) 6.0 (F)	MAX 34	MAX 5	MIN 900	MAX 105	—	MAX 5
TEST RESULTS								
1	0.0	0.36	26	2	1120		2.35	0
2	0.1	0.42	28	3	1090		2.35	0
3	0.1	0.38	20	5	1060		2.36	0
4	0.0	0.30	22	2	1070		2.36	0
				BIN COMPOSITE		92		
R Factor = none								
CaO = 4.7								
AVERAGE	—	—		—	—	—	2.36	—

(a) APPLICABLE ONLY TO CLASS N
(b) OPTIONAL REQUIREMENT

LABORATORY CEMENT USED Ideal, Portland, CO
LABORATORY LIME USED Chemstone

REMARKS: Meets 7 day specification requirements. *28 day test results.

**UP19631 UP13004
UP19432 UP13189
UP19824 UP19767
UP19392 UP19374
UP13139 UP19495

R. E. Reinhold

R. E. REINHOLD
Acting Chief, Cement & Pozzolan Group

NOTE: THE INFORMATION GIVEN IN THIS REPORT SHALL NOT BE USED IN ADVERTISING OR SALES PROMOTION TO INDICATE EITHER EXPLICITLY OR IMPLICITLY ENDORSEMENT OF THIS PRODUCT BY THE U. S. GOVERNMENT.

ENG FORM NO. 6000-R
1 AUG 67

LABORATORY	REPORT OF TESTS ON POZZOLAN	REPORT NO
Structures Laboratory Waterways Exp Station ATTN: Cem & Pozz Unit P O Box 631 Vicksburg, MS 39180	SS-C-1960/5	WES-229F-82 SHEET 1 OF 1 DATE: 22 June 82

CLASS (F) N — KIND OF POZZOLAN: Fly Ash

SOURCE: Pozzolanic International, Rock Springs, WY — BRAND:

TEST RESULTS OF THIS SAMPLE LOT [X] COMPLY [ ] DO NOT COMPLY WITH SPECIFICATION LIMITS (SEE REMARKS)

FOR USE AT: Willow Creek Dam

CONTRACT NO.: DACW68-82-C-0018

DISTRICT(S): Walla Walla

SAMPLED BY: PSP — DATE SAMPLED: 7 June 82

CAR NO.: — BIN NO.: 10 Railroad Cars

FIELD SAMPLE NO.: — LAB SAMPLE NO.:

DATE RECEIVED: 14 June 82 — LAB JOB NO.:

TESTED BY: Cement & Pozzolan Unit — CHECKED BY:

TESTS ON COMPOSITE OF THE 100-TON SAMPLES LISTED BELOW

$SiO_2 + Al_2O_3 + Fe_2O_3$ %	MgO %	SO_3 %	AVAILABLE ALKALIES %	POZZOLAN STRENGTH % CONTROL	INCREASE IN SHRINKAGE % (a)	AUTOCLAVE EXPANSION %	REDUCTION IN EXPANSION % (b)
REQUIREMENTS							
MIN 70.0	MAX 5.0	MAX 4.0	MAX 1.50	MIN 75	MAX 0.03	MAX 0.50	MIN 75
TEST RESULTS							
89.7	2.0	0.4	*	*		0.01	

TESTS ON SAMPLES REPRESENTING 100 TONS OR LESS

SAMPLE NO.	MOISTURE CONTENT %	LOSS ON IGNITION %	Fineness 325 Mesh Sieve % Retained	% pts var from avg prev 10	LIME POZZOLAN STRENGTH PSI	WATER REQUIREMENT % of Control	SPECIFIC GRAVITY	SP GR VARIATION FROM AVERAGE OF PRECEDING 10, %
REQUIREMENTS								
—	MAX 3.0	MAX 6.0 (F)	MAX 34	MAX 5	MIN 900	MAX 105	—	MAX 5
TEST RESULTS								
1	0.1	0.4	25	0	1060		2.35	0
2	0.1	0.4	27	2	1120		2.34	2
3	0.1	0.4	28	3	1050		2.35	0
				BIN COMPOSITE		90		
AVERAGE	—	—		—	—	—		—

(a) APPLICABLE ONLY TO CLASS N — LABORATORY CEMENT USED: Ideal, Portland, CO

(b) OPTIONAL REQUIREMENT — LABORATORY LIME USED: Chemstone

REMARKS: Meets 7 day specification requirements. *28 day test results.

SAMPLE #1	SAMPLE #2	SAMPLE #3
UP-13236	UP-13160	UP-13157
UP-13243	UP-13172	UP-13132
UP-13188	UP-13044	UP-13233
		UP-13019

R. E. Reinhold
R. E. REINHOLD
Chief, Cement & Pozzolan Group

NOTE: THE INFORMATION GIVEN IN THIS REPORT SHALL NOT BE USED IN ADVERTISING OR SALES PROMOTION TO INDICATE EITHER EXPLICITLY OR IMPLICITLY ENDORSEMENT OF THIS PRODUCT BY THE U. S. GOVERNMENT.

ENG FORM NO.

LABORATORY: Structures Laboratory Waterways Exp Station ATTN: Cem & Pozz Unit P O Box 631 Vicksburg, MS 39180	**REPORT OF TESTS ON POZZOLAN** SS-C-1960/5	REPORT NO.: WES-236F-82 SHEET 1 OF 1 DATE: 28 June 82 21 July 82

CLASS (F) N — KIND OF POZZOLAN: Fly Ash

SOURCE: Pozzolanic International, Rock Springs, WY — BRAND:

TEST RESULTS OF THIS SAMPLE LOT [X] COMPLY [ ] DO NOT COMPLY WITH SPECIFICATION LIMITS (SEE REMARKS)

FOR USE AT: Willow Creek Dam

CONTRACT NO.: DACW68-82-C-0018

DISTRICT(S): Walla Walla

SAMPLED BY: Project — DATE SAMPLED: 14 June 82

CAR NO.: — BIN NO.:

FIELD SAMPLE NO.: — LAB SAMPLE NO.:

DATE RECEIVED: 18 June 82 — LAB JOB NO.:

TESTED BY: Cement & Pozzolan Unit — CHECKED BY:

TESTS ON COMPOSITE OF THE 100-TON SAMPLES LISTED BELOW

$SiO_2 + Al_2O_3 + Fe_2O_3$ %	MgO %	SO_3 %	AVAILABLE ALKALIES %	POZZOLAN STRENGTH % CONTROL	INCREASE IN SHRINKAGE % (a)	AUTOCLAVE EXPANSION %	REDUCTION IN EXPANSION % (b)
REQUIREMENTS							
MIN 70.0	MAX 5.0	MAX 4.0	MAX 1.50	MIN 75	MAX 0.03	MAX 0.50	MIN 75
TEST RESULTS							
83.6	1.8	0.2	* 1.20	* 102		0.11	

TESTS ON SAMPLES REPRESENTING 100 TONS OR LESS

SAMPLE NO.	MOISTURE CONTENT %	LOSS ON IGNITION %	Fineness 325 Mesh Sieve % Retained	% pts var from avg prev 10	LIME POZZOLAN STRENGTH PSI	WATER REQUIREMENT % of Control	SPECIFIC GRAVITY	SP GR VARIATION FROM AVERAGE OF PRECEDING 10, %
REQUIREMENTS								
—	MAX 3.0	MAX 10.0 (N) 6.0 (F)	MAX 34	MAX 5	MIN 900	MAX 105	—	MAX 5
TEST RESULTS								
1	0.2	0.1	21	4	1310	90	2.35	0
AVERAGE	—	—		—	—	—		—

(a) APPLICABLE ONLY TO CLASS N
(b) OPTIONAL REQUIREMENT

LABORATORY CEMENT USED: Southwest, Victorville, CA
LABORATORY LIME USED: Chemstone

REMARKS: Meets 7 day specification requirements. *28 day test results.

R. E. Reinhold

R. E. REINHOLD
Chief, Cement & Pozzolan Unit

NOTE: THE INFORMATION GIVEN IN THIS REPORT SHALL NOT BE USED IN ADVERTISING OR SALES PROMOTION TO INDICATE EITHER EXPLICITLY OR IMPLICITLY ENDORSEMENT OF THIS PRODUCT BY THE U. S. GOVERNMENT.

ENG FORM NO. 6000-R
1 AUG 67

LABORATORY		
Structures Laboratory Waterways Exp Station ATTN: Cem & Pozz Unit P O Box 631 Vicksburg, MS 39180	**REPORT OF TESTS ON POZZOLAN** SS-C-1960/5	REPORT NO.: WES-248F-82 SHEET 1 OF 1 DATE: 1 July 82 30 Aug 82

CLASS (F) N — KIND OF POZZOLAN: Fly Ash

SOURCE: Pozzolanic N/W Intl, Rock Springs, WY — BRAND:

TEST RESULTS OF THIS SAMPLE LOT [X] COMPLY [ ] DO NOT COMPLY WITH SPECIFICATION LIMITS (SEE REMARKS)

FOR USE AT: Willow Creek Dam

CONTRACT NO.: DACW68-82-C-0018

DISTRICT(S): Walla Walla

SAMPLED BY: Project — DATE SAMPLED: 19 June 82

CAR NO.: — BIN NO.: RR Cars

FIELD SAMPLE NO.: — LAB SAMPLE NO.:

DATE RECEIVED: 24 June 82 — LAB JOB NO.:

TESTED BY: Cement & Pozzolan Unit — CHECKED BY:

TESTS ON COMPOSITE OF THE 100-TON SAMPLES LISTED BELOW

	$SiO_2 + Al_2O_3 + Fe_2O_3$ %	MgO %	SO_3 %	AVAILABLE ALKALIES %	POZZOLAN STRENGTH % CONTROL	INCREASE IN SHRINKAGE % (a)	AUTOCLAVE EXPANSION %	REDUCTION IN EXPANSION % (b)
REQUIREMENTS	MIN 70.0	MAX 5.0	MAX 4.0	MAX 1.50	MIN 75	MAX 0.03	MAX 0.50	MIN 75
TEST RESULTS	84.8	1.7	0.5	* 1.16	* 95		0.02	

TESTS ON SAMPLES REPRESENTING 100 TONS OR LESS

SAMPLE NO.	MOISTURE CONTENT %	LOSS ON IGNITION %	Fineness 325 Mesh Sieve % Retained	% pts var from avg prev 10	LIME POZZOLAN STRENGTH PSI	WATER REQUIREMENT % of Control	SPECIFIC GRAVITY	SP GR VARIATION FROM AVERAGE OF PRECEDING 10, %
REQUIREMENTS								
—	MAX 3.0	MAX 10.0 (N) 6.0 (F)	MAX 34	MAX 5	MIN 900	MAX 105	—	MAX 5
TEST RESULTS								
1	0.0	0.2	22		1130	94	2.38	
AVERAGE	—	—		—	—	—		—

(a) APPLICABLE ONLY TO CLASS N — LABORATORY CEMENT USED: Ideal, Superior, NE

(b) OPTIONAL REQUIREMENT — LABORATORY LIME USED: Chemstone

REMARKS: Meets 7 day specification requirements. *28 day test results.

R. E. Reinhold

R. E. REINHOLD
Chief, Cement & Pozzolan Unit

ENG FORM NO. 6000-R
1 AUG 67

LABORATORY Structures Laboratory Waterways Exp Station ATTN: Cem & Pozz Unit P O Box 631 Vicksburg, MS 39180	REPORT OF TESTS ON POZZOLAN SS-C-1960/5	REPORT NO.: WES-249F-82 SHEET 1 OF 1 DATE: 1 July 82

CLASS (F) N — KIND OF POZZOLAN: Fly Ash

SOURCE: Pozzolanic N/W Int'l, Rock Springs, WY — BRAND:

TEST RESULTS OF THIS SAMPLE LOT [X] COMPLY [ ] DO NOT COMPLY WITH SPECIFICATION LIMITS (SEE REMARKS)

FOR USE AT: Willow Creek Dam

CONTRACT NO.: DACW65-82-C-0018

DISTRICT(S): Walla Walla

SAMPLED BY: Project — DATE SAMPLED: 22 June 82

CAR NO.: — BIN NO.: RR Cars

FIELD SAMPLE NO.: — LAB SAMPLE NO.:

DATE RECEIVED: 24 June 82 — LAB JOB NO.:

TESTED BY: Cement & Pozzolan Unit — CHECKED BY:

TESTS ON COMPOSITE OF THE 100-TON SAMPLES LISTED BELOW

	$SiO_2 + Al_2O_3 + Fe_2O_3$ %	MgO %	SO_3 %	AVAILABLE ALKALIES %	POZZOLAN STRENGTH % CONTROL	INCREASE IN SHRINKAGE % (a)	AUTOCLAVE EXPANSION %	REDUCTION IN EXPANSION % (b)
REQUIREMENTS	MIN 70.0	MAX 5.0	MAX 4.0	MAX 1.50	MIN 75	MAX 0.03	MAX 0.50	MIN 75
TEST RESULTS	80.5	2.1	0.8	*	*		0.04	

TESTS ON SAMPLES REPRESENTING 100 TONS OR LESS

SAMPLE NO.	MOISTURE CONTENT %	LOSS ON IGNITION %	Fineness 325 Mesh Sieve % Retained	% pts var from avg prev 10	LIME POZZOLAN STRENGTH PSI	WATER REQUIREMENT % of Control	SPECIFIC GRAVITY	SP GR VARIATION FROM AVERAGE OF PRECEDING 10, %
REQUIREMENTS								
—	MAX 3.0	MAX 10.0 (N) 6.0 (F)	MAX 34	MAX 5	MIN 900	MAX 105	—	MAX 5
TEST RESULTS								
1	0.0	0.4	28.0		1050	86	2.40	
AVERAGE	—	—		—	—	—		—

(a) APPLICABLE ONLY TO CLASS N — LABORATORY CEMENT USED Ideal, Superior, NE

(b) OPTIONAL REQUIREMENT — LABORATORY LIME USED Chemstone

REMARKS: Meets 7 day specification requirements. *28 day test results.

R. E. Reinhold

R. E. REINHOLD
Chief, Cement & Pozzolan Unit

NOTE: THE INFORMATION GIVEN IN THIS REPORT SHALL NOT BE USED IN ADVERTISING OR SALES PROMOTION TO INDICATE EITHER EXPLICITLY OR IMPLICITLY ENDORSEMENT OF THIS PRODUCT BY THE U. S. GOVERNMENT.

ENG FORM NO. 6000-R
1 AUG 67

LABORATORY:	REPORT OF TESTS ON POZZOLAN SS-C-1960/5	REPORT NO.: WES-251F-82
Structures Laboratory Waterways Exp Station ATTN: Cem & Pozz Unit P O Box 631 Vicksburg, MS 39180		SHEET 1 OF 1 DATE: 7 July 82

CLASS (F) N — KIND OF POZZOLAN: Fly Ash

SOURCE: Pozzolanic International, Rock Springs, WY — BRAND:

TEST RESULTS OF THIS SAMPLE LOT [X] COMPLY [ ] DO NOT COMPLY WITH SPECIFICATION LIMITS (SEE REMARKS)

FOR USE AT: Willow Creek Dam

CONTRACT NO.: DACW68-82-C-0018

DISTRICT(S): Walla Walla

SAMPLED BY: PSP — DATE SAMPLED: 25 June 82

CAR NO.: — BIN NO.: 10 RR Cars

FIELD SAMPLE NO.: — LAB SAMPLE NO.:

DATE RECEIVED: 28 June 82 — LAB JOB NO.:

TESTED BY: Cement & Pozzolan Unit — CHECKED BY:

TESTS ON COMPOSITE OF THE 100-TON SAMPLES LISTED BELOW

$SiO_2 + Al_2O_3 + Fe_2O_3$ %	MgO %	SO_3 %	AVAILABLE ALKALIES %	POZZOLAN STRENGTH % CONTROL	INCREASE IN SHRINKAGE % (a)	AUTOCLAVE EXPANSION %	REDUCTION IN EXPANSION % (b)
REQUIREMENTS							
MIN 70.0	MAX 5.0	MAX 5.0	MAX 1.50	MIN 75	MAX 0.03	MAX 0.8	MIN 75
TEST RESULTS							
85.6	2.1	0.2	*	*		0.03	

TESTS ON SAMPLES REPRESENTING 100 TONS OR LESS

SAMPLE NO.	MOISTURE CONTENT %	LOSS ON IGNITION %	Fineness 325 Mesh Sieve % Retained	% pts var from avg prev 10	LIME POZZOLAN STRENGTH PSI	WATER REQUIREMENT % of Control	SPECIFIC GRAVITY	SP GR VARIATION FROM AVERAGE OF PRECEDING 10, %
REQUIREMENTS								
—	MAX 3.0	MAX 10.0 (N) 6.0 (F)	MAX 34	MAX 5	MIN 900	MAX 105	—	MAX 5
TEST RESULTS								
1	0.1	0.3	28	3	1140		2.31	2
2	0.1	0.3	29	4	1130		2.29	3
3	0.0	0.3	28	2	1120		2.30	2
				BIN COMPOSITE		95		
AVERAGE	—	—		—	—	—	2.30	—

(a) APPLICABLE ONLY TO CLASS N — LABORATORY CEMENT USED: Lehigh, Metaline Falls, WY

(b) OPTIONAL REQUIREMENT — LABORATORY LIME USED: Chemstone

REMARKS: Meets 7 days specification requirements. *28 day test results.

Sample #1	Sample #2	Sample #3
UP13317	UP13154	UP13095
UP13308	UP13386	UP13270
UP13320	UP13148	UP13176
		UP13342

/s/ R. E. Reinhold

R. E. REINHOLD
Chief, Cement & Pozzolan Unit

NOTE: THE INFORMATION GIVEN IN THIS REPORT SHALL NOT BE USED IN ADVERTISING OR SALES PROMOTION TO INDICATE EITHER EXPLICITLY OR IMPLICITLY ENDORSEMENT OF THIS PRODUCT BY THE U. S. GOVERNMENT.

6000-R

LABORATORY: Structures Laboratory Waterways Exp Station ATTN: Cem & Pozz Unit P O Box 631 Vicksburg, MS 39180	REPORT OF TESTS ON POZZOLAN SS-C-1960/5	REPORT NO.: WES-261F-82 SHEET 1 OF 1 DATE: 21 July 82

CLASS (F) N — KIND OF POZZOLAN: Fly Ash

SOURCE: Pozzolanic Northwest, Rock Springs, WY — BRAND:

TEST RESULTS OF THIS SAMPLE LOT [X] COMPLY [ ] DO NOT COMPLY WITH SPECIFICATION LIMITS (SEE REMARKS)

FOR USE AT: Willow Creek Dam

CONTRACT NO.: DACW68-82-C-0018

DISTRICT(S): Walla Walla

SAMPLED BY: Project — DATE SAMPLED: 29 June 82

CAR NO.: — BIN NO.: RR Cars

FIELD SAMPLE NO.: — LAB SAMPLE NO.:

DATE RECEIVED: 2 July 82 — LAB JOB NO.:

TESTED BY: Cement & Pozzolan Unit — CHECKED BY:

TESTS ON COMPOSITE OF THE 100-TON SAMPLES LISTED BELOW

	$SiO_2 + Al_2O_3 + Fe_2O_3$ %	MgO %	SO_3 %	AVAILABLE ALKALIES %	POZZOLAN STRENGTH % CONTROL	INCREASE IN SHRINKAGE % (a)	AUTOCLAVE EXPANSION %	REDUCTION IN EXPANSION % (b)
REQUIREMENTS	MIN 70.0	MAX 5.0	MAX 5.0	MAX 1.50	MIN 75	MAX 0.03	MAX 0.8	MIN 75
TEST RESULTS	82.4	1.9	0.5	*1.35	*90		0.09	

TESTS ON SAMPLES REPRESENTING 100 TONS OR LESS

SAMPLE NO.	MOISTURE CONTENT %	LOSS ON IGNITION %	Fineness 325 Mesh Sieve % Retained	% pts var from avg prev 10	LIME POZZOLAN STRENGTH PSI	WATER REQUIREMENT % of Control	SPECIFIC GRAVITY	SP GR VARIATION FROM AVERAGE OF PRECEDING 10, %
REQUIREMENTS								
—	MAX 3.0	MAX 10.0 (N) 6.0 (F)	MAX 34	MAX 5	MIN 900	MAX 105	—	MAX 5
TEST RESULTS								
1	0.0	0.3	25		1190	92	2.38	
AVERAGE	—	—		—	—	—		—

(a) APPLICABLE ONLY TO CLASS N — LABORATORY CEMENT USED: Southwestern, Victorville, CA

(b) OPTIONAL REQUIREMENT — LABORATORY LIME USED: Chemstone

REMARKS: Meets 7 day specification requiarement. *28 day test results.

Tony B. Husbands

for R. E. REINHOLD
Chief, Cement & Pozzolan Unit

NOTE: THE INFORMATION GIVEN IN THIS REPORT SHALL NOT BE USED IN ADVERTISING OR SALES PROMOTION TO INDICATE EITHER EXPLICITLY OR IMPLICITLY ENDORSEMENT OF THIS PRODUCT BY THE U. S. GOVERNMENT.

ENG FORM NO. 6000-R
1 AUG 67

LABORATORY:	REPORT OF TESTS ON POZZOLAN	REPORT NO.: WES-278F-82
Structures Laboratory Waterways Exp Station ATTN: Cem & Pozz Unit P O Box 631 Vicksburg, MS 39180	SS-C-1960/5	SHEET 1 OF 1 DATE: 21 July 82

CLASS (F) N — KIND OF POZZOLAN: Fly Ash

SOURCE: Pozzolanic Northwest, Rock Springs, WY — BRAND:

TEST RESULTS OF THIS SAMPLE LOT [X] COMPLY [ ] DO NOT COMPLY WITH SPECIFICATION LIMITS (SEE REMARKS)

FOR USE AT: Cucamonga Creek, Deer-Hillside

CONTRACT NO.: DACW09-82-C-0017

DISTRICT(S): Los Angeles

SAMPLED BY: Project — DATE SAMPLED: 2 July 82

CAR NO.: — BIN NO.:

FIELD SAMPLE NO.: — LAB SAMPLE NO.:

DATE RECEIVED: 12 July 82 — LAB JOB NO.:

TESTED BY: Cement & Pozzolan Unit — CHECKED BY:

TESTS ON COMPOSITE OF THE 100-TON SAMPLES LISTED BELOW

	$SiO_2 + Al_2O_3 + Fe_2O_3$ %	MgO %	SO_3 %	AVAILABLE ALKALIES %	POZZOLAN STRENGTH % CONTROL	INCREASE IN SHRINKAGE % (a)	AUTOCLAVE EXPANSION %	REDUCTION IN EXPANSION % (b)
REQUIREMENTS	MIN 70.0	MAX 5.0	MAX 5.0	MAX 1.50	MIN 75	MAX 0.03	MAX 0.8	MIN 75
TEST RESULTS	80.2	2.5	0.5	* 1.23	* 84		0.07	

TESTS ON SAMPLES REPRESENTING 100 TONS OR LESS

SAMPLE NO.	MOISTURE CONTENT %	LOSS ON IGNITION %	Fineness 325 Mesh Sieve % Retained	% pts var from avg prev 10	LIME POZZOLAN STRENGTH PSI	WATER REQUIREMENT % of Control	SPECIFIC GRAVITY	SP GR VARIATION FROM AVERAGE OF PRECEDING 10, %
REQUIREMENTS								
—	MAX 3.0	MAX 10.0 (N) 6.0 (F)	MAX 34	MAX 5	MIN 900	MAX 105	—	MAX 5
TEST RESULTS								
1	0.0	0.3	28	3	1310	91	2.35	0
AVERAGE	—	—		—	—	—		—

(a) APPLICABLE ONLY TO CLASS N
(b) OPTIONAL REQUIREMENT

LABORATORY CEMENT USED Lehigh, Metaline Falls, WA
LABORATORY LIME USED Chemstone

REMARKS: Meets 7 day specification requirements. *28 day test results.

Tony B. Husbands
for R. E. REINHOLD
Chief, Cement & Pozzolan Unit

NOTE: THE INFORMATION GIVEN IN THIS REPORT SHALL NOT BE USED IN ADVERTISING OR SALES PROMOTION TO INDICATE EITHER EXPLICITLY OR IMPLICITLY ENDORSEMENT OF THIS PRODUCT BY THE U. S. GOVERNMENT.

ENG FORM NO. 6000-R
1 AUG 67

LABORATORY:
Structures Laboratory
Waterways Exp Station
ATTN: Cem & Pozz Unit
P O Box 631
Vicksburg, MS 39180

REPORT OF TESTS ON POZZOLAN
SS-C-1960/5

REPORT NO.: WES-281F-92
SHEET 1 OF 1
DATE: 26 July 82

CLASS (F) N — KIND OF POZZOLAN: FlyAsh
SOURCE: Pozzolanic Northwest, Rock Springs, WY — BRAND:
TEST RESULTS OF THIS SAMPLE LOT [X] COMPLY [ ] DO NOT COMPLY WITH SPECIFICATION LIMITS (SEE REMARKS)
FOR USE AT:
CONTRACT NO.:
DISTRICT(S): Walla Walla & Bu of Rec
SAMPLED BY: PSP — DATE SAMPLED: 9 July 82
CAR NO.: — BIN NO.: 3 & RR Car = 1150
FIELD SAMPLE NO.: — LAB SAMPLE NO.:
DATE RECEIVED: 14 July 82 — LAB JOB NO.:
TESTED BY: Cement & Pozzolan Unit — CHECKED BY:

TESTS ON COMPOSITE OF THE 100-TON SAMPLES LISTED BELOW

	$SiO_2 + Al_2O_3 + Fe_2O_3$ %	MgO %	SO_3 %	AVAILABLE ALKALIES %	POZZOLAN STRENGTH % CONTROL	INCREASE IN SHRINKAGE % (a)	AUTOCLAVE EXPANSION %	REDUCTION IN EXPANSION % (b)
REQUIREMENTS	MIN 70.0	MAX 5.0	MAX 5.0	MAX 1.50	MIN 75	MAX 0.03	MAX 0.8	MIN 75
TEST RESULTS	87.0	2.1	0.1	*	*		0.09	

TESTS ON SAMPLES REPRESENTING 100 TONS OR LESS

SAMPLE NO.	MOISTURE CONTENT %	LOSS ON IGNITION %	Fineness 325 Mesh Sieve % Retained	% pts var from avg prev 10	LIME POZZOLAN STRENGTH PSI	WATER REQUIREMENT % of Control	SPECIFIC GRAVITY	SP GR VARIATION FROM AVERAGE OF PRECEDING 10, %
REQUIREMENTS								
—	MAX 3.0	MAX 10.0 (N) 6.0 (F)	MAX 34	MAX 5	MIN 900	MAX 105	—	MAX 5
TEST RESULTS								
1	0.0	0.2	24	2	1360	93	2.27	4
R Factor = None								
CaO = 4.0								
AVERAGE	—	—		—	—	—		—

(a) APPLICABLE ONLY TO CLASS N
(b) OPTIONAL REQUIREMENT

LABORATORY CEMENT USED Southwestern, Victorville, CA
LABORATORY LIME USED Chemstone

REMARKS: Meets 7 day specification requirements. *28 day test results.

R. E. Reinhold
R. E. REINHOLD
Chief, Cement & Pozzolan Unit

NOTE: THE INFORMATION GIVEN IN THIS REPORT SHALL NOT BE USED IN ADVERTISING OR SALES PROMOTION TO INDICATE EITHER EXPLICITLY OR IMPLICITLY ENDORSEMENT OF THIS PRODUCT BY THE U. S. GOVERNMENT.

ENG FORM NO 6000-R
1 AUG 67

LABORATORY		
Structures Laboratory Waterways Exp Station P.O. Box 631 Vicksburg, MS 39180 Cement & Pozzolan Unit	REPORT OF TESTS ON POZZOLAN SS-C-1960/5	REPORT NO.: WES-290-F-82 SHEET 1 OF 1 DATE: 5 August 1982

CLASS (F) N — KIND OF POZZOLAN: Fly Ash

SOURCE: Pozz. Int'l, Rock Springs, WY — BRAND:

TEST RESULTS OF THIS SAMPLE LOT [X] COMPLY [ ] DO NOT COMPLY WITH SPECIFICATION LIMITS (SEE REMARKS)

FOR USE AT: Willow Creek DAm

CONTRACT NO.: DACW68-82-C-0018

DISTRICT(S): Walla-Walla

SAMPLED BY: PSP — DATE SAMPLED: 20 July 1982

CAR NO.: — BIN NO.: 10 RR cars-1000 tons

FIELD SAMPLE NO.: — LAB SAMPLE NO.:

DATE RECEIVED: 23 July 1982 — LAB JOB NO.:

TESTED BY: Cement & Pozzolan Unit — CHECKED BY:

TESTS ON COMPOSITE OF THE 100-TON SAMPLES LISTED BELOW

$SiO_2 + Al_2O_3 + Fe_2O_3$ %	MgO %	SO_3 %	AVAILABLE ALKALIES %	POZZOLAN STRENGTH % CONTROL	INCREASE IN SHRINKAGE % (c)	AUTOCLAVE EXPANSION %	REDUCTION IN EXPANSION % (b)
REQUIREMENTS							
MIN 70.0	MAX 5.0	MAX 5.0	MAX 1.50	MIN 75	MAX 0.03	MAX 0.8	MIN 75
TEST RESULTS							
84.3	2.1	0.4	*	*		-0.05	

TESTS ON SAMPLES REPRESENTING 100 TONS OR LESS

SAMPLE NO.	MOISTURE CONTENT %	LOSS ON IGNITION %	Fineness 325 Mesh Sieve % Retained	% pts var from avg prev 10	LIME POZZOLAN STRENGTH PSI	WATER REQUIREMENT % of Control	SPECIFIC GRAVITY	SP GR VARIATION FROM AVERAGE OF PRECEDING 10, %
REQUIREMENTS								
—	MAX 3.0	MAX 10.0 (N) 6.0 (F)	MAX 34	MAX 5	MIN 900	MAX 105	—	MAX 5
TEST RESULTS								
1	0.1	0.19	28	2	1150		2.34	0
2	0.1	0.08	31	4	1180		2.34	0
				Bin Composite		92		
AVERAGE	—	—		—		—	2.34	—

(a) APPLICABLE ONLY TO CLASS N
(b) OPTIONAL REQUIREMENT

LABORATORY CEMENT USED Lehigh-Metaline Falls, WA
LABORATORY LIME USED Chemstone

REMARKS: Meets 7 day specification requirements. *28 day test results.

1. UP13145 2. UP13189
13027 13172
13252 13129
13231 13109
13139 13011

R. E. Reinhold
R. E. REINHOLD
Chief, Cement & Pozzolan Unit

NOTE: THE INFORMATION GIVEN IN THIS REPORT SHALL NOT BE USED IN ADVERTISING OR SALES PROMOTION TO INDICATE EITHER EXPLICITLY OR IMPLICITLY ENDORSEMENT OF THIS PRODUCT BY THE U. S. GOVERNMENT.

ENG FORM NO. 6000-R
1 AUG 67

LABORATORY:
Structures Laboratory
Waterways Exp Station
ATTN: Cem & Pozz Unit
P.O. Box 631
Vicksburg, MS 39180

REPORT OF TESTS ON POZZOLAN
SS-C-1960/5

REPORT NO.: WES-307-F-82

SHEET 1 OF 1

DATE: 12 August 1982
14 September 1982

CLASS (F) N

KIND OF POZZOLAN: Fly Ash

SOURCE: Pozzolanic Int'l, Rock Springs, WY

BRAND:

TEST RESULTS OF THIS SAMPLE LOT [X] COMPLY [ ] DO NOT COMPLY WITH SPECIFICATION LIMITS (SEE REMARKS)

FOR USE AT: Willow Creek Dam

CONTRACT NO.: DACW68-82-C-0018

DISTRICT(S): Walla Walla

SAMPLED BY: PSP

DATE SAMPLED: 30 July 1982

CAR NO.: Bin No:RR cars - 1500 tons

FIELD SAMPLE NO.:

LAB SAMPLE NO.:

DATE RECEIVED: 4 August 1982

LAB JOB NO.:

TESTED BY: Cement & Pozzolan Unit

CHECKED BY:

TESTS ON COMPOSITE OF THE 100-TON SAMPLES LISTED BELOW

$SiO_2 + Al_2O_3 + Fe_2O_3$ %	MgO %	SO_3 %	AVAILABLE ALKALIES %	POZZOLAN STRENGTH % CONTROL	INCREASE IN SHRINKAGE % (a)	AUTOCLAVE EXPANSION %	REDUCTION IN EXPANSION % (b)
REQUIREMENTS							
MIN 70.0	MAX 5.0	MAX 5.0	MAX 1.50	MIN 75	MAX 0.03	MAX 0.8	MIN 75
TEST RESULTS							
84.3	2.0	0.5	*1.76	* 81		0.06	

TESTS ON SAMPLES REPRESENTING 100 TONS OR LESS

SAMPLE NO.	MOISTURE CONTENT %	LOSS ON IGNITION %	Fineness 325 Mesh Sieve % Retained	% pts var from avg prev 10	LIME POZZOLAN STRENGTH PSI	WATER REQUIREMENT % of Control	SPECIFIC GRAVITY	SP GR VARIATION FROM AVERAGE OF PRECEDING 10, %
REQUIREMENTS								
—	MAX 3.0	MAX 10.0 (N) 6.0 (F)	MAX 34	MAX 5	MIN 900	MAX 105	—	MAX 5
TEST RESULTS								
1	0.0	0.4	31	3	1180		2.30	1
2	0.1	0.3	32	4	1010		2.31	1
3	0.0	0.3	33	4	1120		2.31	1
				BIN COMPOSITE		94		
AVERAGE	—	—	32	—	—	—	2.31	—

(a) APPLICABLE ONLY TO CLASS N
(b) OPTIONAL REQUIREMENT

LABORATORY CEMENT USED Lehigh, Metaline Falls, WA
LABORATORY LIME USED Chemstone

REMARKS: Meets 7 day specification requirements. *28 day test results.

1. UP13157
13233
13317
13320
13342

2. UP13194
13101
13308
13313
13243

3. 13044
13152
13178
13132
13088

R. E. REINHOLD
Chief, Cement & Pozzolan Unit

NOTE: THE INFORMATION GIVEN IN THIS REPORT SHALL NOT BE USED IN ADVERTISING OR SALES PROMOTION TO INDICATE EITHER EXPLICITLY OR IMPLICITLY ENDORSEMENT OF THIS PRODUCT BY THE U. S. GOVERNMENT.

ENG FORM NO 6000-R
1 AUG 67

LABORATORY:
Structures Laboratory
Waterways Exp Station
ATTN: Cem & Pozz Unit
P.O. BOx 631
Vicksburg, MS 39180

REPORT OF TESTS ON POZZOLAN
SS-C-1960/5

REPORT NO.: WES-316-F-82
SHEET 1 OF 1
DATE: 23 August 1982
16 September 1982

CLASS (F) N
KIND OF POZZOLAN: Fly Ash
SOURCE: Pozzolanic Northwest, Rock Springs, WY
BRAND:
TEST RESULTS OF THIS SAMPLE LOT [X] COMPLY [ ] DO NOT COMPLY WITH SPECIFICATION LIMITS (SEE REMARKS)
FOR USE AT: Willow Creek Dam
CONTRACT NO.: DACW68-82-C-0018
DISTRICT(S): Walla Walla
SAMPLED BY: PSP
DATE SAMPLED: 11 August 1982
CAR NO.:
BIN NO.:
FIELD SAMPLE NO.:
LAB SAMPLE NO.:
DATE RECEIVED: 16 August 1982
LAB JOB NO.:
TESTED BY: Cement & Pozzolan
CHECKED BY:

TESTS ON COMPOSITE OF THE 100-TON SAMPLES LISTED BELOW

	$SiO_2 + Al_2O_3 + Fe_2O_3$ %	MgO %	SO_3 %	AVAILABLE ALKALIES %	POZZOLAN STRENGTH % CONTROL	INCREASE IN SHRINKAGE % (a)	AUTOCLAVE EXPANSION %	REDUCTION IN EXPANSION % (b)
REQUIREMENTS	MIN 70.0	MAX 5.0	MAX 5.0	MAX 1.50	MIN 75	MAX 0.03	MAX 0.8	MIN 75
TEST RESULTS	86.4	2.0	0.5	* 1.27	* 78		0.06	

TESTS ON SAMPLES REPRESENTING 100 TONS OR LESS

SAMPLE NO.	MOISTURE CONTENT %	LOSS ON IGNITION %	Fineness 325 Mesh Sieve % Retained	% pts var from avg prev 10	LIME POZZOLAN STRENGTH PSI	WATER REQUIREMENT % of Control	SPECIFIC GRAVITY	SP GR VARIATION FROM AVERAGE OF PRECEDING 10, %
REQUIREMENTS								
—	MAX 3.0	MAX 10.0 (N) 6.0 (F)	MAX 34	MAX 5	MIN 900	MAX 105	—	MAX 5
TEST RESULTS								
1	0.1	0.2	33	2	1080	93	2.31	0
AVERAGE	—	—		—	—	—		—

(a) APPLICABLE ONLY TO CLASS N
(b) OPTIONAL REQUIREMENT

LABORATORY CEMENT USED: Lehigh, Metaline Falls, WA
LABORATORY LIME USED: Chemstone

REMARKS: Meets 7 day specification requirements. *28 day test results.

R. E. Reinhold

R. E. REINHOLD
Chief, Cement & Pozzolan Unit

NOTE: THE INFORMATION GIVEN IN THIS REPORT SHALL NOT BE USED IN ADVERTISING OR SALES PROMOTION TO INDICATE EITHER EXPLICITLY OR IMPLICITLY ENDORSEMENT OF THIS PRODUCT BY THE U. S. GOVERNMENT.

ENG FORM NO. 6000-R
1 AUG 67

LABORATORY:
Structures Laboratory
Waterways Exp Station
ATTN: Cem & Pozz Unit
P O Box 631
Vicksburg, MS 39180

REPORT OF TESTS ON POZZOLAN
SS-C-1960/5

REPORT NO.: WES-343-F-82

SHEET 1 OF 1

DATE: 14 Sept 82

CLASS (F) N | KIND OF POZZOLAN: Fly Ash

SOURCE: Pozzolanic Int., Rock Springs, WY | BRAND:

TEST RESULTS OF THIS SAMPLE LOT [X] COMPLY [ ] DO NOT COMPLY WITH SPECIFICATION LIMITS (SEE REMARKS)

FOR USE AT:

CONTRACT NO.:

DISTRICT(S): Walla Walla & Bur of Rec

SAMPLED BY: PSP | DATE SAMPLED: 23 Aug 82

CAR NO.: | BIN NO.: 2 & RR = 650Tons

FIELD SAMPLE NO.: | LAB SAMPLE NO.:

DATE RECEIVED: 30 Aug 82 | LAB JOB NO.:

TESTED BY: Cem & Pozz Unit | CHECKED BY:

TESTS ON COMPOSITE OF THE 100-TON SAMPLES LISTED BELOW

$SiO_2 + Al_2O_3 + Fe_2O_3$ %	MgO %	SO_3 %	AVAILABLE ALKALIES %	POZZOLAN STRENGTH % CONTROL	INCREASE IN SHRINKAGE % (a)	AUTOCLAVE EXPANSION %	REDUCTION IN EXPANSION % (b)
REQUIREMENTS							
MIN 70.0	MAX 5.0	MAX 5.0	MAX 1.50	MIN 75	MAX 0.03	MAX 0.8	MIN 75
TEST RESULTS							
84.3	1.9	0.4	*	*		0.05	

TESTS ON SAMPLES REPRESENTING 100 TONS OR LESS

SAMPLE NO.	MOISTURE CONTENT %	LOSS ON IGNITION %	Fineness 325 Mesh Sieve % Retained	% pts var from avg prev 10	LIME POZZOLAN STRENGTH PSI	WATER REQUIREMENT % of Control	SPECIFIC GRAVITY	SP GR VARIATION FROM AVERAGE OF PRECEDING 10, %
REQUIREMENTS								
—	MAX 3.0	MAX 10.0 (N) 6.0 (F)	MAX 34	MAX 5	MIN 900	MAX 105	—	MAX 5
TEST RESULTS								
1	0.1	0.4	12	-	1310	92	2.32	-
R Factor	:	None						
CaO%	:	4.2						
AVERAGE	—	—		—	—	—	—	—

(a) APPLICABLE ONLY TO CLASS N
(b) OPTIONAL REQUIREMENT

LABORATORY CEMENT USED Lehigh, Metaline Falls, WA
LABORATORY LIME USED Chemstone

REMARKS: Meets 7 day specification requirements. *28 day test results.
UP: 13176, 13328, 13270, 13148, 13069

R. E. Reinhold
R. E. REINHOLD
Chief, Cement & Pozzolan Unit

NOTE: THE INFORMATION GIVEN IN THIS REPORT SHALL NOT BE USED IN ADVERTISING OR SALES PROMOTION TO INDICATE EITHER EXPLICITLY OR IMPLICITLY ENDORSEMENT OF THIS PRODUCT BY THE U. S. GOVERNMENT.

ENG FORM NO. 6000-R
1 AUG 67

LABORATORY:	REPORT OF TESTS ON POZZOLAN	REPORT NO.: WES-376F-82
Structures Laboratory Waterways Exp Station ATTN: Cem & Pozz Unit P O Box 631 Vicksburg, MS 39180	SS-C-1960/5	SHEET 1 OF 1 DATE: 4 Oct 82 27 Oct 82

CLASS (F) N — KIND OF POZZOLAN: Fly Ash

SOURCE: Pozzolonic Int, Rock Springs, WYO — BRAND:

TEST RESULTS OF THIS SAMPLE LOT XX COMPLY ☐ DO NOT COMPLY WITH SPECIFICATION LIMITS (SEE REMARKS)

FOR USE AT: Willow Creek Project

CONTRACT NO.: DACW68-82-C-0018

DISTRICT(S): Walla Walla

SAMPLED BY: PSP — DATE SAMPLED: 22 Sept 82

CAR NO.: — BIN NO.: RR Cars-200 tons

FIELD SAMPLE NO.: — LAB SAMPLE NO.:

DATE RECEIVED: 27 Sept 82 — LAB JOB NO.:

TESTED BY: Cem & Pozz Unit — CHECKED BY:

TESTS ON COMPOSITE OF THE 100-TON SAMPLES LISTED BELOW

$SiO_2 + Al_2O_3 + Fe_2O_3$ %	MgO %	SO_3 %	AVAILABLE ALKALIES %	POZZOLAN STRENGTH % CONTROL	INCREASE IN SHRINKAGE % (a)	AUTOCLAVE EXPANSION %	REDUCTION IN EXPANSION % (b)
REQUIREMENTS							
MIN 70.0	MAX 5.0	MAX 5.0	MAX 1.50	MIN 75	MAX 0.03	MAX 0.8	MIN 75
TEST RESULTS							
83.1	1.7	0.6	*1.68	*80		0.07	

TESTS ON SAMPLES REPRESENTING 100 TONS OR LESS

SAMPLE NO.	MOISTURE CONTENT %	LOSS ON IGNITION %	Fineness 325 Mesh Sieve % Retained	% pts var from avg prev 10	LIME POZZOLAN STRENGTH PSI	WATER REQUIREMENT % of Control	SPECIFIC GRAVITY	SP GR VARIATION FROM AVERAGE OF PRECEDING 10, %
REQUIREMENTS								
—	MAX 3.0	MAX 10.0 (N) 6.0 (F)	MAX 34	MAX 5	MIN 900	MAX 105	—	MAX 5
TEST RESULTS								
1	0.1	0.5	32	3	1,190	93	2.32	0
AVERAGE	—	—		—	—	—		—

(a) APPLICABLE ONLY TO CLASS N
(b) OPTIONAL REQUIREMENT

LABORATORY CEMENT USED Lehigh, Metaline Falls
LABORATORY LIME USED Chemstone

REMARKS: Meets 7 day specification requirements.*28 day test results
UP13236, UP13160

R. E. Reinhold

R. E. REINHOLD
Chief, Cement & Pozzolan Unit

NOTE: THE INFORMATION GIVEN IN THIS REPORT SHALL NOT BE USED IN ADVERTISING OR SALES PROMOTION TO INDICATE EITHER EXPLICITLY OR IMPLICITLY ENDORSEMENT OF THIS PRODUCT BY THE U. S. GOVERNMENT.

ENG FORM NO. 6000-R
1 AUG 67

Manz 4/23/82

COAL BY-PRODUCTS UTILIZATION INSTITUTE
ENGINEERING EXPERIMENT STATION-UNIVERSITY OF NORTH DAKOTA
GRAND FORKS, NORTH DAKOTA

ASTM C 618 Specification for fly ash and raw or calcined natural pozzolan for use as a mineral admixture in Portland Cement concrete

Sample 82-71 Pozzolanic, Boardman, Fly Ash, Docket 901-1003
BM-239-82 Rec'd 2/24/82

		Mineral Admixture Class C	Requirements Class F
CHEMICAL ANALYSIS			
Silicon dioxide (SiO_2) 33.0 plus Aluminum oxide (Al_2O_3) 17.4 plus iron oxide (Fe_2O_3) 6.3	Wt.% 56.7	Min.Wt.% 50.0	70.0
Sulfur trioxide (SO_3)	Wt.% 3.31	Max.Wt.% 5.0	5.0
Calcium Oxide (CaO)*	Wt.% 27.7		
Magnesium Oxide (MgO)*	Wt.% 5.9	Max.Wt.% 5.0	5.0
Moisture content	Wt.% .07	Max.Wt.% 3.0	3.0
Loss on Ignition	Wt.% .15	Max.Wt.% 6.0	12.0
Available Alkalies, total as Na_2O* Na_2O* 1.35, K_2O* .21	Wt.% 1.49	Max.Wt.% 1.50	1.50
PHYSICAL ANALYSIS			
Amount retained when wet sieved on No. 325 (45μm) sieve	Wt.% 18.48	Max.Wt.% 34	34
Pozzolanic Activity Index: with portland cement at 28 days, percent of control	% 89	Min.% 75	75
with lime at 7 days, psi	psi 1836	Min. psi 800	800
Water requirement, percent of control	% 90	Max.% 105	105
Autoclave expansion or contraction, percent	% .24	Max.% 0.8	0.8
Increase of drying shrinkage* of mortar bars at 28 days	% .023	Max.% 0.03	0.03
Specific gravity	2.67		

Date 4/19/82

O. E. Manz, Director

*Optional Tests

EXHIBIT 2.2
Sheet 17 of 19

Mailed 4/20/82

RECEIVED APR - 1 1982 POZZOLANIC

COAL BY-PRODUCTS UTILIZATION INSTITUTE
ENGINEERING EXPERIMENT STATION-UNIVERSITY OF NORTH DAKOTA
GRAND FORKS, NORTH DAKOTA

ASTM C 618 Specification for fly ash and raw or calcined natural pozzolan for use as a mineral admixture in Portland Cement concrete

Sample 82-51 Pozzolanic Northwest, Fly Ash, Boardman BM-229-82

Docket 837-900 Rec'd 2/1/82

		Mineral Admixture Class C	Requirements Class F
CHEMICAL ANALYSIS			
Silicon dioxide (SiO_2) 33.0 plus Aluminum oxide (Al_2O_3) 17.2 plus Iron oxide (Fe_2O_3) 6.2	Wt.% 56.4	Min.Wt.% 50.0	70.0
Sulfur trioxide (SO_3)	Wt.% 2.55	Max.Wt.% 5.0	5.0
Calcium Oxide (CaO)*	Wt.% 28.2		
Magnesium Oxide (MgO)*	Wt.% 5.9	Max.Wt.% 5.0	5.0
Moisture content	Wt.% .07	Max.Wt.% 3.0	3.0
Loss on Ignition	Wt.% .18	Max.Wt.% 6.0	12.0
Available Alkalies, total as Na_2O* Na_2O* 1.46, K_2O* .21	Wt.% 1.60	Max.Wt.% 1.50	1.50
PHYSICAL ANALYSIS			
Amount retained when wet sieved on No. 325 (45μm) sieve	Wt.% 21.61	Max.Wt.% 34	34
Pozzolanic Activity Index: with portland cement at 28 days, percent of control	% 89	Min.% 75	75
with lime at 7 days, psi	psi 1790	Min. psi 800	800
Water requirement, percent of control	% 89	Max.% 105	105
Autoclave expansion or contraction, percent	% .25	Max.% 0.8	0.8
Increase of drying shrinkage* of mortar bars at 28 days	% +.013	Max.% 0.03	0.03
Specific gravity	2.74		

Date 3/29/82

OE Manz
O. E. Manz, Director

*Optional Tests

Maller 3/31/82

COAL BY-PRODUCTS UTILIZATION INSTITUTE
ENGINEERING EXPERIMENT STATION-UNIVERSITY OF NORTH DAKOTA
GRAND FORKS, NORTH DAKOTA

RECEIVED MAR 26 1982 POZZOLA...

ASTM C 618 Specification for fly ash and raw or calcined natural pozzolan ~~for use as a~~ mineral admixture in Portland Cement concrete

Sample 82-4 Pozzolanic Northwest, Fly Ash, Boardman BM-225-81

Dockets 586-676 Rec'd 1/6/82

			Mineral Admixture Class C	Requirements Class F
CHEMICAL ANALYSIS				
Silicon dioxide (SiO_2) 33.5 plus				
Aluminum oxide (Al_2O_3) 17.6 plus				
iron oxide (Fe_2O_3) 6.0	Wt.%	57.0	Min.Wt.% 50.0	70.0
Sulfur trioxide (SO_3)	Wt.%	2.41	Max.Wt.% 5.0	5.0
Calcium Oxide (CaO)*	Wt.%	27.5		
Magnesium Oxide (MgO)*	Wt.%	5.8	Max.Wt.% 5.0	5.0
Moisture content	Wt.%	.05	Max.Wt.% 3.0	3.0
Loss on Ignition	Wt.%	.26	Max.Wt.% 6.0	12.0
Available Alkalies, total as Na_2O* Na_2O* 1.46, K_2O* .21	Wt.%	1.60	Max.Wt.% 1.50	1.50
PHYSICAL ANALYSIS				
Amount retained when wet sieved on No. 325 (45μm) sieve	Wt.%	19.68	Max.Wt.% 34	34
Pozzolanic Activity Index: with portland cement at 28 days, percent of control	%	94	Min.% 75	75
with lime at 7 days, psi	psi	1552	Min. psi 800	800
Water requirement, percent of control	%	88	Max.% 105	105
Autoclave expansion or contraction, percent	%	.24	Max.% 0.8	0.8
Increase of drying shrinkage* of mortar bars at 28 days	%	.009	Max.% 0.03	0.03
Specific gravity		2.62		

Date 3/22/82

O. E. Manz, Director

*Optional Tests

CHAPTER 3

AGGREGATE PRODUCTION

GENERAL

Results of initial aggregate processing and quality studies including the test quarry are discussed in detail in the project design memorandum. The foundation report will include pertinent information about the production quarry and its operation during construction.

Plates 1.5 through 1.11 of the introduction are aerial photos of the project showing the layout of the quarry, crusher plant, and aggregate stockpiles in relation to the dam at monthly increments throughout the project. Plate 3.1 shows cumulative aggregate production versus calendar date. Plates 3.2 and 3.3 show the crusher and quarry operations. Plates 3.4 through 3.6 show the initial setup for aggregate processing and the crusher schemes actually used.

Investigations during design showed that there was an insufficient quantity of natural aggregate in the area to allow it to be the sole source of material for the RCC. Also, by themselves, most of the natural deposits contained too much silt to be used without some screening. A quarry site was located near the dam and designated as the prime source of aggregate material in the specifications. However, material from anywhere within the project boundaries, including all required excavation, was permitted to be used in RCC aggregate production. The entire rock deposit in the quarry was similar jointed basalt. Overburden in the quarry area consisted of a layer of silt on top of a deposit of silty sandy gravels with rock fragments. Most of the upper layer of silt was removed earlier by a separate contractor and used for embankment fill in road construction.

The specifications required the dam contractor to use the remaining overburden in a quantity of at least 5 percent of the raw feed to the crusher and allowed all of it to be used providing that the overall gradations were met and the amount of fines passing the No. 200 sieve did not exceed 7 percent of the total aggregate weight. Later this was increased to 10 percent for nonplastic fines. The contractor utilized all overburden, estimated to be about 25 percent of the total material fed to the crusher. In the end, all that was left was a clean pit with about a dozen oversize pieces and no overburden material. The effect on production of adding the overburden and allowing the fines is obvious - higher production, lower cost, no settling ponds, no winter shutdowns, etc. The effect on strength is discussed in Chapter 9, "Test Cylinders and Compressive Strength Results." Higher silt contents gave higher strength. It also resulted in less segregation. However, if the silt content exceeded its limit, previous tests showed that it would be difficult to mix and could result in "pickup" on the roller when compacting the RCC.

The specifications required at least half of the aggregate to be in stockpile by the start of RCC placing, and for that to begin by 1 May. There were two basic reasons for this. First, by producing the bulk of the materials during the winter and putting them in huge stockpiles, a naturally cool aggregate was available for use during the warm months of RCC mixing. Discussion of how well this worked, the resulting mix temperature, and the elimination of a need for forced cooling and/or monolith joints is contained in Chapter 18, "Temperatures and Thermal Behavior."

The second main reason for the large stockpiles was to assure enough material to sustain the expected (and required) high production rate of RCC. In actuality, RCC production and aggregate production finished almost simultaneously with not enough leftover aggregate for one more day of full RCC production. Aggregate production started about the second week in January and averaged about 3,800 tons per day throughout the job. Aggregate usage started about the first of May and averaged about 6,800 tons per day. A side advantage to early aggregate production was that separate payment was made and cash flow benefited.

Because of the requirement for RCC mixes having 3/4-, 1-1/2-, and 3-inch nominal maximum size, three separate stockpiles were required. There was no specified gradation for each stockpile providing that they could be blended to give the combined 3-inch maximum size overall gradation needed for that mix. From previous studies, it had been concluded that whatever the contractor provided for his controls in the other stockpiles could be used to make acceptable RCC.

PRODUCTION EQUIPMENT

All material was fed to the crusher by D-8 Caterpillar dozer. During high production, two dozers were required but part of the time only one was used. Blending of the overburden with rock was done by the operator as he pushed the material to the jaw. Material was hauled from the bins and surge piles to stockpiles by "catwagon" end dump, with each load being weighed.

The intent during aggregate investigations for design was to establish a usable gradation band which could make acceptable RCC with minimal processing and expense. The thought was that aggregate could be produced with no waste using a jaw crusher followed by cone and an impact crusher or by two impact crushers in series. The contractor used a more complicated system for much of his production, primarily because of the equipment within his inventory, to provide more control and partially because of the ingrained attitude that concrete aggregate production historically is more complicated. In fact, the final aggregate processing equipment scheme was simplified to include a jaw, cone, and impact crusher. A detailed description of the three basic processing schemes used by the contractor follows.

5 January - 1 April:

The production equipment and layout are shown on Plate 3.5. A 10-HP plate feeder brought dozed material continuously to a 30-inch 125-HP jaw crusher. A 42-inch belt fed this product to a 5-foot x 14-foot El Jay screen which separated the natural 3/4 minus material and sent it to a separate stockpile. The separate 3/4 pile was eliminated soon after production got underway. Material was conveyed to a 6-foot x 16-foot El Jay screen which separated the primary crushed material into each size group and the oversize. The oversize dropped into a Model 1500 Telesmith cone which returned the crushed product in a closed loop to the belt feeding from the jaw to the El Jay screen. Later, a 250-HP Kenwood impact crusher was added into the loop following the cone primarily because the cone by itself resulted in flat and elongated particle shapes. Excess 3- and 1-1/2-inch aggregate from the bins was collected by chute and conveyed initially to the 250-HP Kenwood impact crusher. Almost all material was from the 3-inch bin. The impact crusher was later moved into the closed loop following the cone crusher as described above, and was replaced by a 24-inch double roll crusher. When the rolls were used, a closed loop was established there so that material did not leave until it all passed the 3/4-inch screen and was conveyed directly onto the 3/4-inch minus conveyor to that storage bin.

1 April - 1 June:

The production equipment and layout are shown on Plate 3.6. The purpose of the change was to increase total production and 3/4-inch-minus production. The scheme is easy to understand if considered as two separate plants connected only at the surge feeder. On the right side, a 42-inch jaw crusher feeds onto a 6-foot x 16-foot 3-deck El Jay screen. Screen sizes used were 3-inch on the top deck, 1-1/2-inch on the middle deck, and 3/4-inch on the bottom. The 3-inch to 1-1/2-inch material and the 1-1/2-inch to 3/4-inch were conveyed directly to the load-out bins. The 3/4-inch minus was conveyed into the surge feeder. All oversize material retained on the 3-inch screen was fed into a 300-HP Model 1500 Telesmith cone. Discharge from this cone was then recirculated onto the main conveyor belt back up to the 3-deck El Jay screen.

On the left side, a 36-inch jaw crusher was used for primary crushing. Material passing through this jaw was screened over a 2-deck 5-foot x 14-foot El Jay screen. The 3/4-inch minus was scalped off this screen and conveyed directly to the load-out bin. All other material was fed to a 54-inch El Jay standard cone. This material was then put into a closed circuit of two 5-foot x 14-foot El Jay 2-deck screens, a 54-inch El Jay fine head cone, a 54-inch set of Pioneer rolls, and a 72-inch Kenwood impact crusher. All 3/4-inch-minus material was screened out and sent to the pay belt. All material between 1-1/4-inch and 3/4-inch was screened out and sent to the surge feeder. This material, as well as the 3/4-inch minus obtained from the 3-deck 6-foot x 16-foot El Jay screen, was fed into a 72-inch impact crusher. Once it passed through the impact crusher, it recirculated up to the closed circuit screens where the 3/4-inch minus and the 1-1/4-inch to 3/4-inch were removed.

Production from this setup varied according to the amount of material which was fed to it, but the average production was about 3,700 tons per single shift. The system worked satisfactorily and used available equipment but probably was more complicated than necessary.

1 June - 23 September:

The final setup used was the simplest and worked quite satisfactorily. It is shown on Plate 3.6. Both a 42-inch and a 36-inch jaw crusher were used at different times for the setup. All material passing through the jaw was fed to a 6-foot x 16-foot El Jay 3-deck screen. The screen sizes used on this were a 3-inch on the top deck, 1-1/2-inch on the middle deck, and a 3/4-inch on the bottom deck. All material retained on the 3-inch screen was fed into a 300-HP Model 1500 Telesmith cone. After passing through this cone crusher, it was then recirculated onto the main conveyor going to the screen. All material passing the 3-inch screen but retained on the 1-1/2-inch screen was conveyed to the 3-inch bin and hauled away. All material passing the 1-1/2-inch screen but retained on the 3/4-inch screen was conveyed to the 1-1/2-inch bin and hauled away. All material passing the 3/4-inch screen was conveyed to a surge feeder where this material was metered into a 72-inch Kenwood impact crusher. All material passing through the Kenwood impact crusher was then sent to the 3/4-inch pile where it was hauled away.

This setup was used from approximately 1 June until the end of the job. It produced approximately 2,800 tons per single shift.

ACTUAL AGGREGATE PRODUCTION

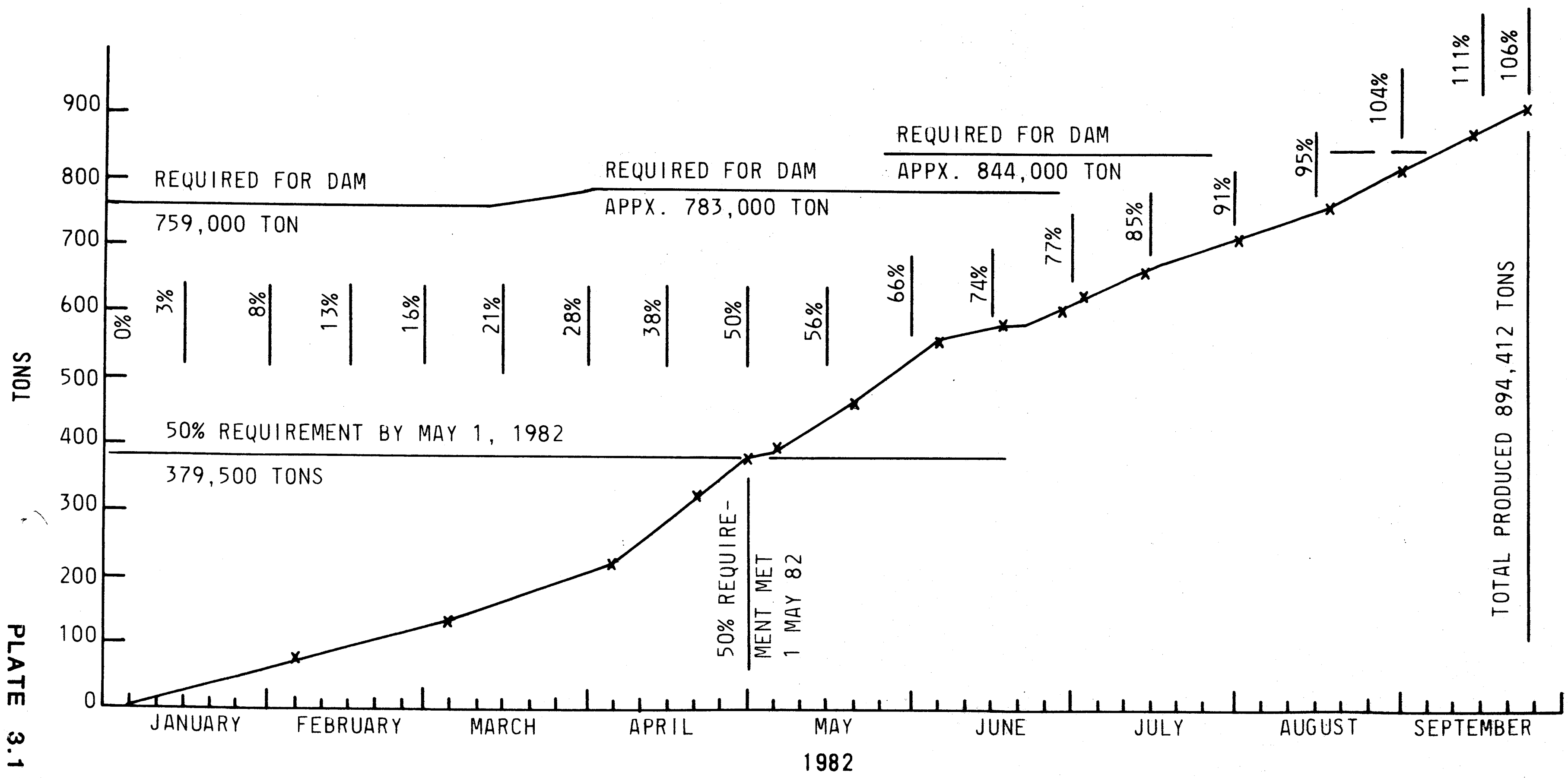
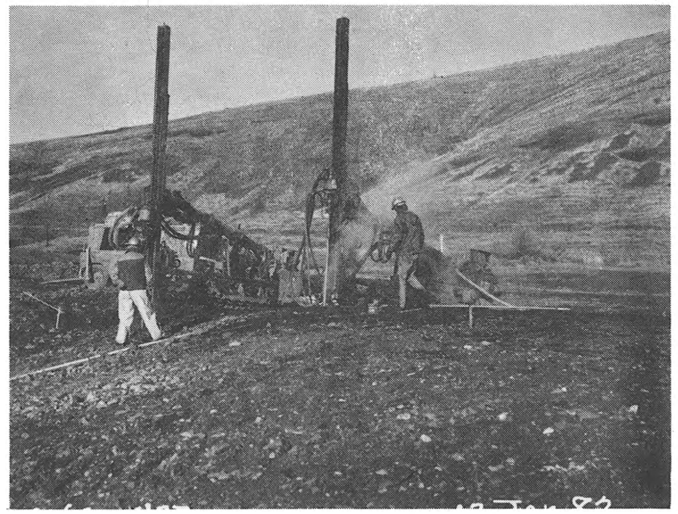


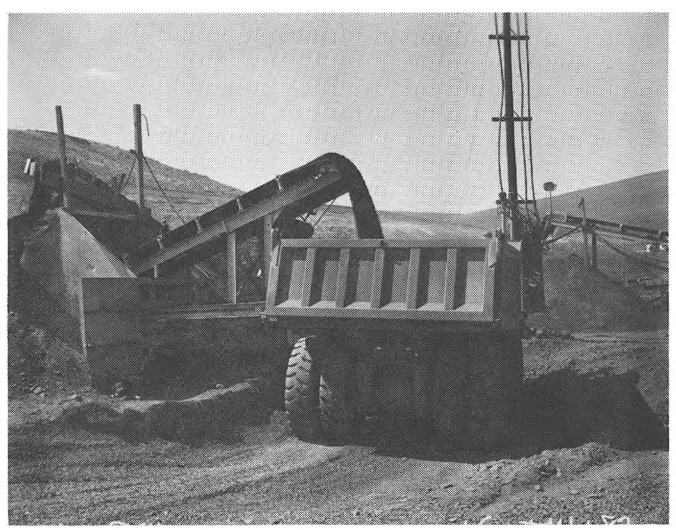
PLATE 3.1



DRILLING THE QUARRY.

DOZING SHOT ROCK TO THE CRUSHER.

DOZING OVERBURDEN TO THE CRUSHER.



LOADING 3/4 MINUS AGGREGATE.

LOADING 1 1/2 AND 3 INCH AGGREGATE.

EACH LOAD TO STOCKPILE WAS WEIGHED.

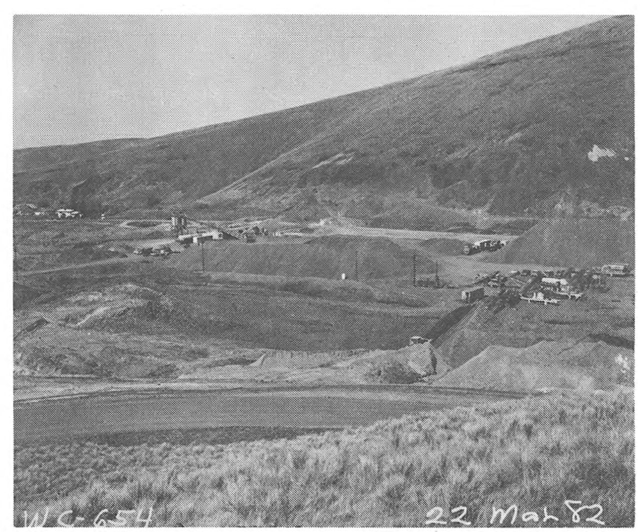
QUARRY OPERATION AND AGGREGATE LOADING

PLATE 3.2

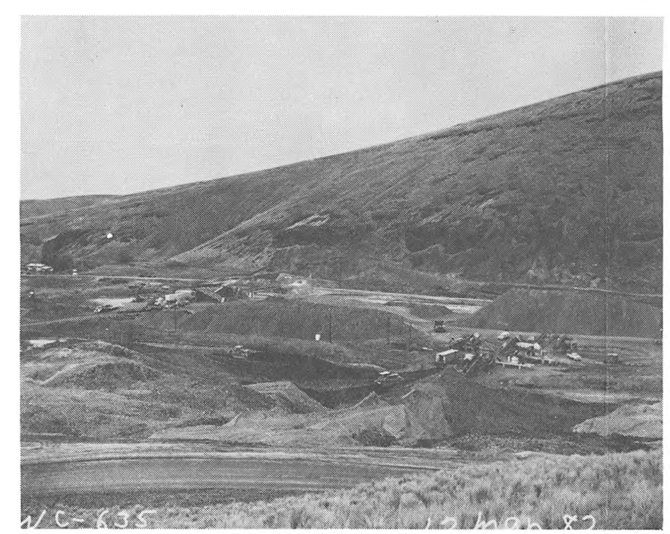
20 JULY 1982.

22 JUNE 1982.

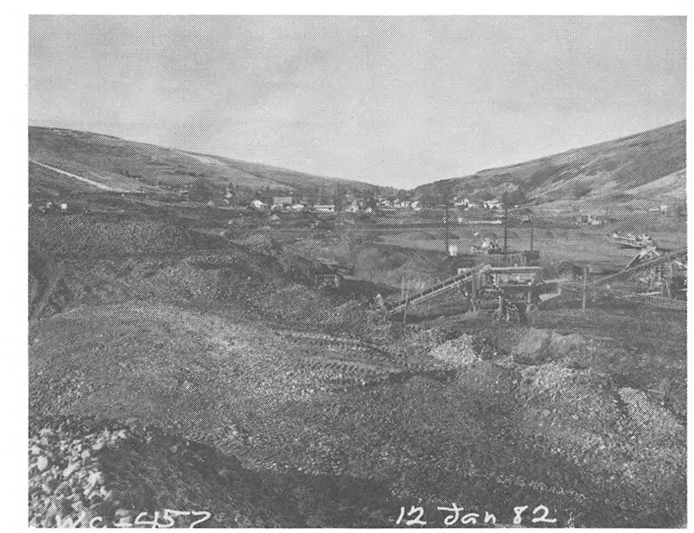
19 APRIL 1982.



22 MARCH 1982.



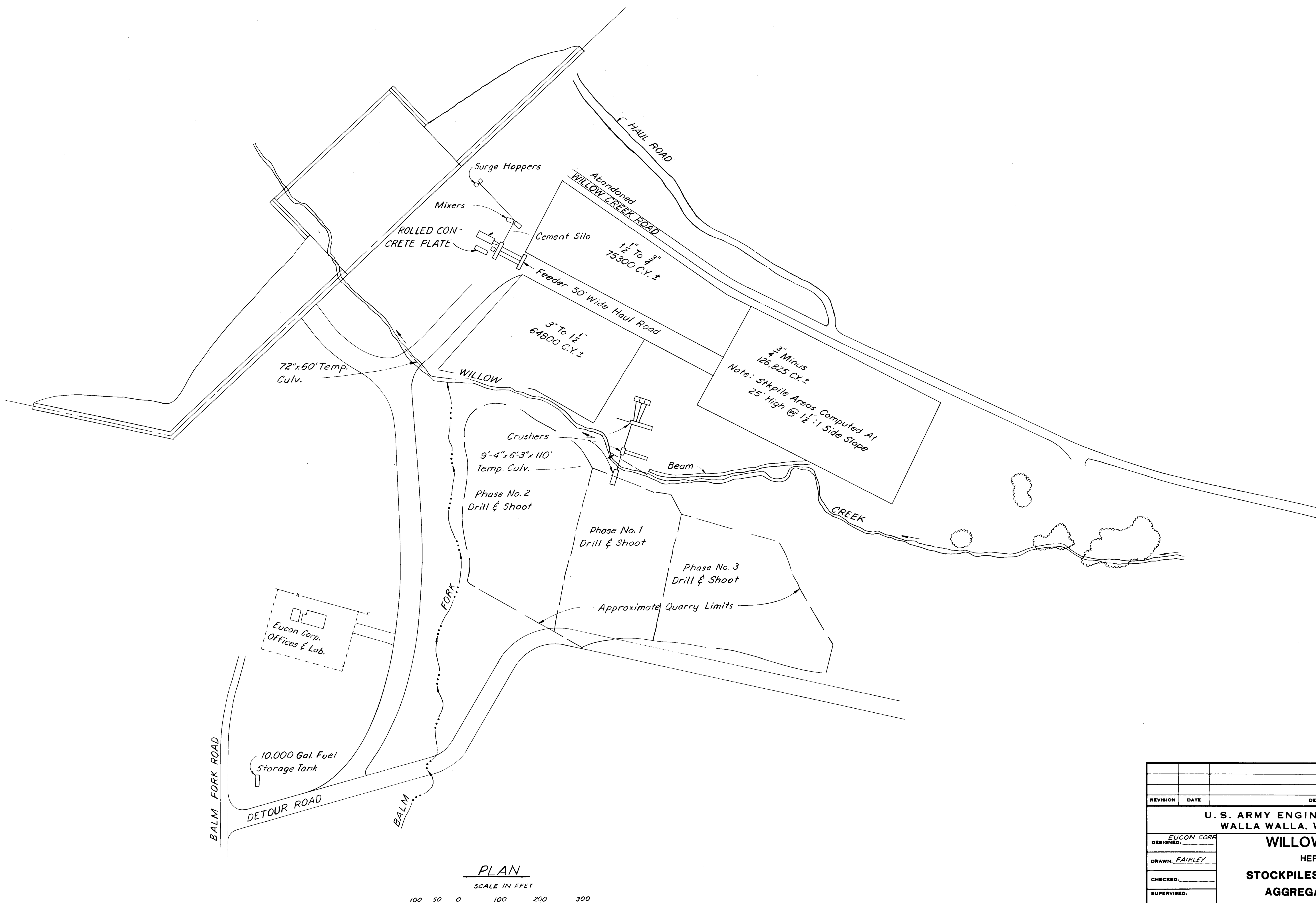
12 MARCH 1982.



12 JANUARY 1982.

CRUSHER ARRANGEMENTS AND AGGREGATE STOCKPILES

PLATE 3.3



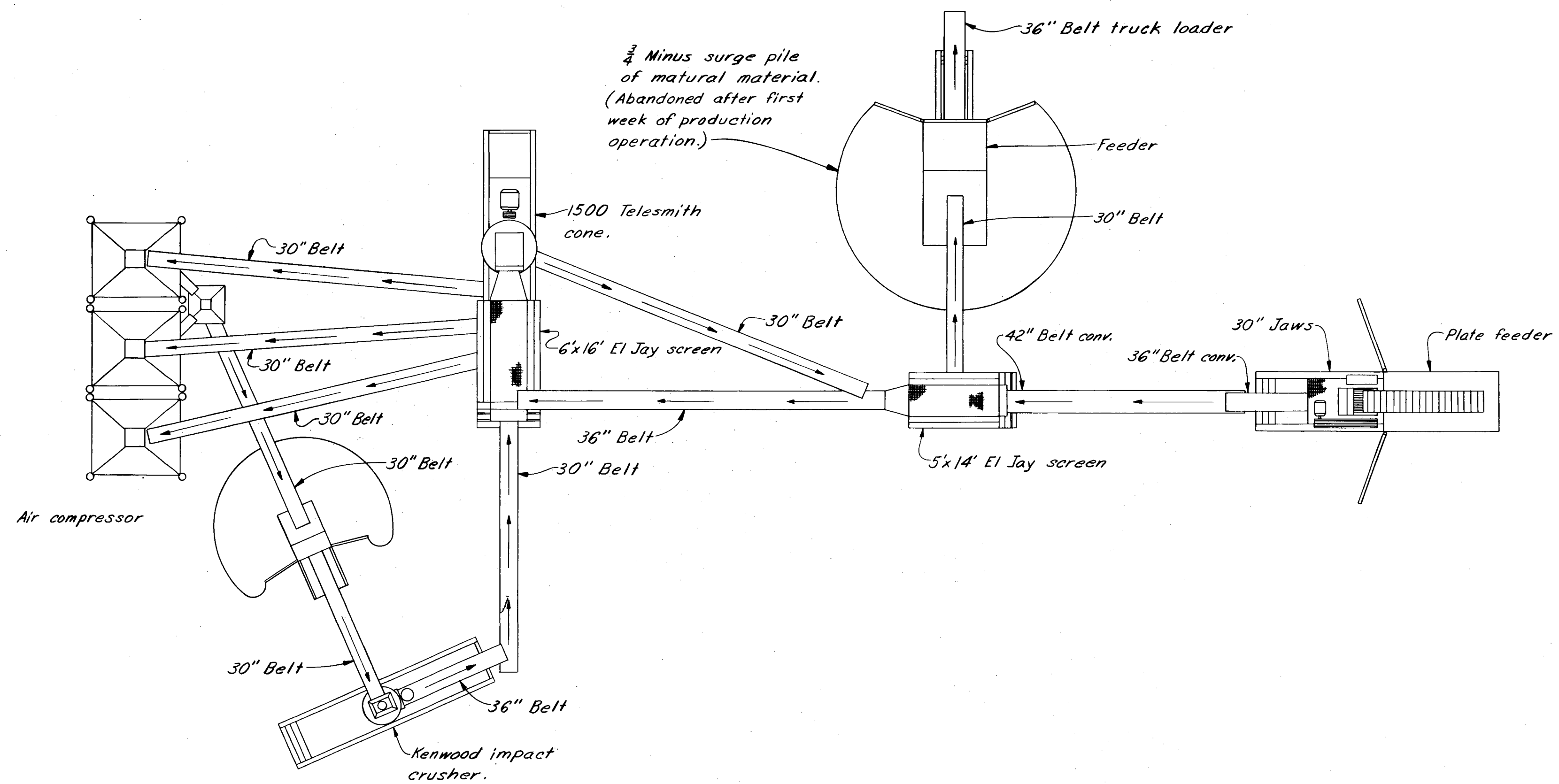
REVISION	DATE	DESCRIPTION	BY

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA, WASHINGTON

DESIGNED: EUCON CORP.
DRAWN: FAIRLEY
CHECKED:
SUPERVISED:
CHIEF MAT'L'S SECTION

WILLOW CREEK LAKE
HEPPENER OREGON
STOCKPILES, QUARRY AND INITIAL AGGREGATE PLANT LAYOUT

SUBMITTED: DATE
CHIEF, FOUNDATION'S AND MATERIAL'S BRANCH
SCALE AS SHOWN | INV. NO. | FILE NO. | SHEET



REVISION	DATE	DESCRIPTION	BY

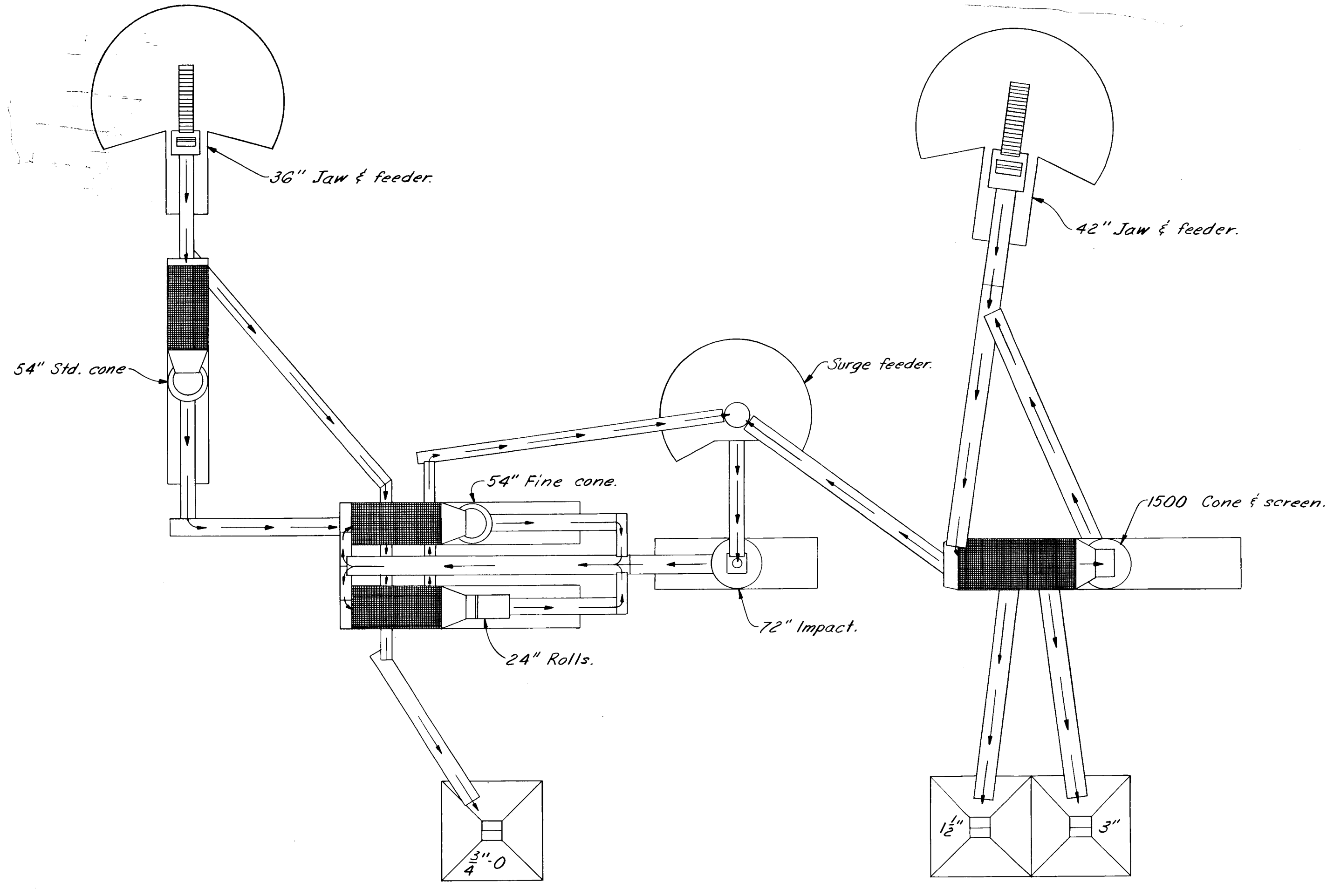
U. S. ARMY ENGINEER DISTRICT
WALLA WALLA, WASHINGTON

DESIGNED: Pro Fab
DRAWN: L. Parsons
CHECKED: Schrader
SUPERVISED:
CHIEF MATL. DES. SECT.
SUBMITTED:
CHIEF, FOUNDATIONS AND MATERIALS BRANCH

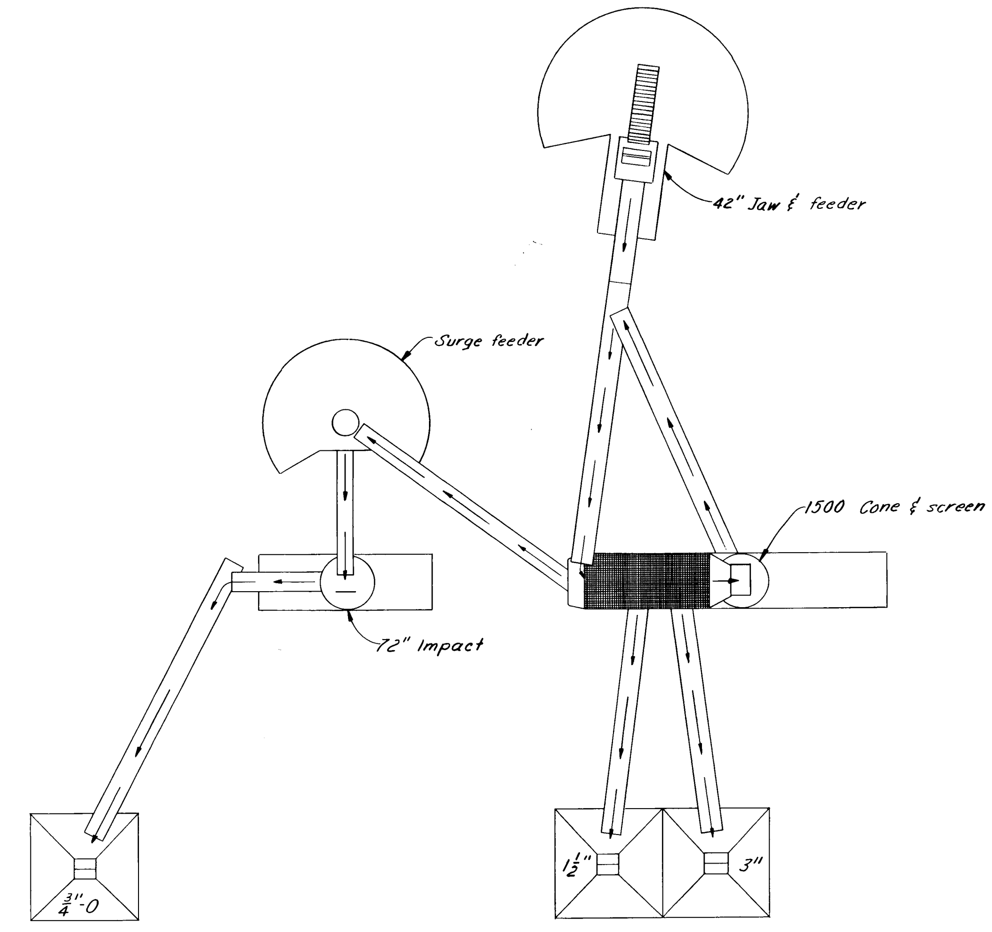
WILLOW CREEK LAKE
HEPPNER, OREGON

CRUSHING LAYOUT

DATE
SCALE AS SHOWN
INV. NO.
FILE NO.
SHEET



SEVEN UNIT



TWO UNIT

REVISION	DATE	DESCRIPTION	BY

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA, WASHINGTON

DESIGNED: Pro Fab
DRAWN: L. Parsons
CHECKED: Schrader
SUPERVISED:
CHIEF MAT. DES. SECT.

WILLOW CREEK LAKE
HEPPNER, OREGON

TWO AND SEVEN UNIT PLANT SET UP

SUBMITTED: DATE

CHIEF, FOUNDATION AND MATERIALS BRANCH

SCALE AS SHOWN | INV. NO. | FILE NO. | SHEET

CHAPTER 4

AGGREGATE GRADATIONS AND MIX PROPORTIONS

Five basic RCC mixes were used as originally specified. The vast majority had 3-inch maximum size aggregate but there also was some 1-1/2-inch maximum size aggregate mix (used in the spillway) and some 3/4-inch maximum size aggregate mix (used for special bedding between cold joints). Because the mixes required three separate maximum sizes, three separate stockpiles were necessary. There was no requirement for a separate sand stockpile. The contractor was given maximum latitude in controlling gradation in the stockpiles. The only requirement was that he be able to combine material from the three stockpiles so that it resulted in the overall gradations shown below and so that the size groups were maintained within the following general guidelines.

Group I - 100% passing the 3-inch screen.
- 97% retained on the 1-inch screen.

Group II - 100% passing the 2-inch screen.
- 97% retained on the 1-inch screen.

Group III - 100% passing the 1-inch screen.

Sieve	Percent Finer
3	100
2-1/2	95-99
2	86-96
1-1/2	72-84
1	56-66
3/4	48-58
3/8	37-47
4	28-37
8	23-31
16	19-28
30	15-25
50	10-19
100	4-11
200	1-7

The amount of material passing the 200 sieve was further controlled depending on its plasticity. A table was included in the specifications showing the maximum allowed amount of fines based on their liquid limit and plastic index. Highly plastic fines were limited to 1 percent but nonplastic fines were allowed to reach 7 percent. Later, the range for nonplastic fines was changed to 3-percent minimum and 10-percent maximum. Generally, the amount actually was about 7 percent with almost every test showing no plasticity. This resulted in the 3/4-inch aggregate stockpile containing about 15-percent material passing the 200 sieve.

Plate 4.1 shows the combined gradation band for the Willow Creek RCC and also the combined gradation band for typical conventional concrete. In addition to the obvious difference in the amount of fines, several other things are apparent. (1) The allowable range for each screen is generally double that otherwise allowed. (2) The 3-inch maximum size was 100-percent passing rather than a 3-inch nominal size with some larger pieces. (3) Starting in the 3/8- to 3/4-inch range, the RCC contains considerably more of the smaller sizes. This is mostly attributed to the minus 200 material but it also contains more 3/8-inch material. (4) The gradation is closer to that of a road base or embankment than to a normal concrete aggregate.

After production was underway and the product was being consistently stockpiled at about the same gradation, samples were sent to the Division laboratory to verify that RCC mixes made with these materials would be similar to those used in the design studies. There was no significant difference.

As expected, the portion of the gradation most difficult to achieve was in the No. 16, No. 30, and No. 50 sizes. To help correct this deficiency (on the order of 5 to 10 percent too low earlier in production), the contractor added a natural fine blend sand at the batch plant. The sand was located in the reservoir area near the stockpiles and was removed by scraper. As time progressed, the deficiency was made up in the crushing operation by pushing more overburden in with the shotrock at the crusher. The amount of blend was systematically diminished and then eliminated. It was also recognized that operating while out by a few percent on these screen sizes was acceptable. In fact, when the gradation band was established, it was deliberately pushed a few percentage points higher in this area to help force attention on the problem. Therefore, operating marginally out of the specification band in this area was technically acceptable and it offered a buffer to contract requirements.

During RCC production, the combined gradation being produced was determined and reported for each shift by the contractor and reviewed by the Corps the following morning. The average results for the day were plotted as a gradation curve on a graph also showing the "target" gradation on which mix designs were based. For the 3-inch mix, the specification limits were also shown. When a trend began to develop over a period of several days (where the gradation began to shift), appropriate adjustments were made in the batch weights of the individual aggregate size groups to shift the gradation back towards the target again. Sometimes adjustments would be made every few days and at other times they would be made after several weeks of consistent operation. Exhibit 4.1 shows the standard form that was used each time aggregate proportions were adjusted. It includes all proportions, batch weights, specific gravity, absorption, and yield data. Exhibit 4.2 shows the gradation and aggregate batch proportions being used in each mix on each Monday. Gradations for all other days are available if requested.

A study was made comparing gradations for the 10 highest and 10 lowest cylinder strengths of each mix at each age to see if a correlation existed between gradation and strength. There was no indication of any relationship.

COMBINED GRADATION LIMITS FOR WILLOW CREEK RCC

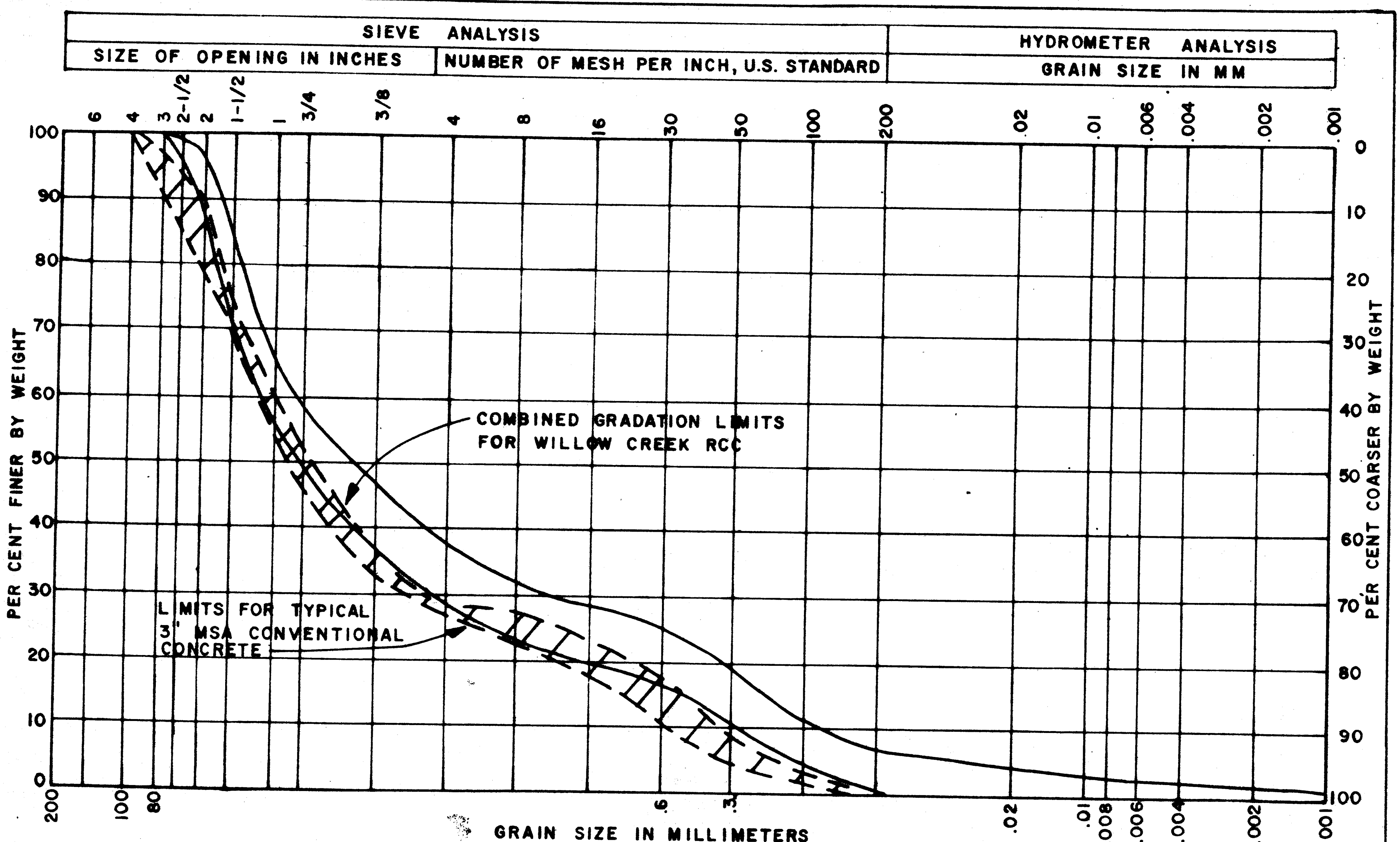


PLATE 4.1

EXHIBIT 4.1

TYPICAL MIX PROPORTION ADJUSTMENT SHEET
AS USED DURING CONSTRUCTION

Typical Mix Proportion Adjustment Computations

Mr. E. Schrader (Corps of Engineers) requested the change in R.C.C. Blend Mix Percentages as indicated below. Effective 26 Aug 1982 at 1430 hours.

Mix Designation: 29-17-54-0

SSD BATCH WEIGHTS (lbs/cy)					
Mix No.	1	2	3	4	5
Mix Identification	80/32	175/00	175/80	315/135	330/130
Primary Use	Int Mass	u/s face	d/s face	spillway	bedding
Group 1 Agg (3")	1148 (29%)	1133 (29%)	1130 (29%)	0	0
Group 2 Agg (1 1/2")	673 (17%)	663 (17%)	646 (17%)	1147 (33%)	0
Group 3 Agg (3/4")	2135 (54%)	2106 (54%)	2050 (54%)	2330 (67%)	3313 (100%)
Blend Sand	0	0	0	0	0
Cement	80	175	175	315	330
Ash	32	0	80	135	130
Water	142	146	150	184	225
Theoretical Unit Wt.	155.9	156.4	155.7	152.2	148.1
Assumed Air	1.2%	1.2%	1.2%	1.2%	1.2%

These mixes are based on the following specific gravity and absorption values. Considered representative of materials now being used at the project.

Type	Source	Sp. G.	Abs.
Group 1 Agg (3")	Quarry	2.79	0.70
Group 2 Agg (1 1/2")	Quarry	2.71	0.80
Group 3 Agg (3/4")	Quarry	2.59	2.80
Blend	Pit Run	2.25	8.00
Cement (Type II)	Lehigh	3.15	
Ash (Class F)	Bridger	2.30	
Water	Well	1.00	

It is understood that aggregate batch weight adjustment should not be made due to surface moisture change that may occur from day to day.

The placement foreman has the responsibility to adjust water as necessary during the day for placement.

The only adjustment of batch weights will be that Q.C. will inform the batch plant of what water to start with on a daily basis.

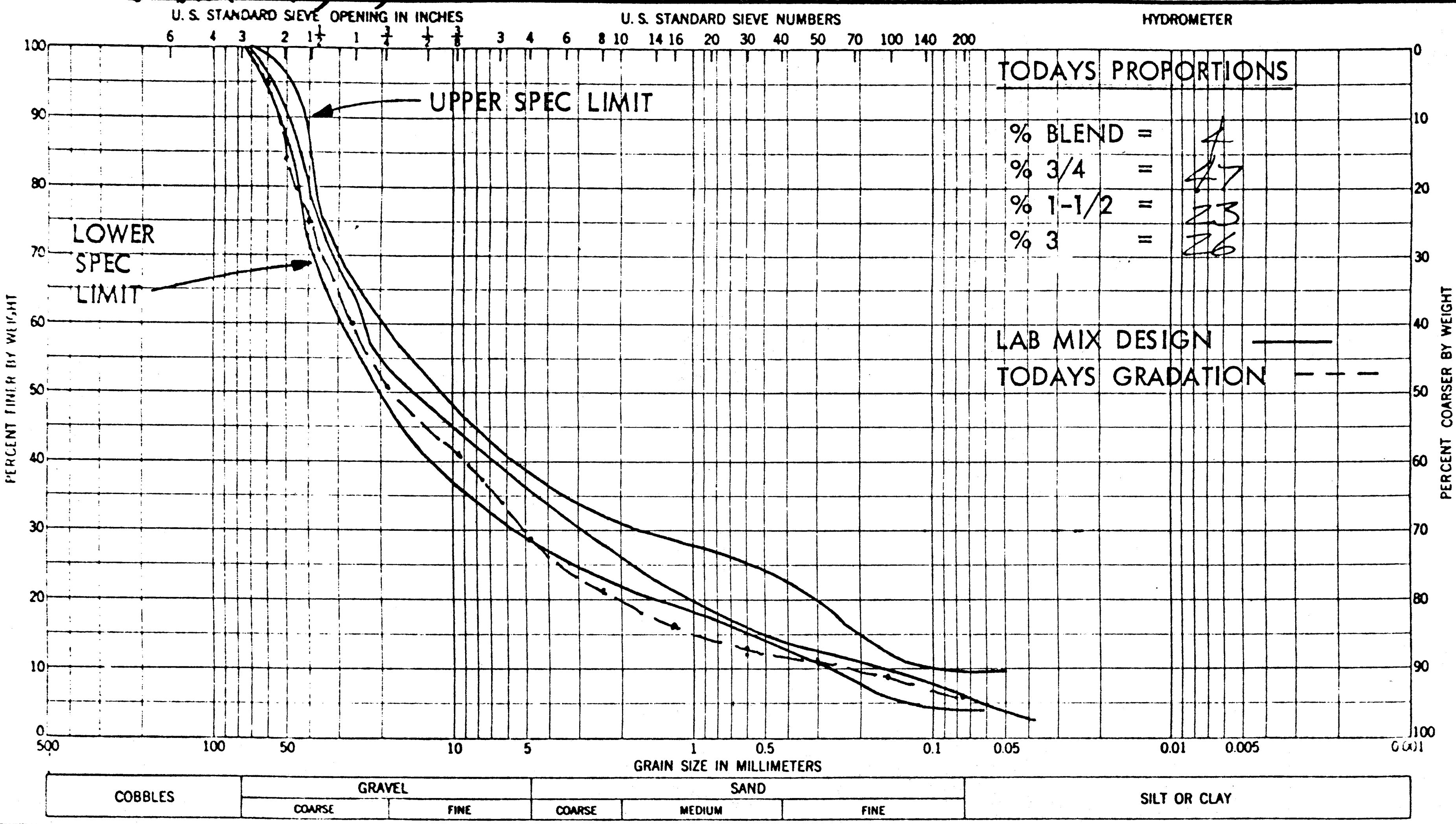
Q.C. Supervisor, Eucon Corporation

EXHIBIT 4.2

COMBINED GRADATION AND AGGREGATE PROPORTIONS
FOR EACH MIX AS USED ON EACH MONDAY

(These are the working sheets as produced daily during construction. Only the first day of the week is shown here because of space. Sheets for all other days are available in the District Office.)

Mix 1, 2, & 3



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

GRADATION CURVES

Project WILLOW CREEK DAM

3-INCH COMBINED GRADATION

Area

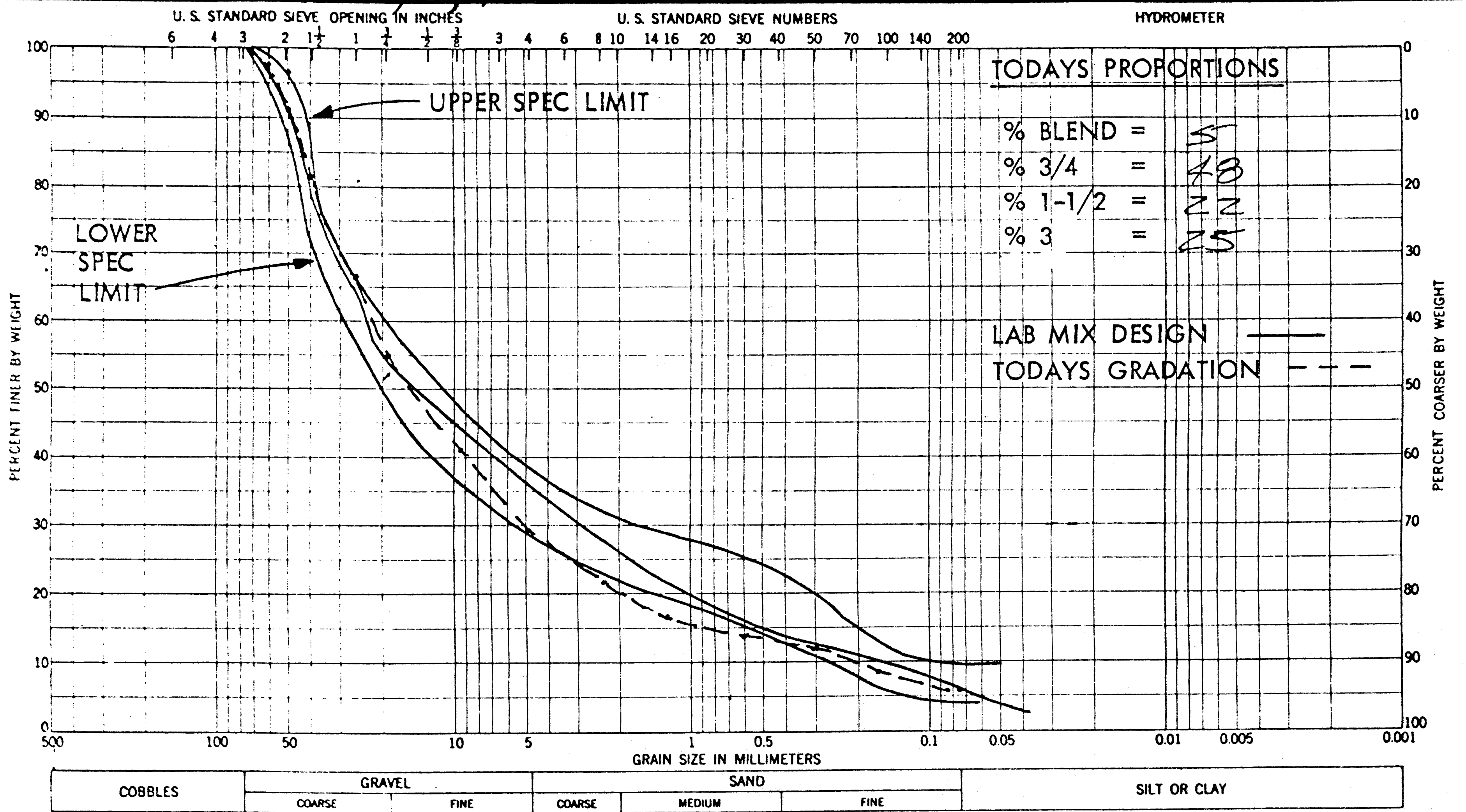
Boring No.

Date 5-10-82

ENG FORM 1 MAY 63 2087

EXHIBIT 4.2
Sheet 1 of 50

Mix 1, 2, & 3



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

3-INCH COMBINED GRADATION

Area

Boring No.

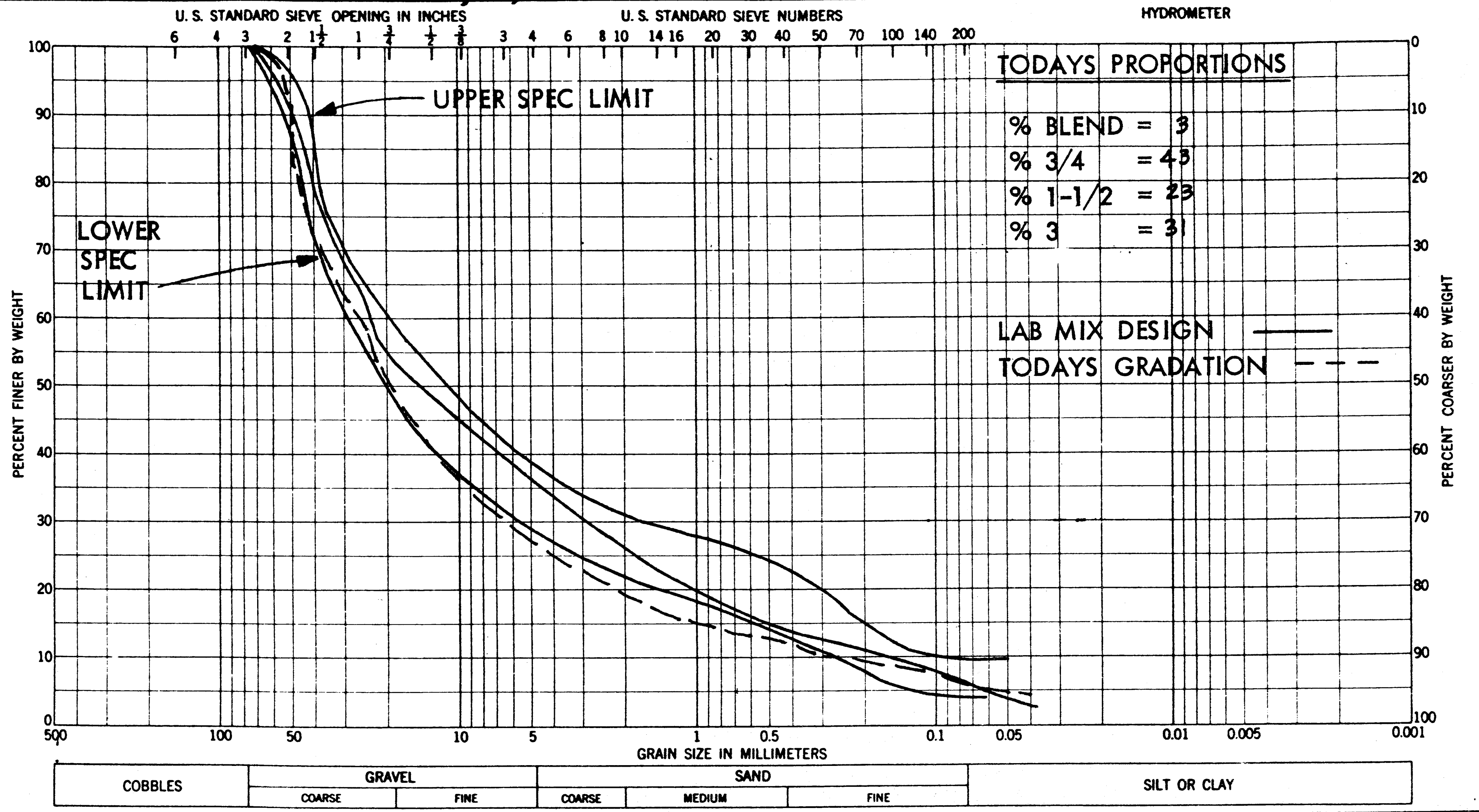
Date 5-17-82

GRADATION CURVES

EXHIBIT 4.2
Sheet 2 of 50

ENG FORM 1 MAY 63 2087

mix 1, 2, & 3



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

3-INCH COMBINED GRADATION

Area

Boring No.

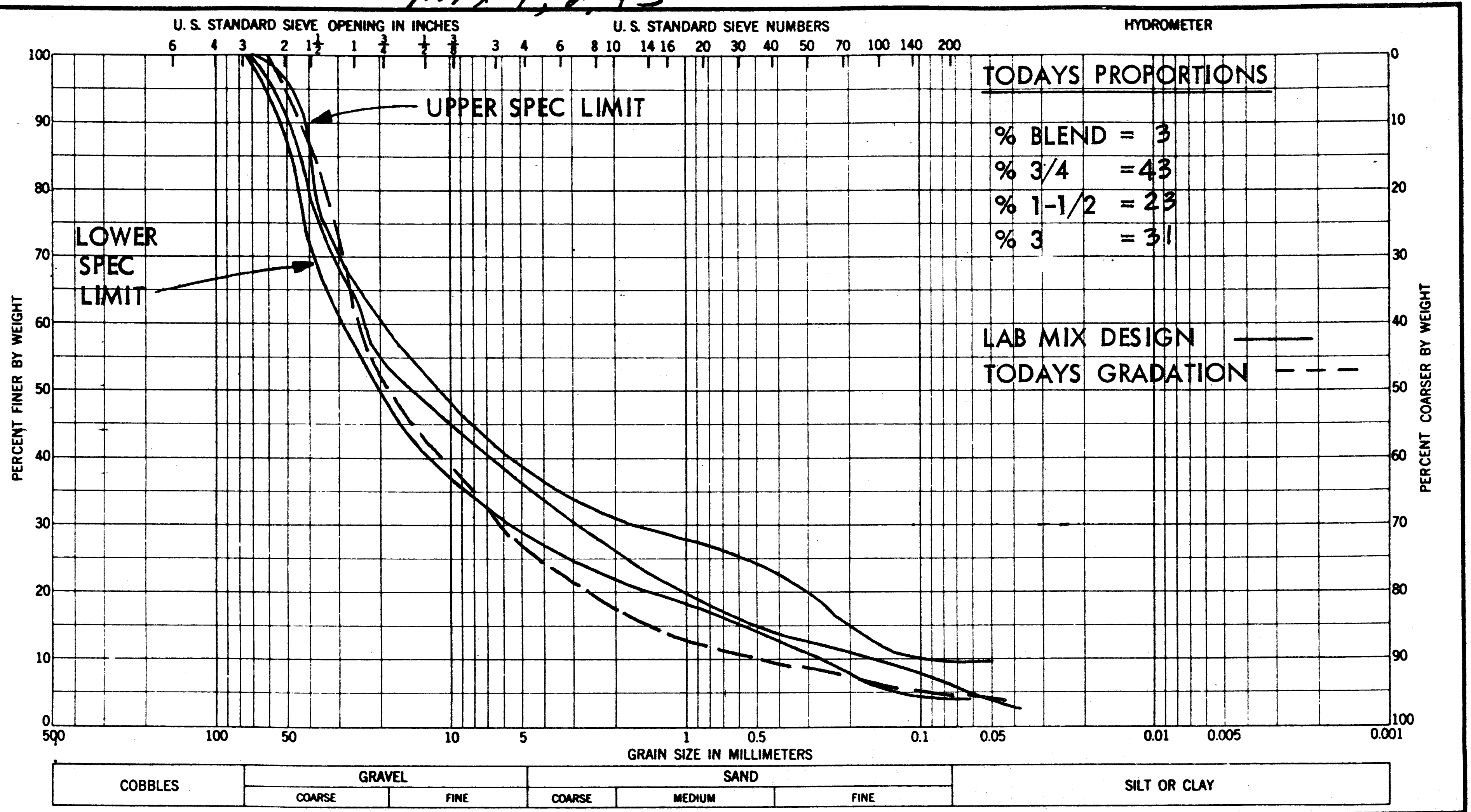
Date 5-24-82

GRADATION CURVES

EXHIBIT 4.2
Sheet 3 of 50

ENG FORM 1 MAY 63 2087

mix 1, 2, & 3



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

3-INCH COMBINED GRADATION

Area

Boring No.

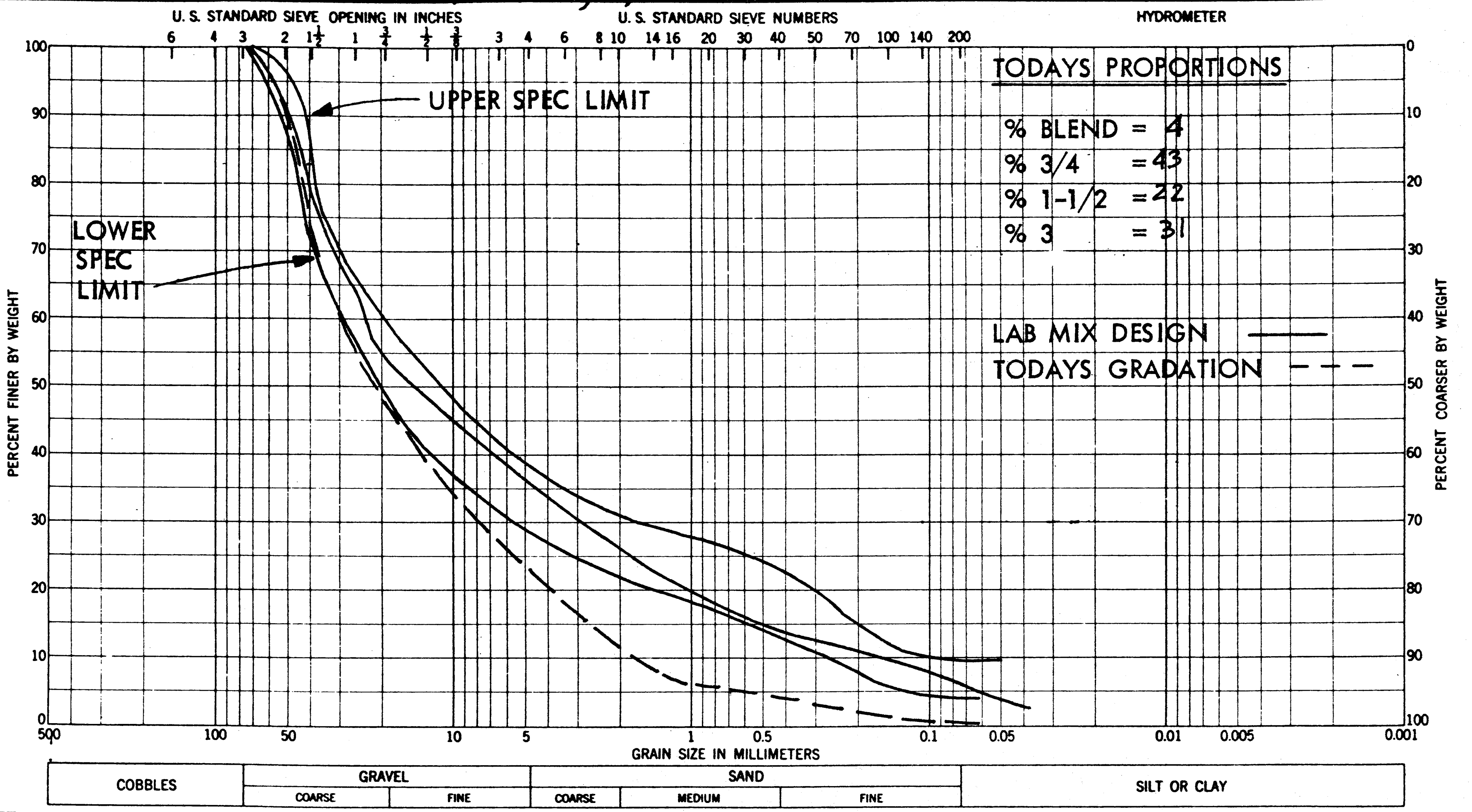
Date 6-7-82

GRADATION CURVES

ENG FORM 1 MAY 63 2087

EXHIBIT 4.2
Sheet 4 of 50

Mix 1, 2, & 3



COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

3-INCH COMBINED GRADATION

Area

Boring No.

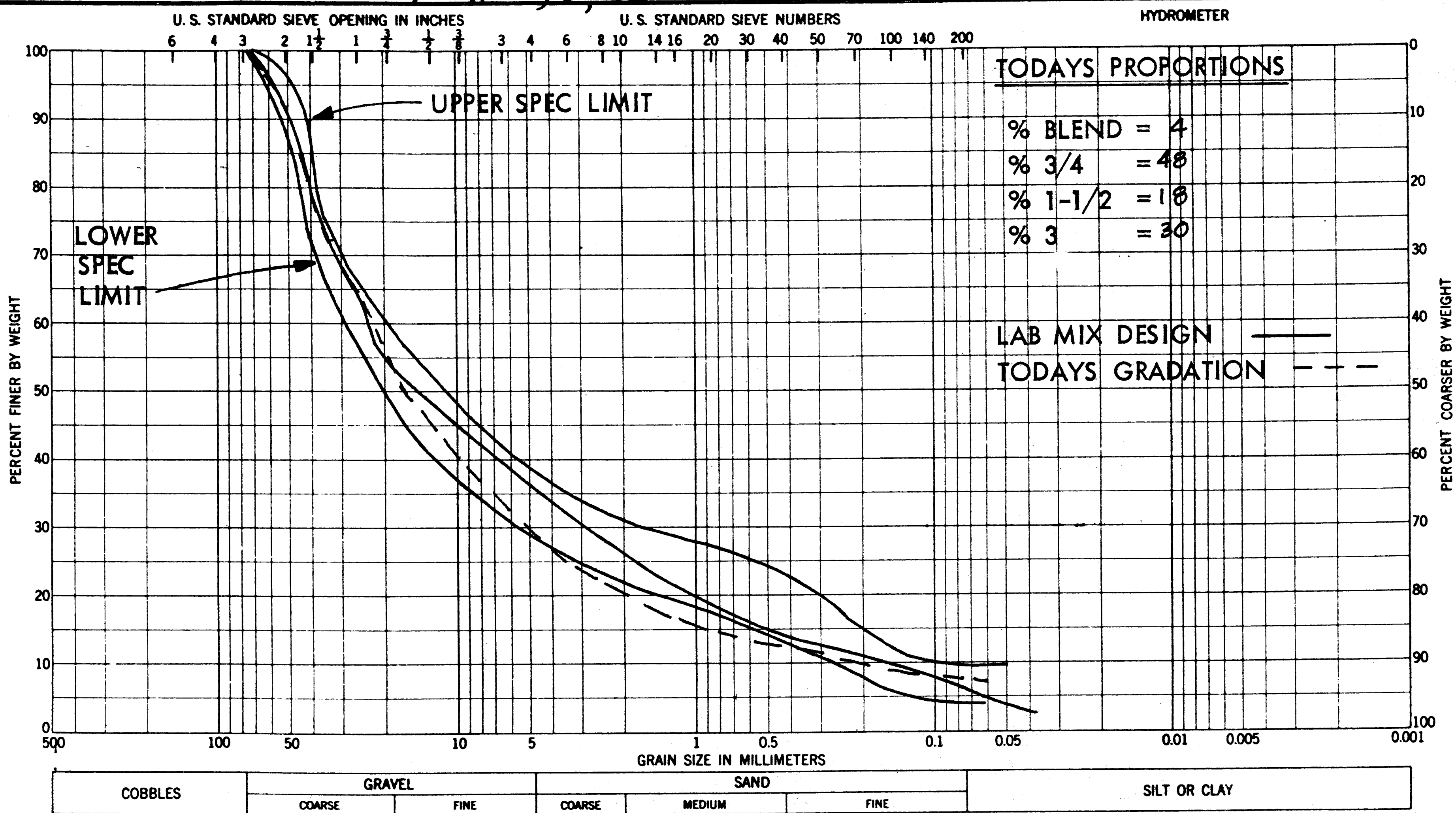
Date 6-14-82

GRADATION CURVES

ENG FORM 1 MAY 63 2087

EXHIBIT 4.2
Sheet 5 of 50

Mix 1, 2, &3



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

GRADATION CURVES

Project WILLOW CREEK DAM

3-INCH COMBINED GRADATION

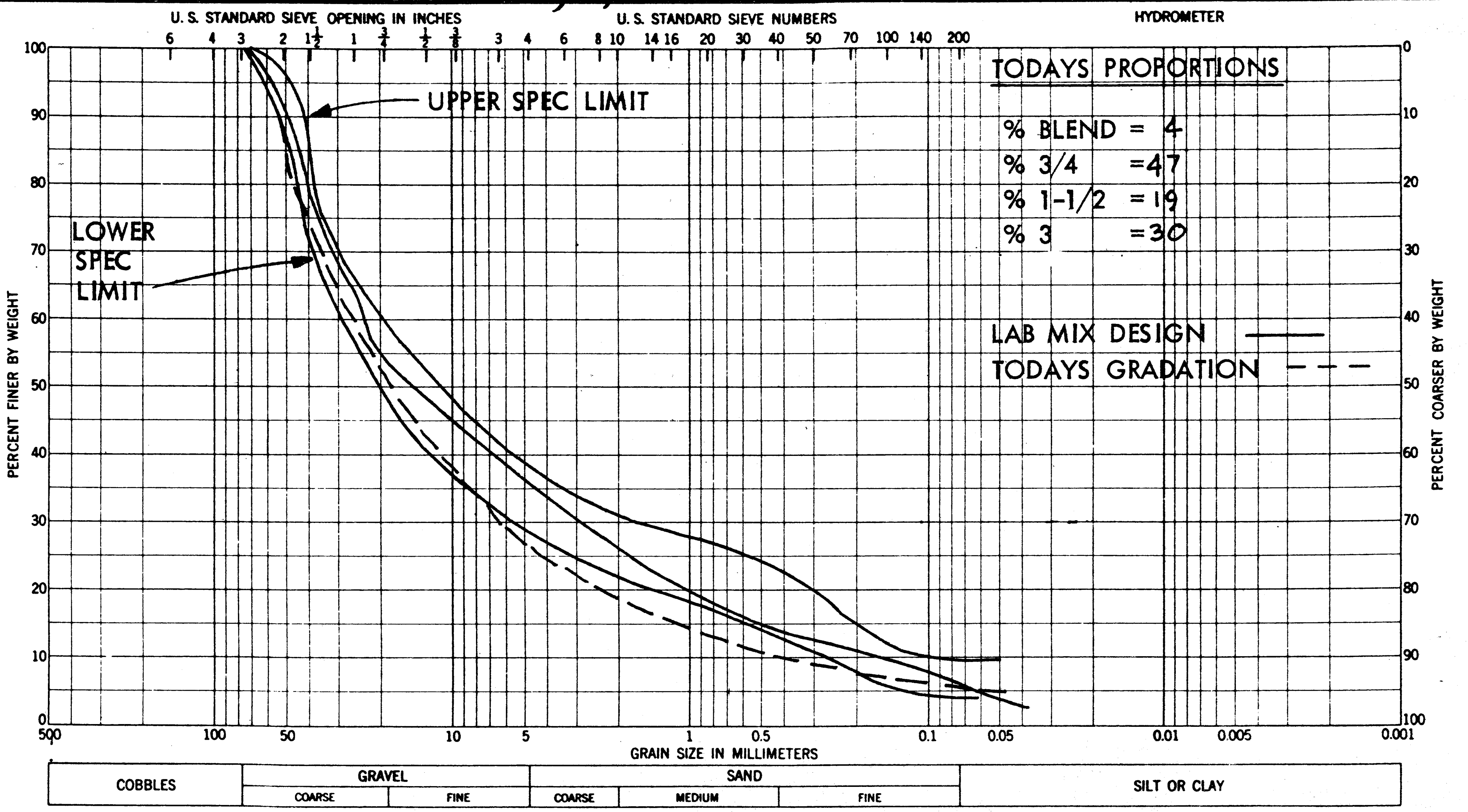
Area

Boring No.

Date 6-21-82

ENG FORM 1 MAY 63 2087

mix 1, 2, &3



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

3-INCH COMBINED GRADATION

Area

Boring No.

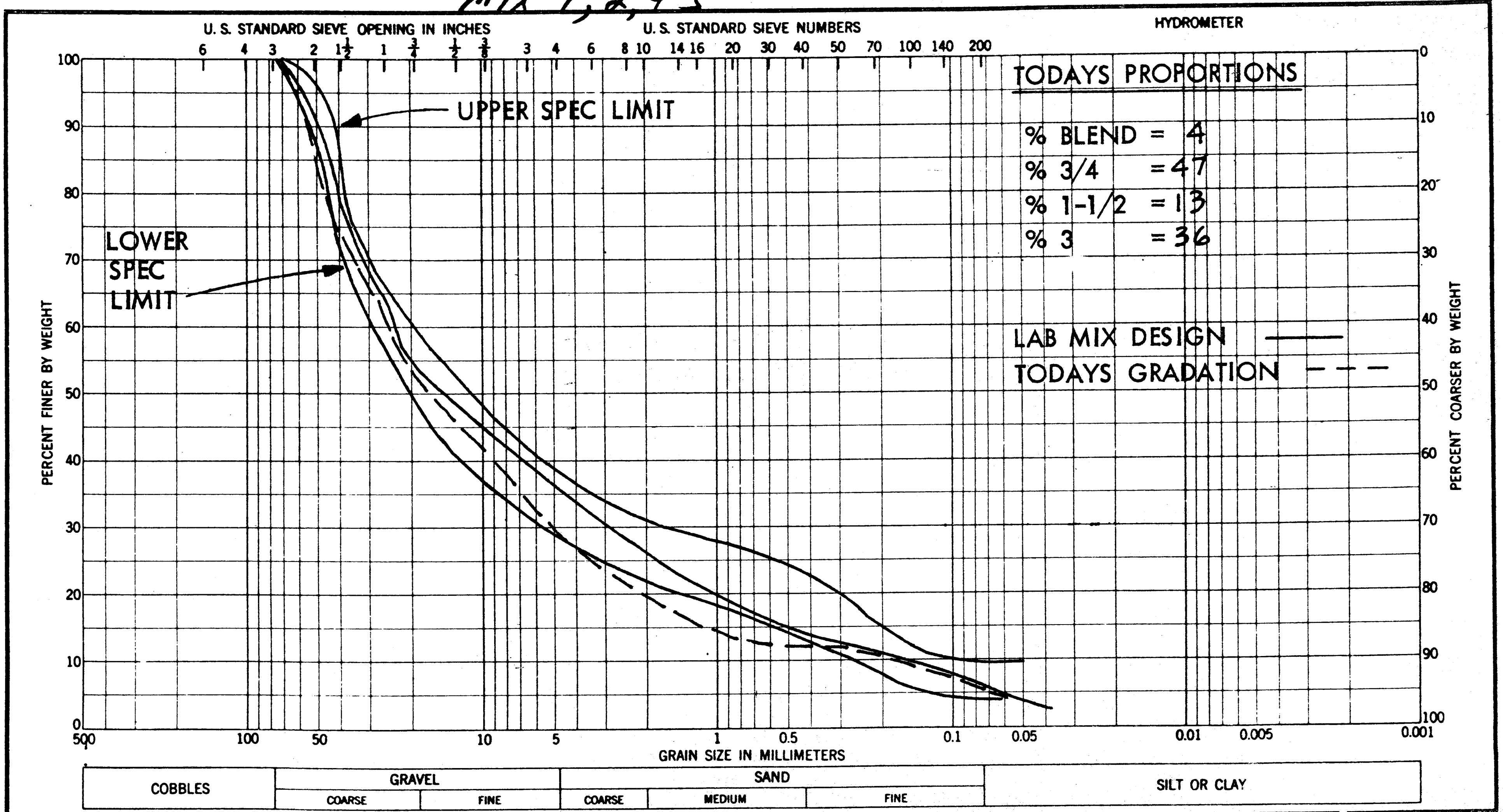
Date 6-28-82

GRADATION CURVES

EXHIBIT 4.2
Sheet 7 of 50

ENG FORM 1 MAY 63 2087

Mix 1, 2, & 3



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

3-INCH COMBINED GRADATION

Area

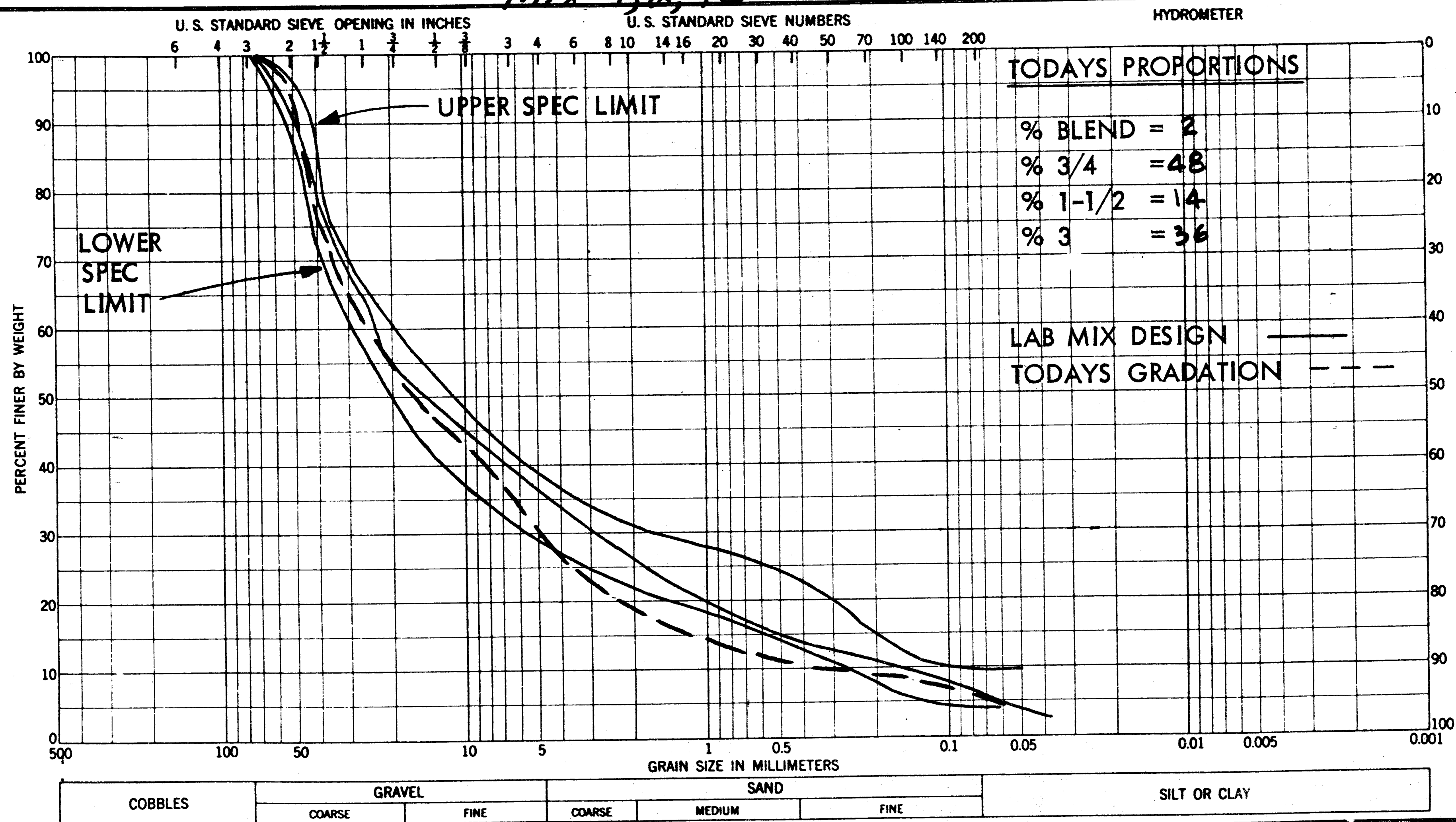
Boring No.

Date 7-19-82

GRADATION CURVES

ENG FORM 1 MAY 63 2087

mix 1,2,&3



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

GRADATION CURVES

Project WILLOW CREEK DAM

3-INCH COMBINED GRADATION

Area

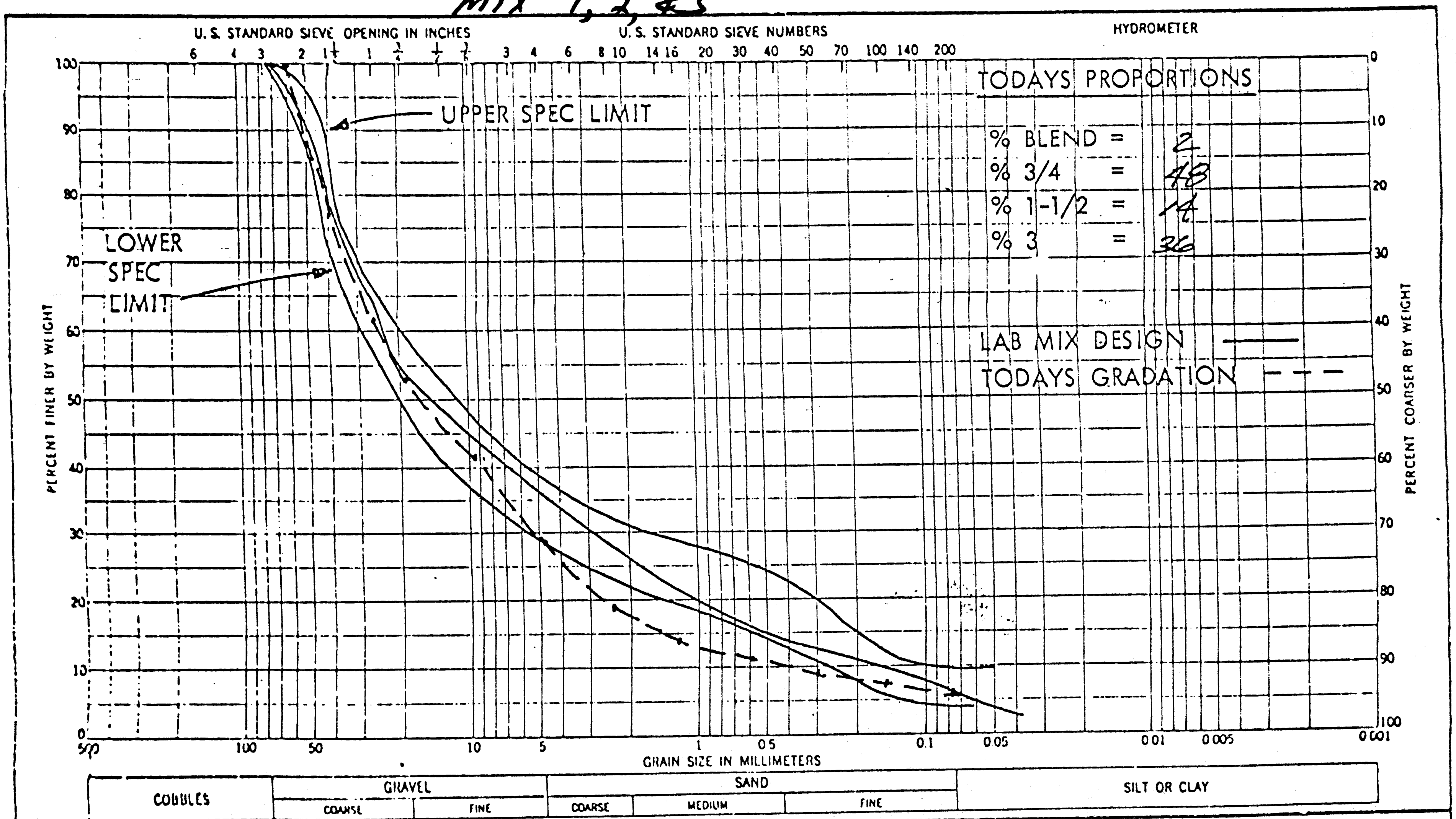
Boring No.

Date 7-26-82

ENG FORM 1 MAY 63 2087

EXHIBIT 4.2
Sheet 9 of 50

mix 1, 2, &3



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

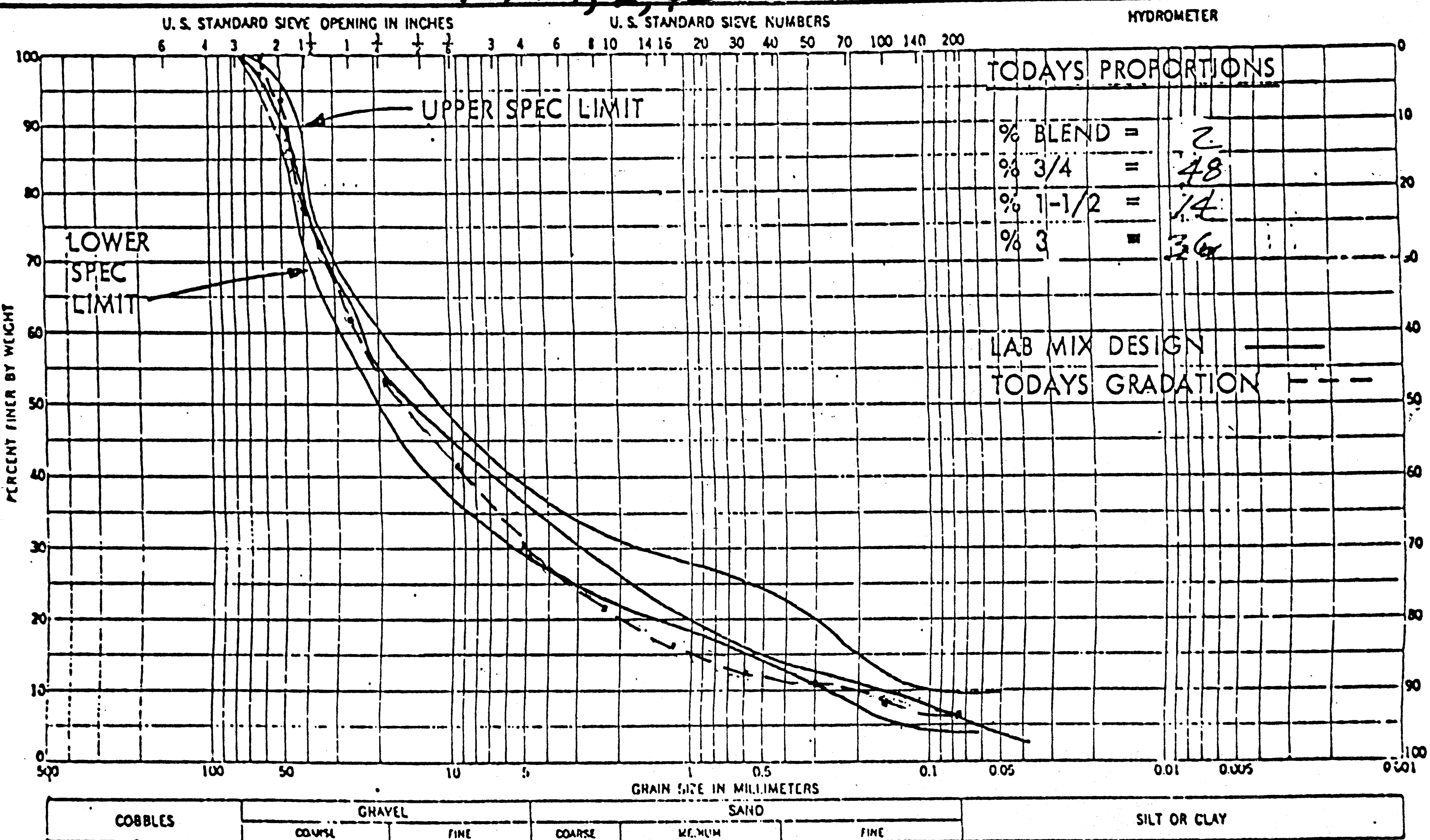
Project WILLOW CREEK DAM
3-INCH COMBINED GRADATION
Area
Boring No.
Date 8-2-82

GRADATION CURVES

ENG FORM 1 MAY 63 2087

EXHIBIT 4.2
Sheet 10 of 50

MIX 1, 2, & 3



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

3-INCH COMBINED GRADATION

Area

Boring No.

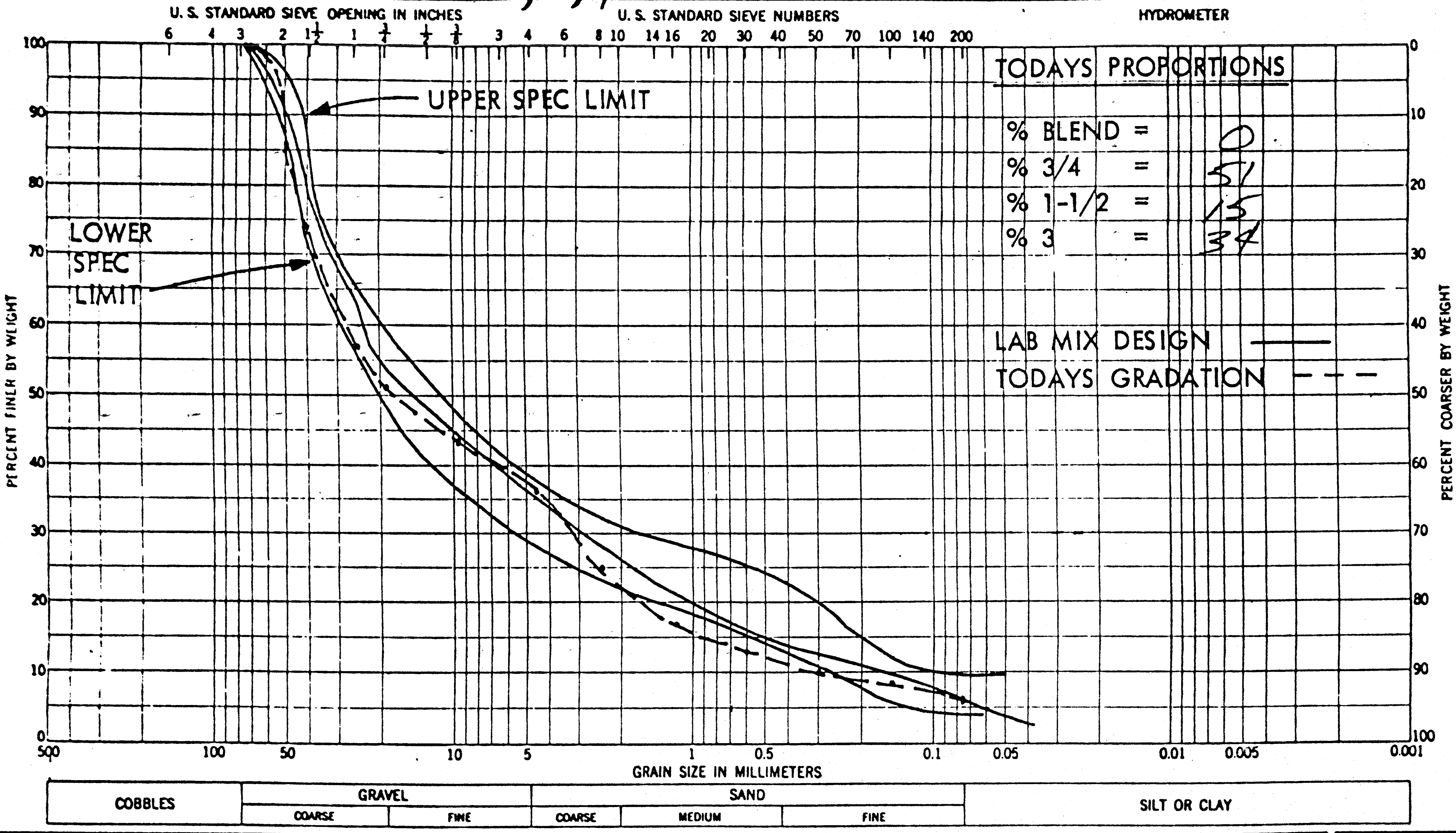
Date 8-9-82

GRADATION CURVES

ENG FORM 1 MAY 63 2087

EXHIBIT 4.2
Sheet 11 of 50

Mix 1, 2, & 3



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

3-INCH COMBINED GRADATION

Area

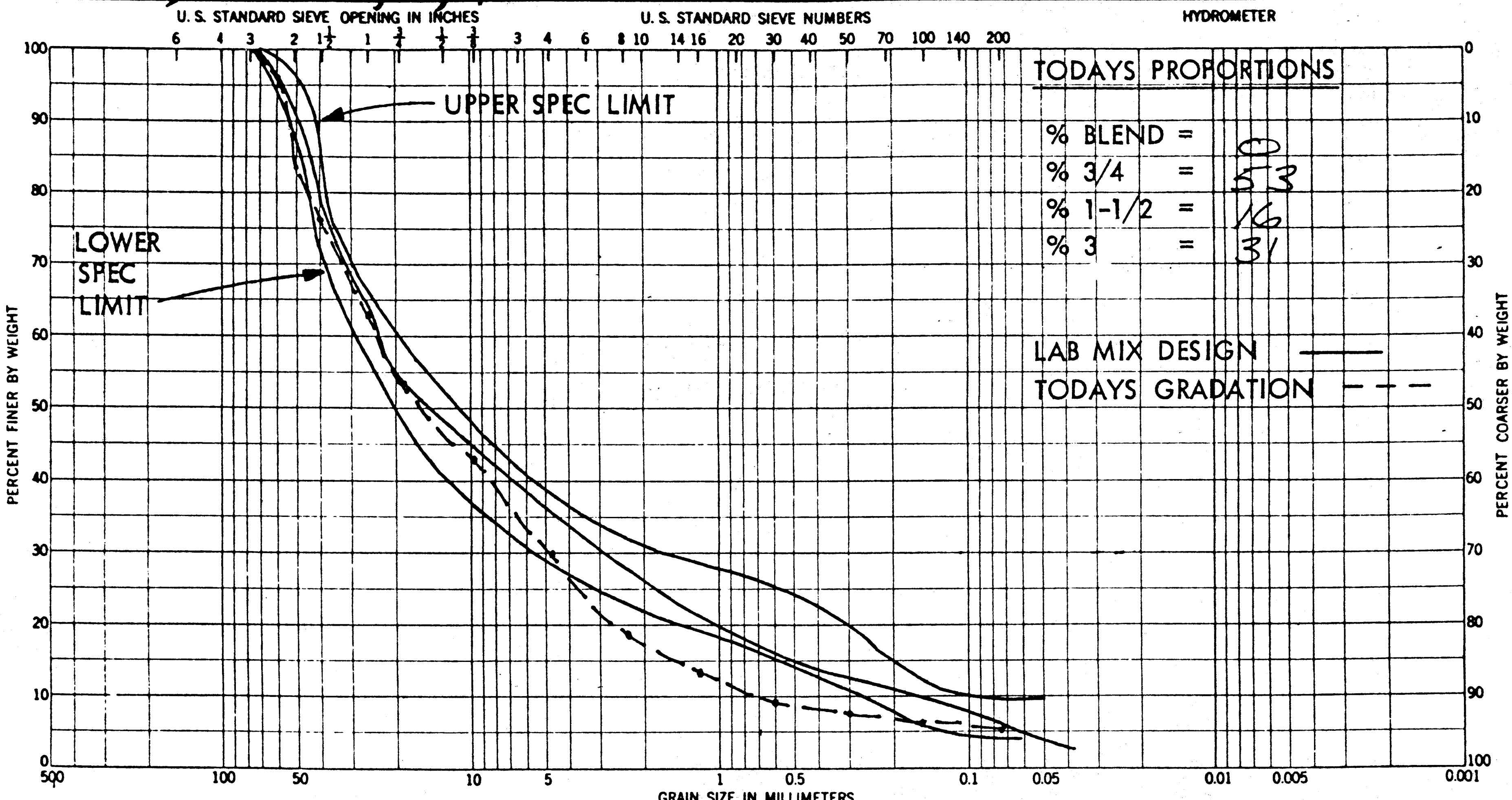
Boring No.

Date 8-16-87

GRADATION CURVES

ENG FORM 1 MAY 63 2087

Mix 1, 2, & 3



COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

3-INCH COMBINED GRADATION

Area

Boring No.

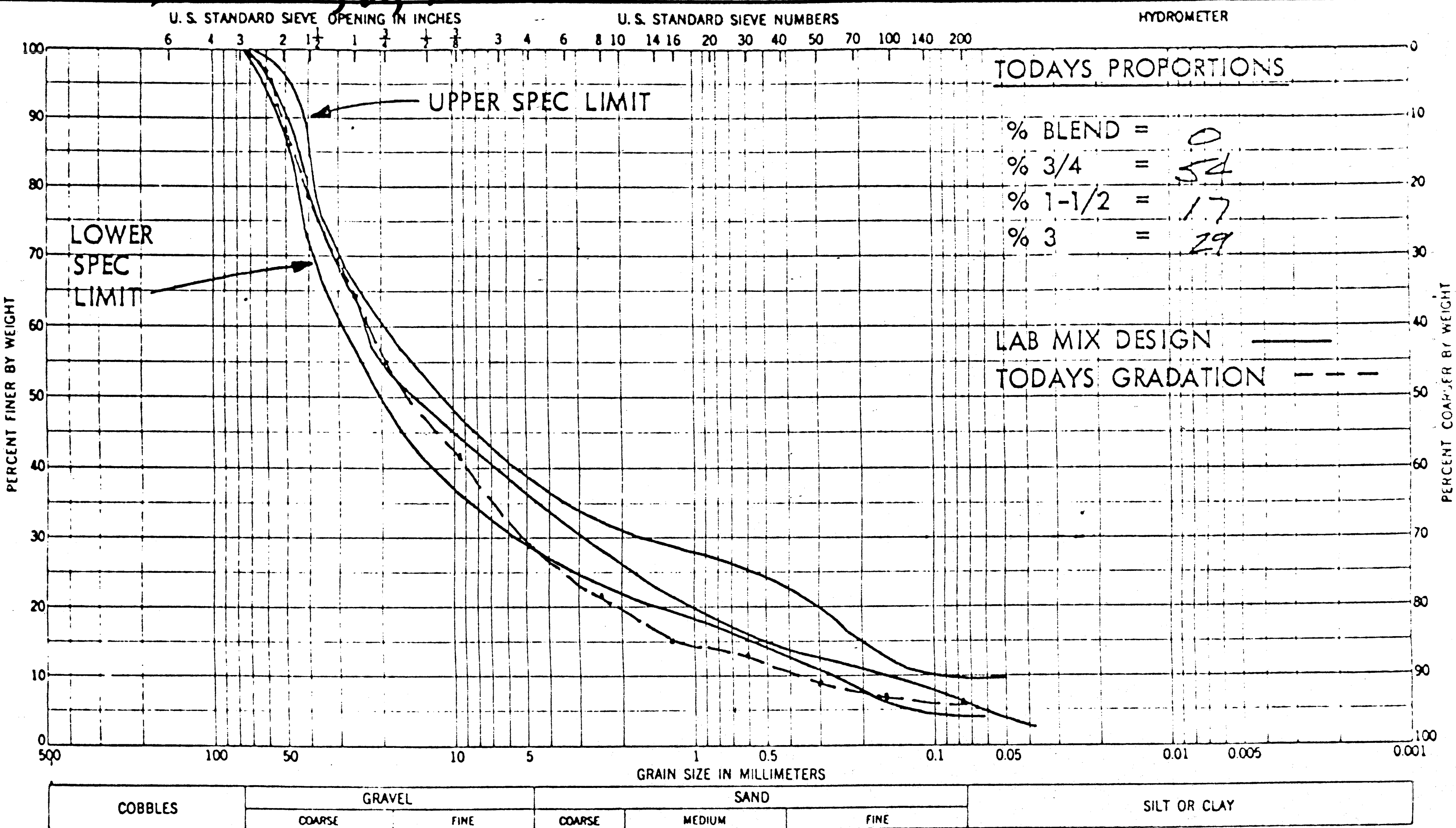
Date 8-23-87

GRADATION CURVES

EXHIBIT 4.2
Sheet 13 of 50

ENG FORM 1 MAY 63 2087

Mix 1, 2, & 3



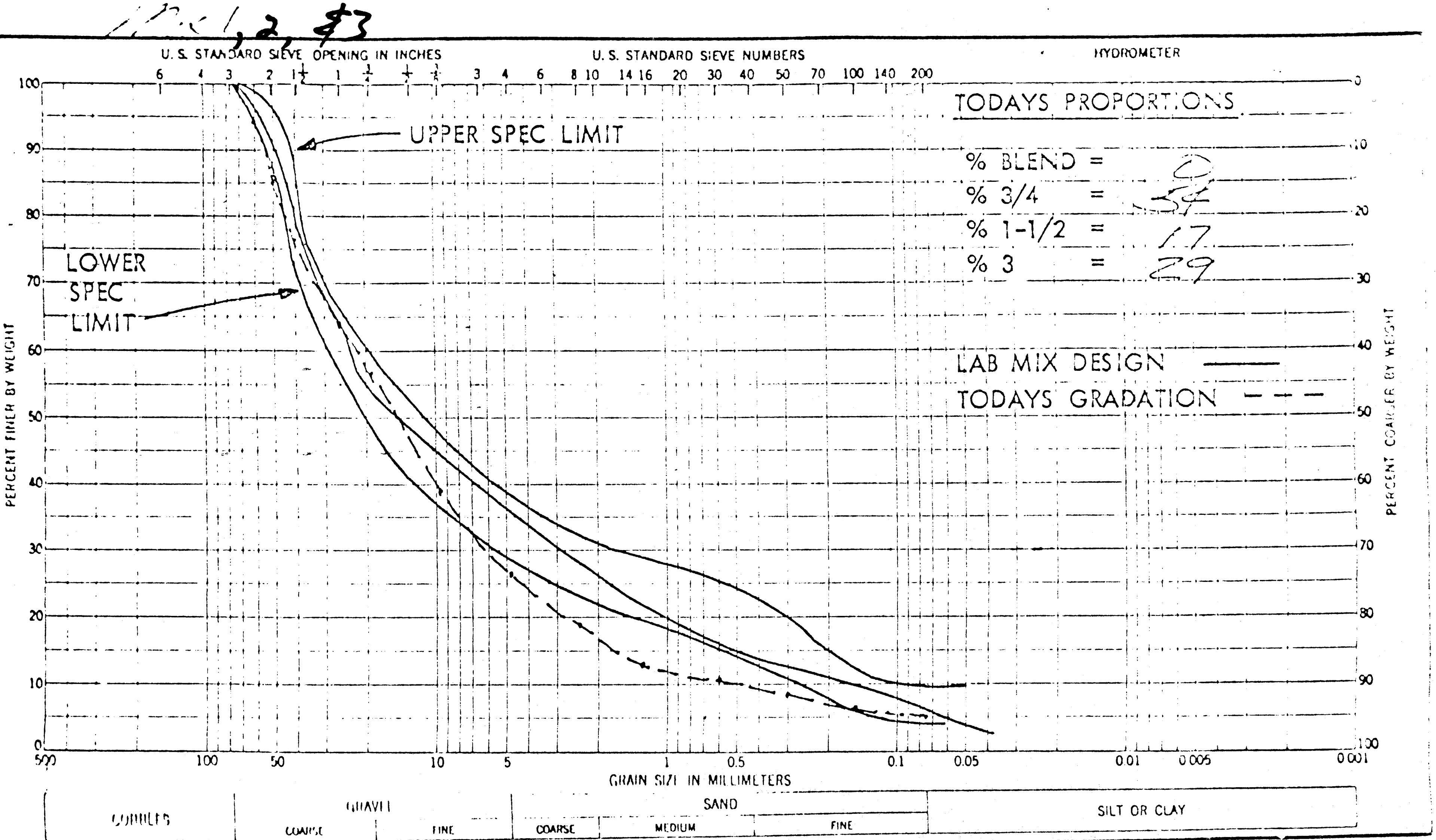
Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM
3-INCH COMBINED GRADATION
Area
Boring No.
Date 8-30-82

GRADATION CURVES

ENG FORM 1 MAY 63 2087

EXHIBIT 4.2
Sheet 14 of 50



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

3-INCH COMBINED GRADATION

Area

Boring No.

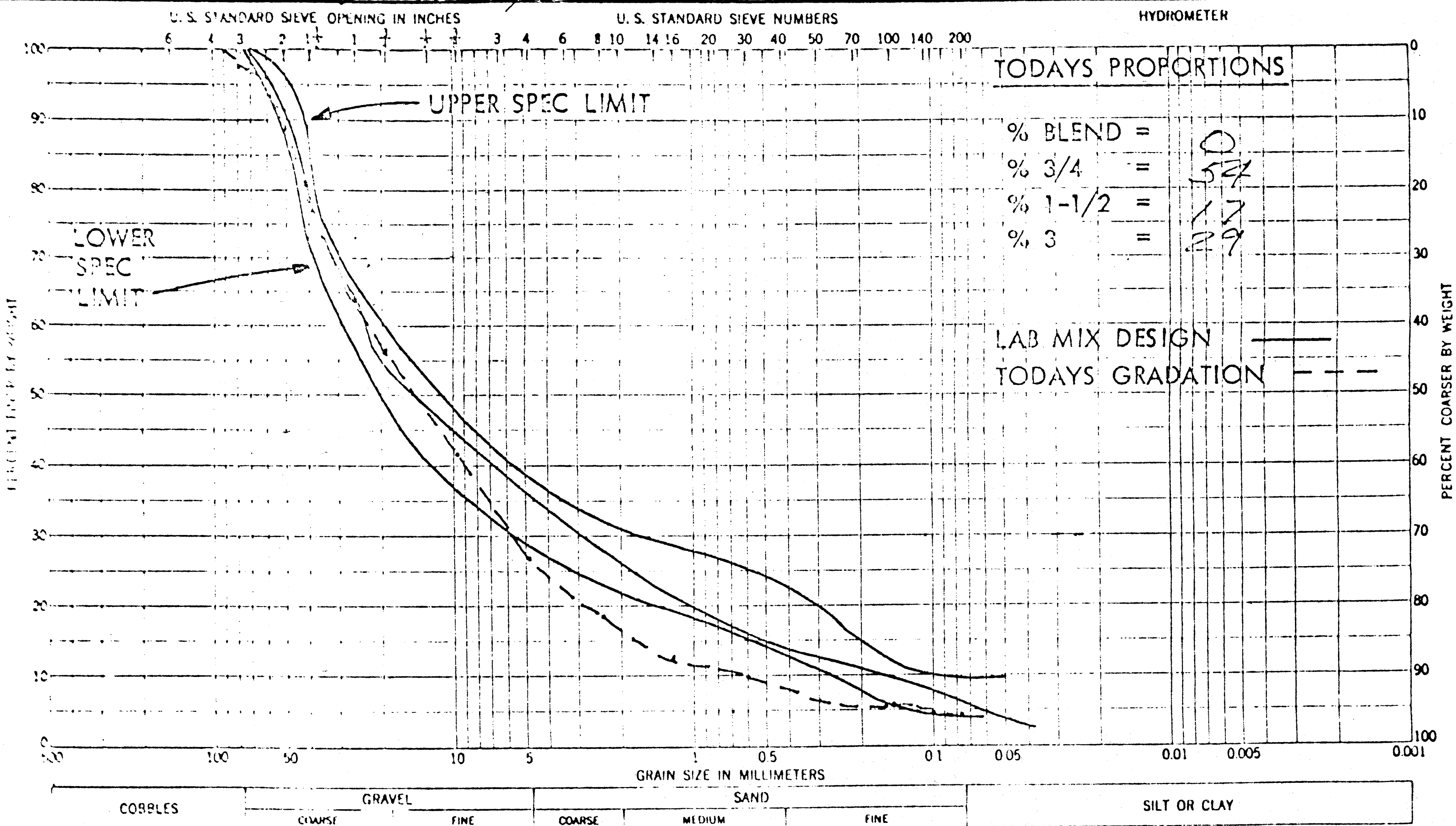
Date 9-13-82

GRADATION CURVES

ENG FORM 1 MAY 63 2087

EXHIBIT 4.2
Sheet 15 of 50

Mix 1&2,3



Sample No	Elev or Depth	Classification	Nat w %	LL	PL	PI

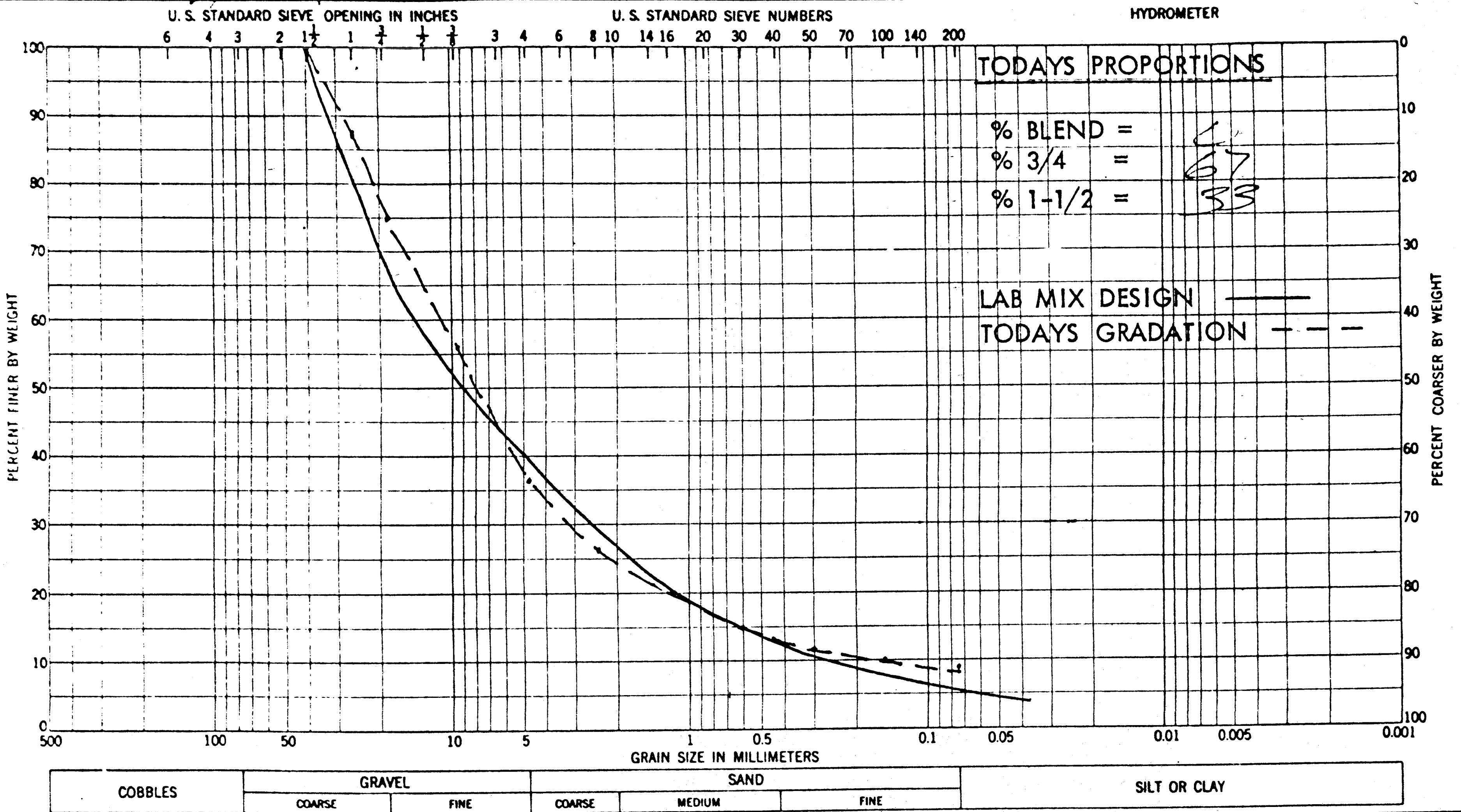
Project WILLOW CREEK DAM
3-INCH COMBINED GRADATION
Area
Boring No
Date 9-20-82

GRADATION CURVES

EXHIBIT 4.2
Sheet 16 of 50

ENG FORM 2087

Mix 4



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

1-1/2-INCH COMBINED GRADATION

Area

Boring No.

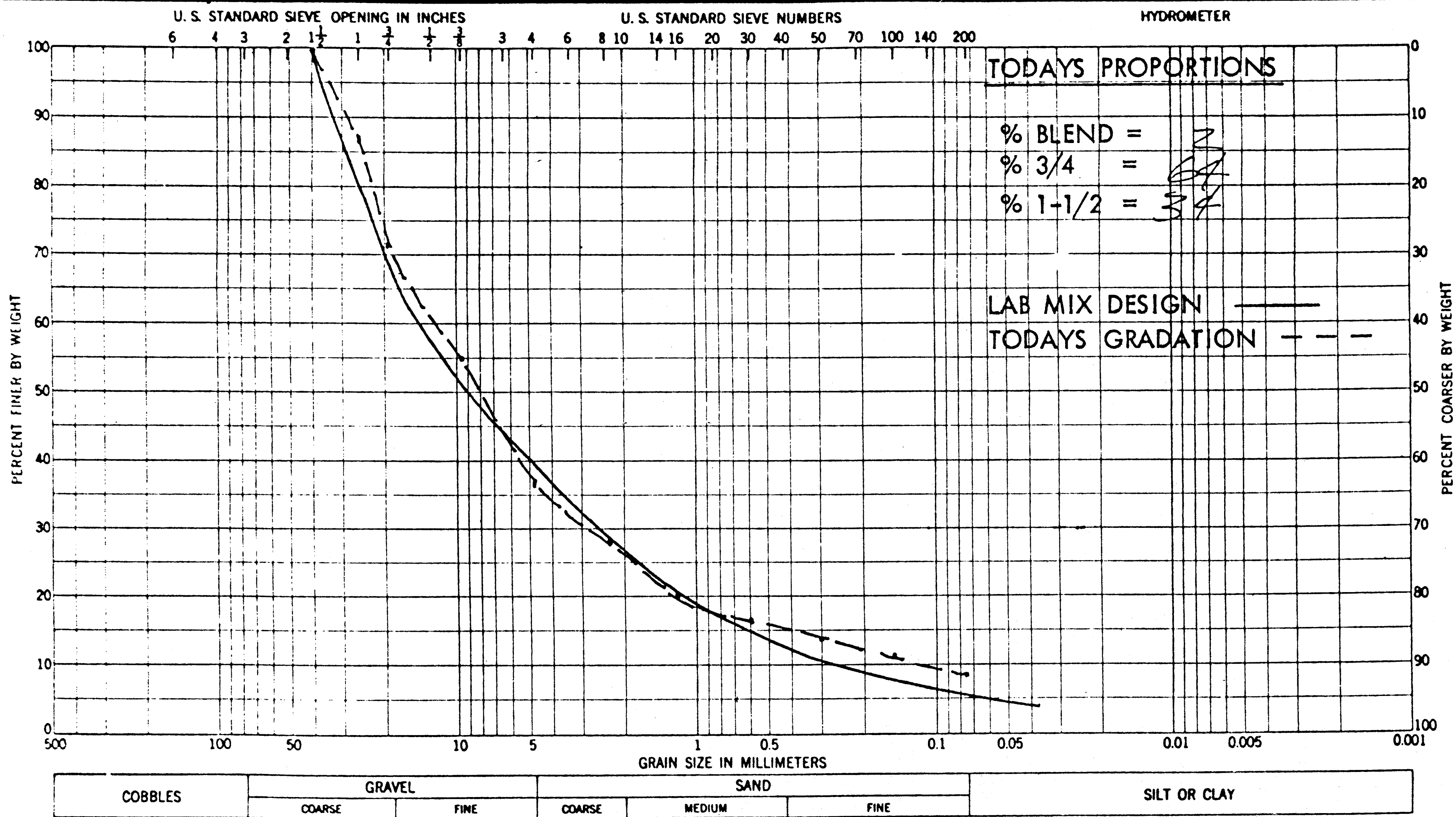
Date 5-3-82

GRADATION CURVES

ENG FORM 1 MAY 63 2087

EXHIBIT 4.2
Sheet 17 of 50

Mix 4



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

1-1/2-INCH COMBINED GRADATION

Area

Boring No.

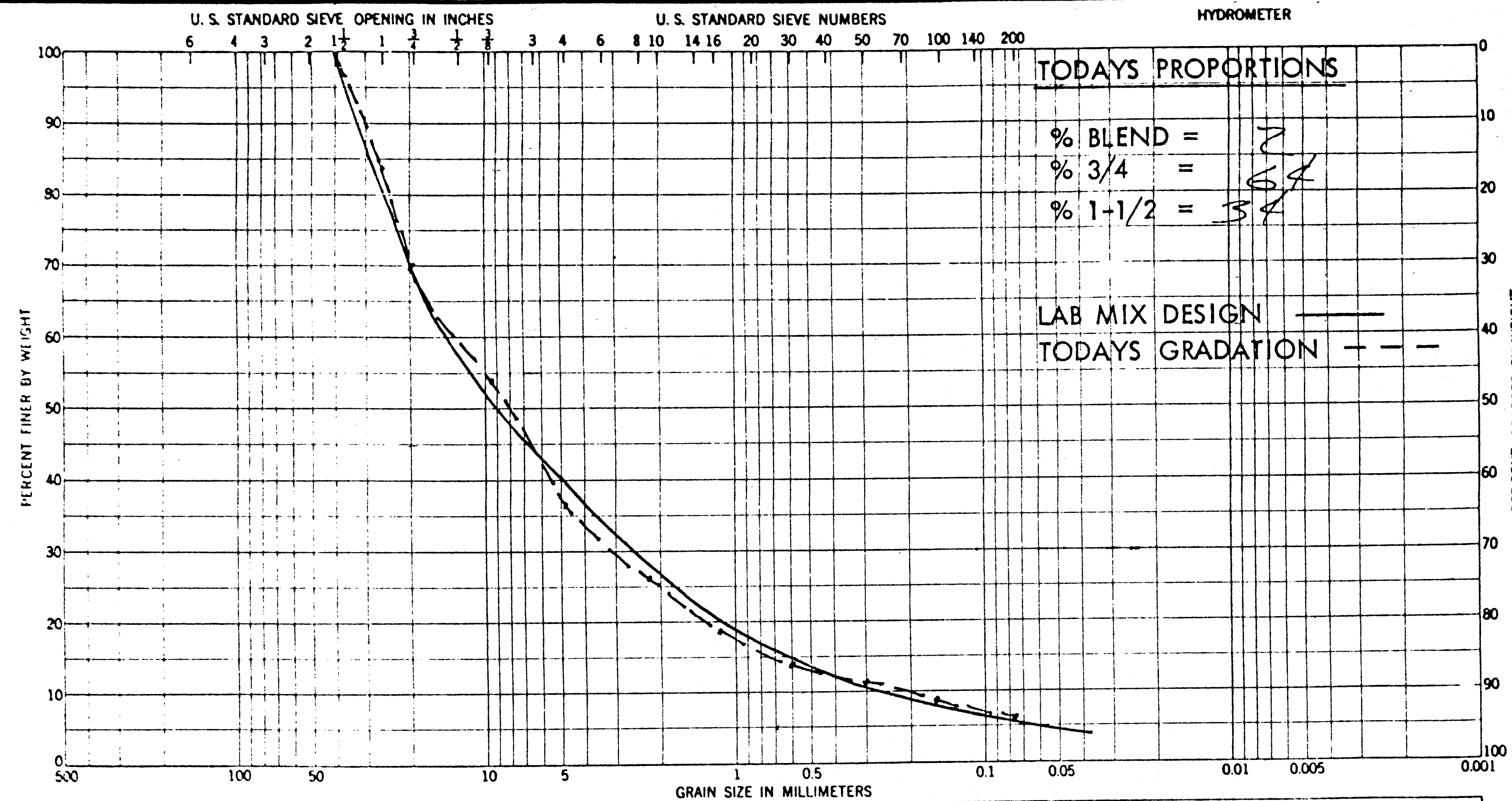
Date 5-10-82

GRADATION CURVES

ENG FORM 1 MAY 63 2087

EXHIBIT 4.2
Sheet 18 of 50

Mix 4



COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

1-1/2-INCH COMBINED GRADATION

Area

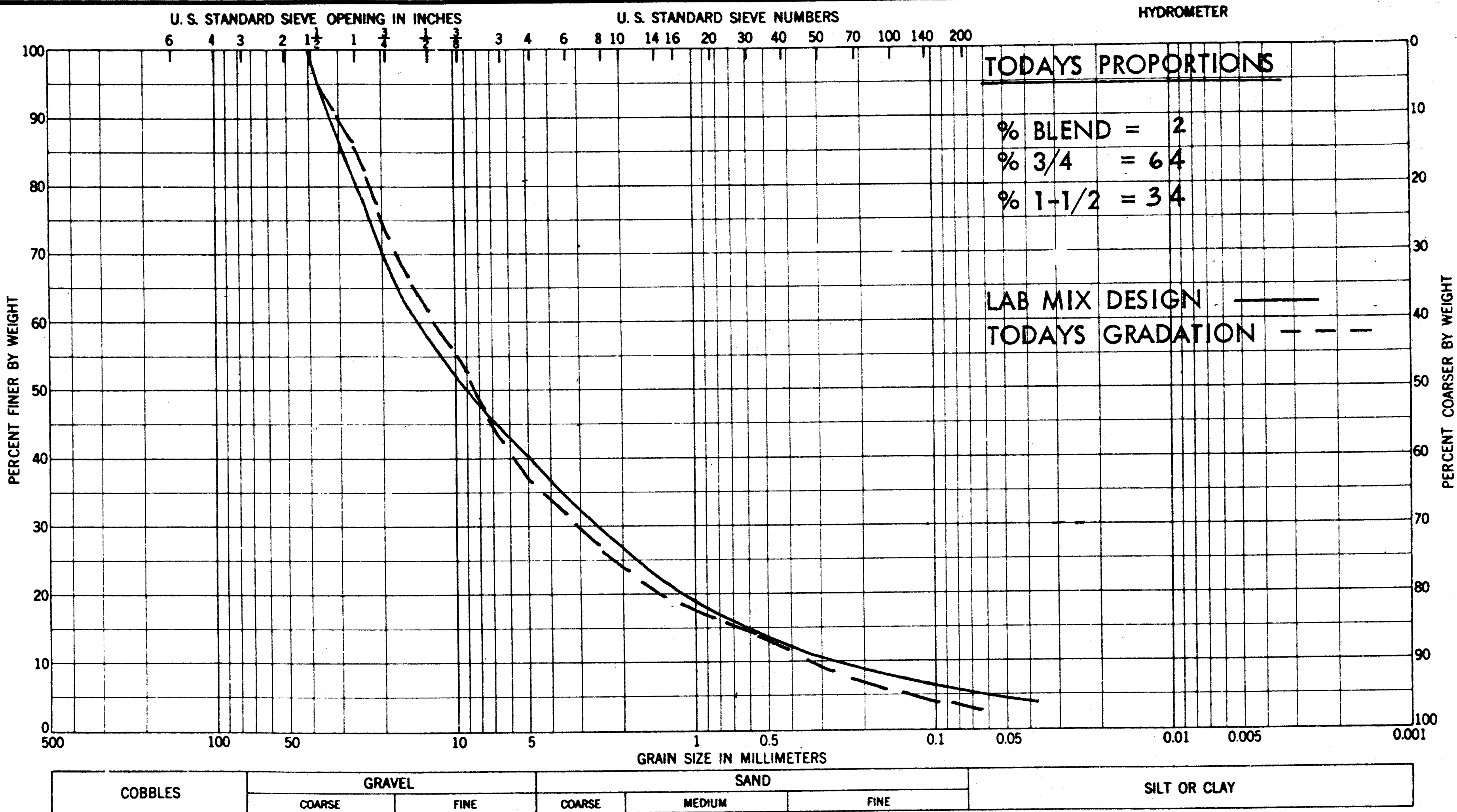
Boring No.

Date 5-17-82

GRADATION CURVES

ENG FORM 1 MAY 63 2087

EXHIBIT 4.2
Sheet 19 of 50



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

1-1/2-INCH COMBINED GRADATION

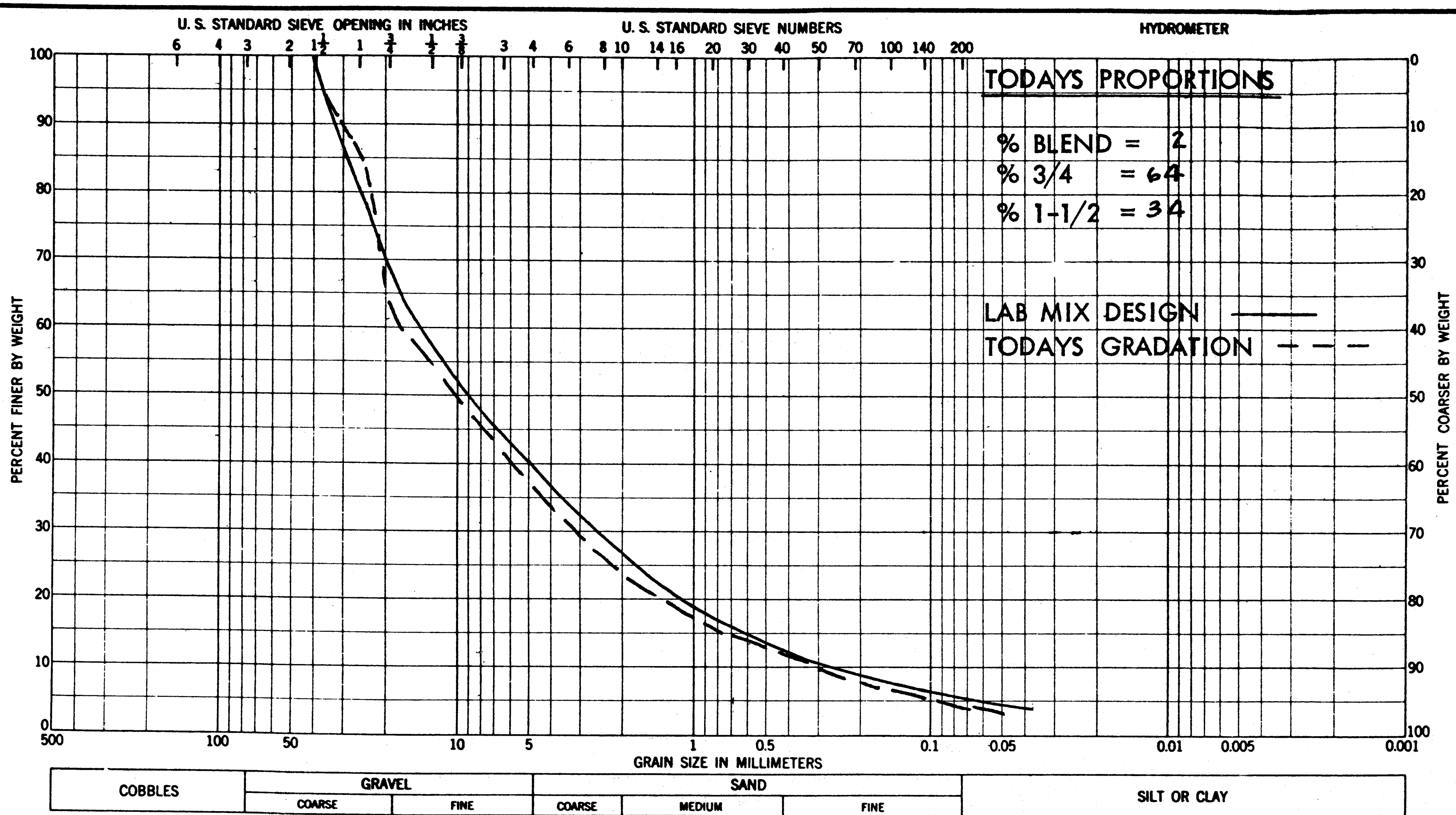
Area

Boring No.

Date 5-24-82

GRADATION CURVES

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

GRADATION CURVES

Project WILLOW CREEK DAM

1-1/2-INCH COMBINED GRADATION

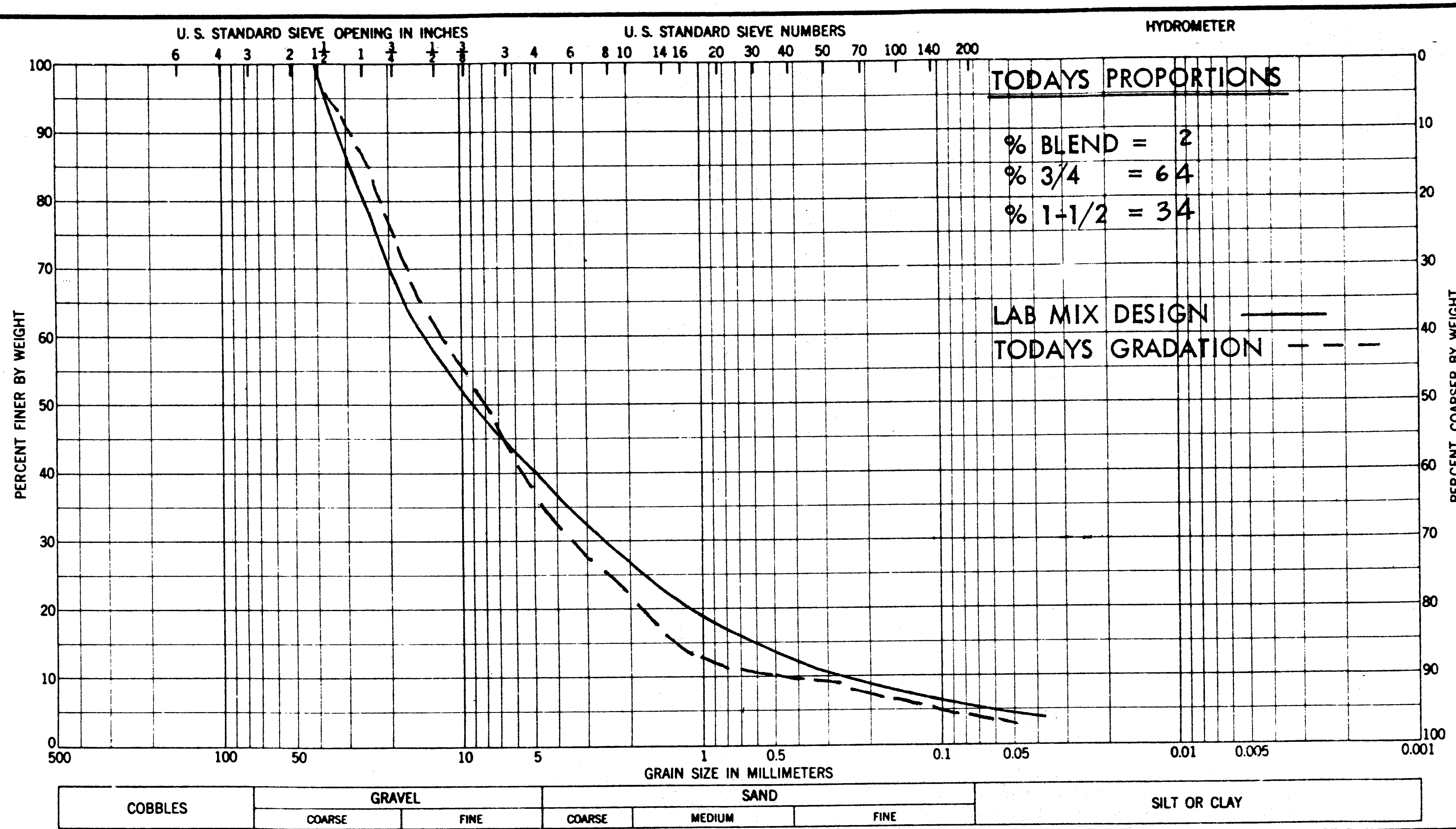
Area

Boring No.

Date 6-7-82

EXHIBIT 4.2
Sheet 21 of 50

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

1-1/2-INCH COMBINED GRADATION

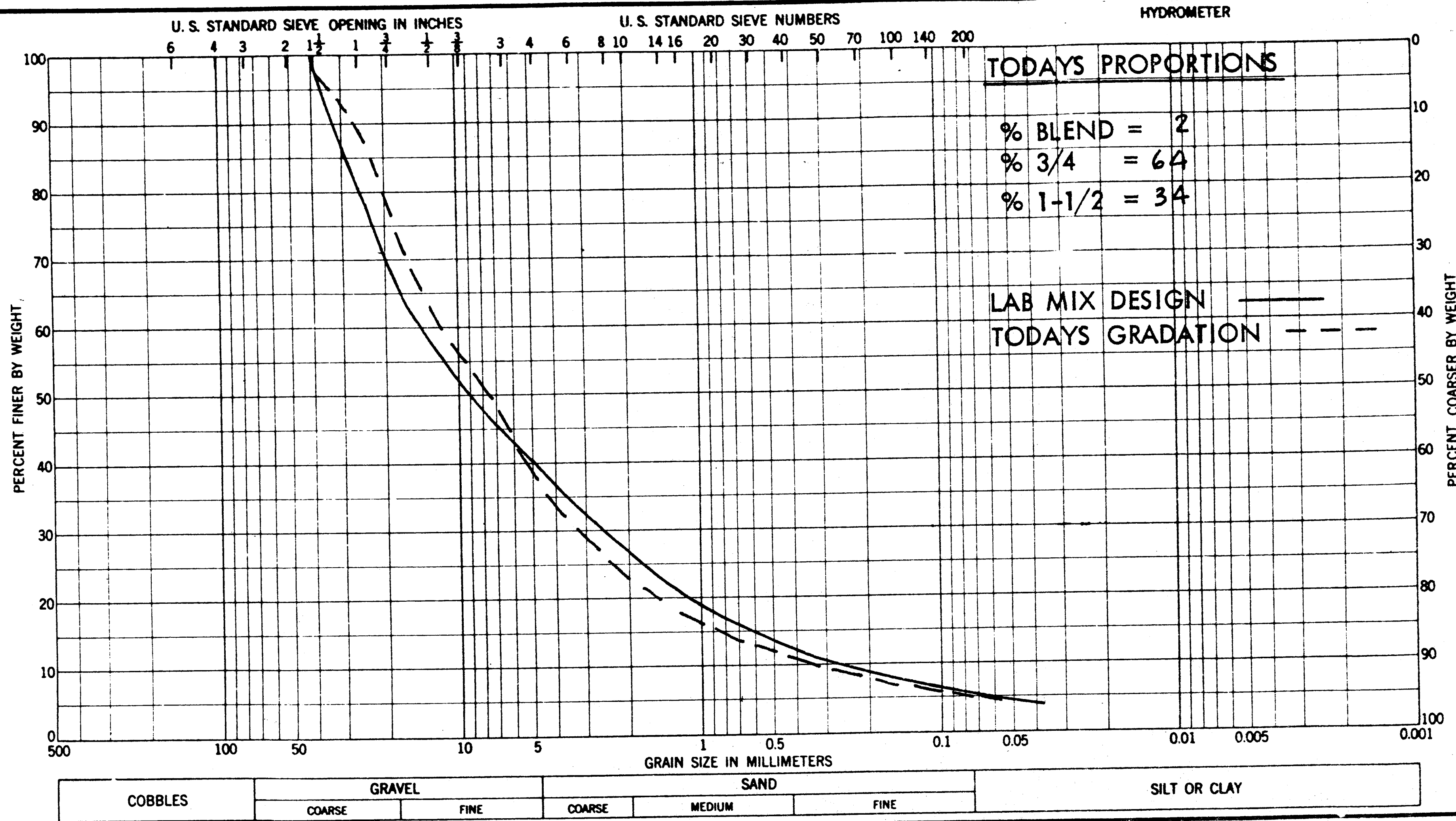
Area

Boring No.

Date 6-14-82

GRADATION CURVES

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

1-1/2-INCH COMBINED GRADATION

Area

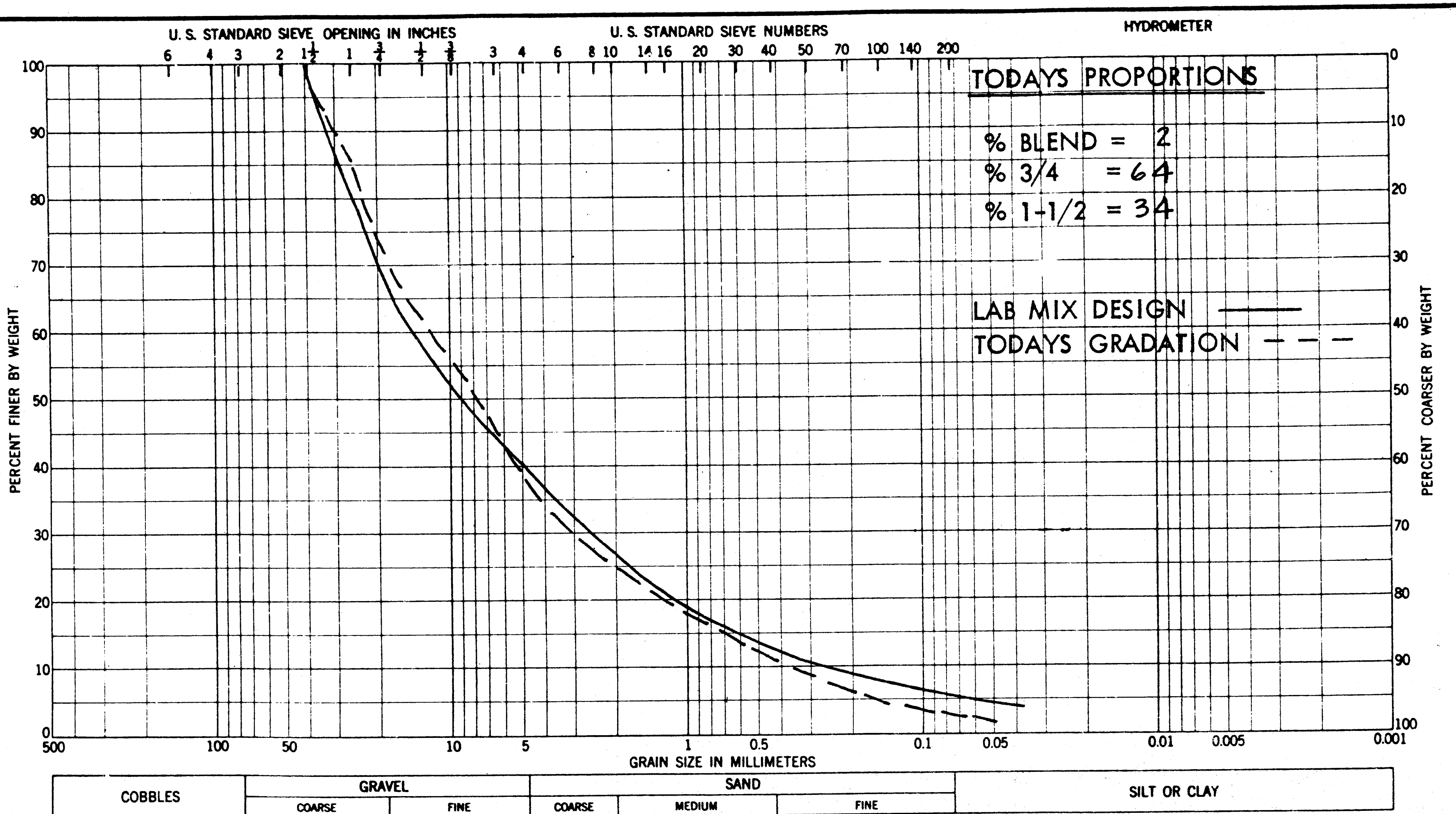
Boring No.

Date 6-21-82

GRADATION CURVES

EXHIBIT 4.2
Sheet 23 of 50

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

1-1/2-INCH COMBINED GRADATION

Area

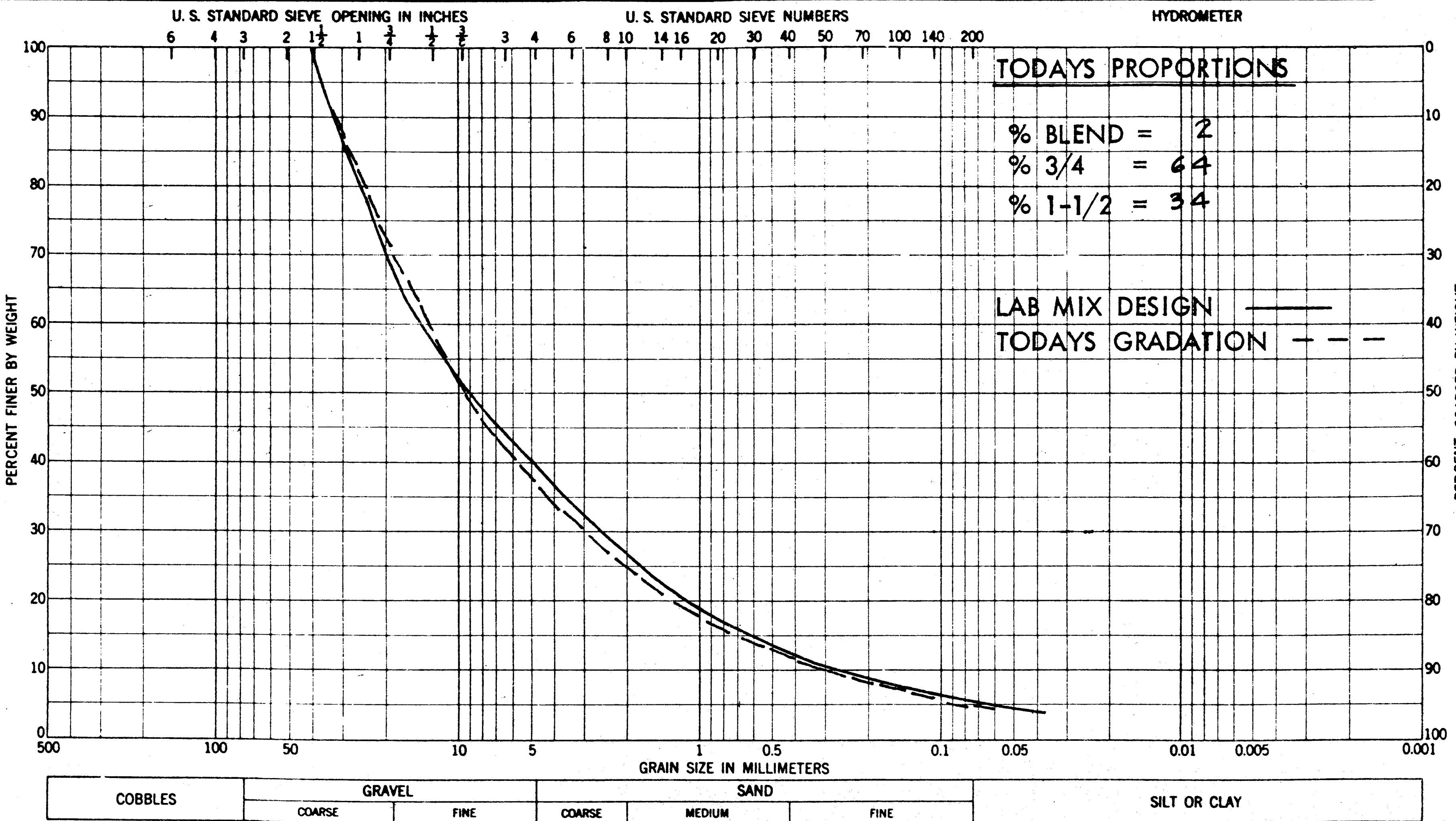
Boring No.

Date 6-21-82

GRADATION CURVES

EXHIBIT 4.2
Sheet 24 of 50

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

1-1/2-INCH COMBINED GRADATION

Area

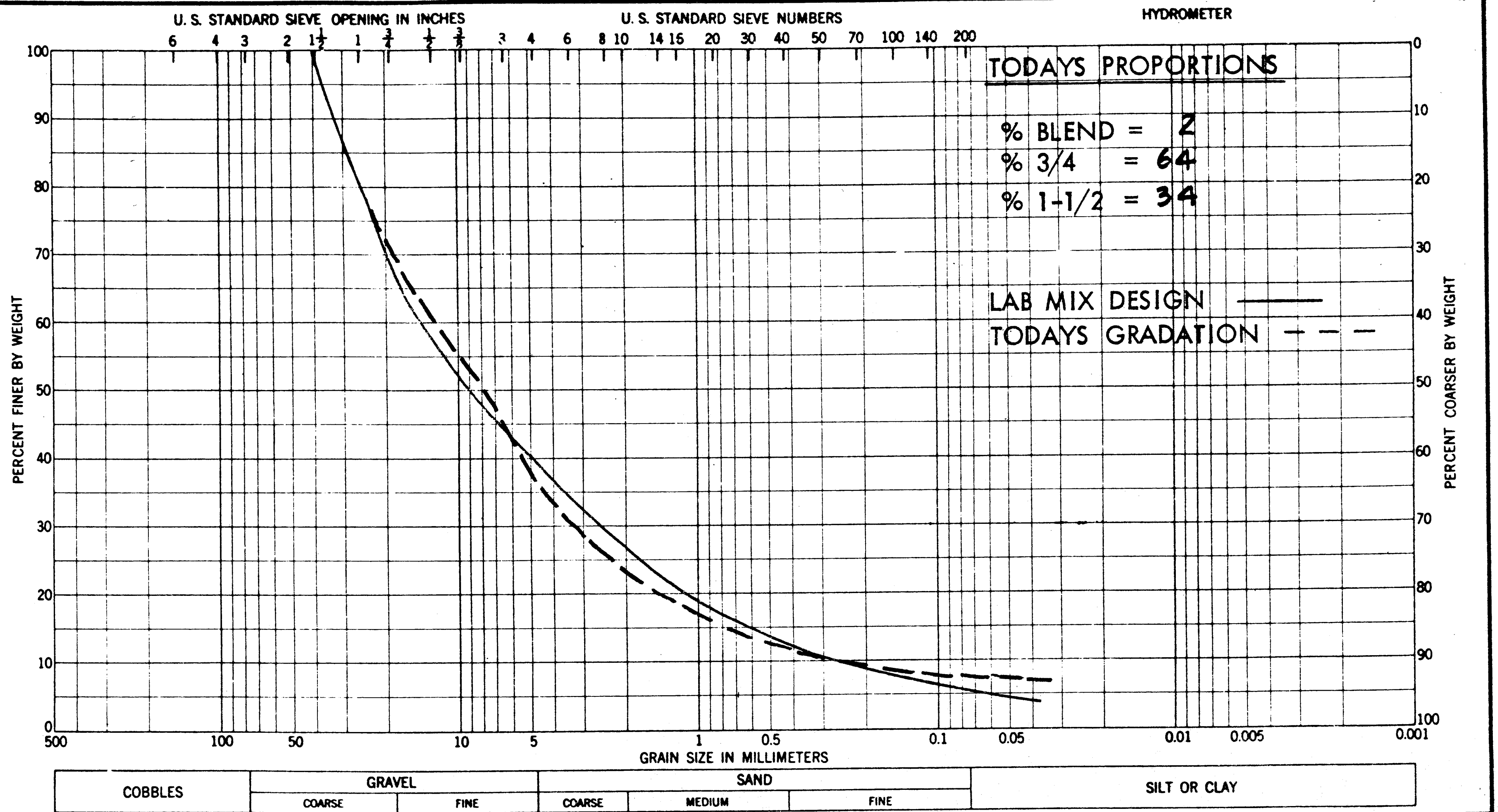
Boring No.

Date 6-28-82

GRADATION CURVES

ENG FORM 1 MAY 63 2087

EXHIBIT 4.2
Sheet 25 of 50



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

1-1/2-INCH COMBINED GRADATION

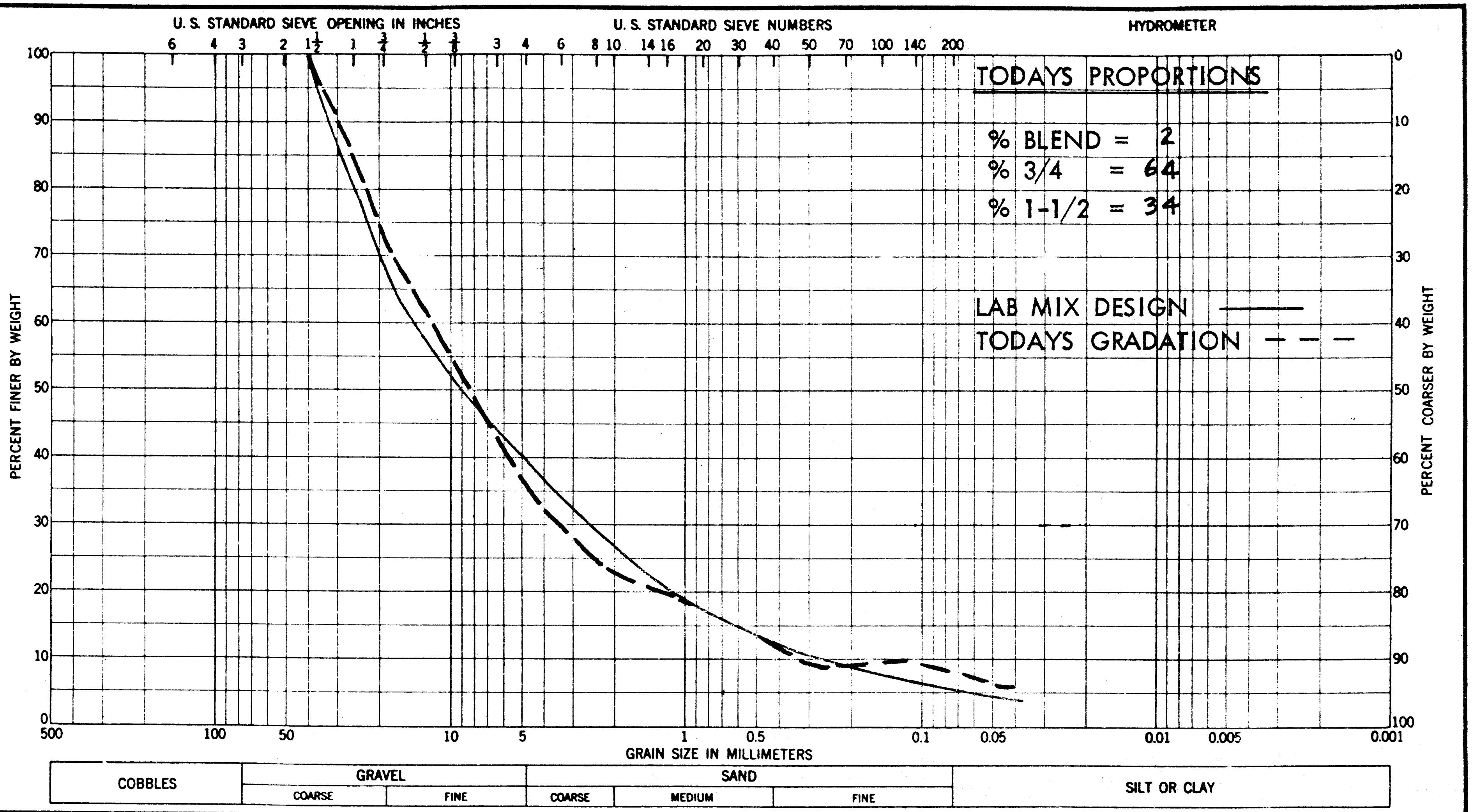
Area

Boring No.

Date 7-12-82

GRADATION CURVES

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

1-1/2-INCH COMBINED GRADATION

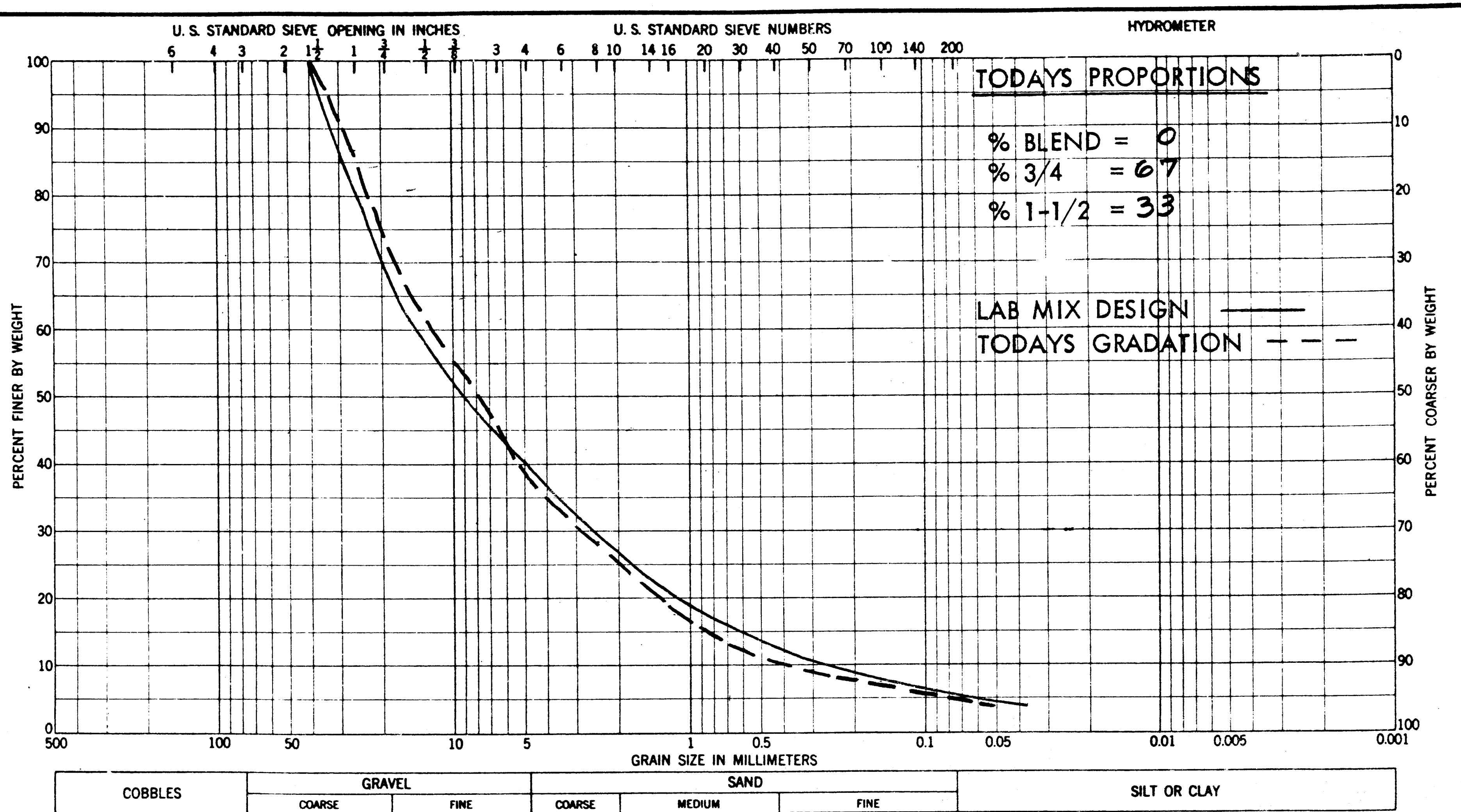
Area

Boring No.

Date 7-19-82

GRADATION CURVES

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

1-1/2-INCH COMBINED GRADATION

Area

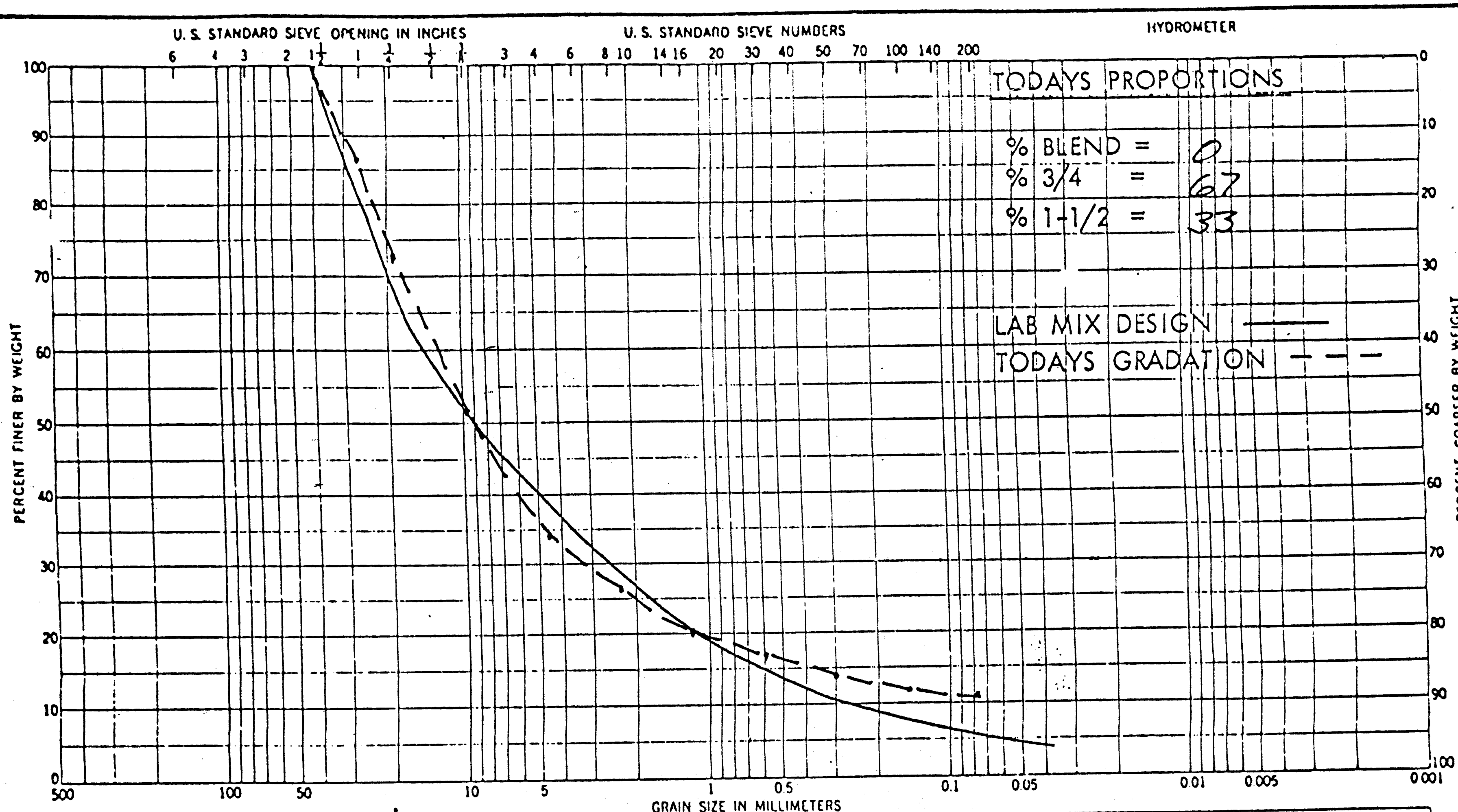
Boring No.

Date 7-26-82

GRADATION CURVES

EXHIBIT 4.2
Sheet 28 of 50

ENG FORM 1 MAY 63 2087



COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

1-1/2-INCH COMBINED GRADATION

Area

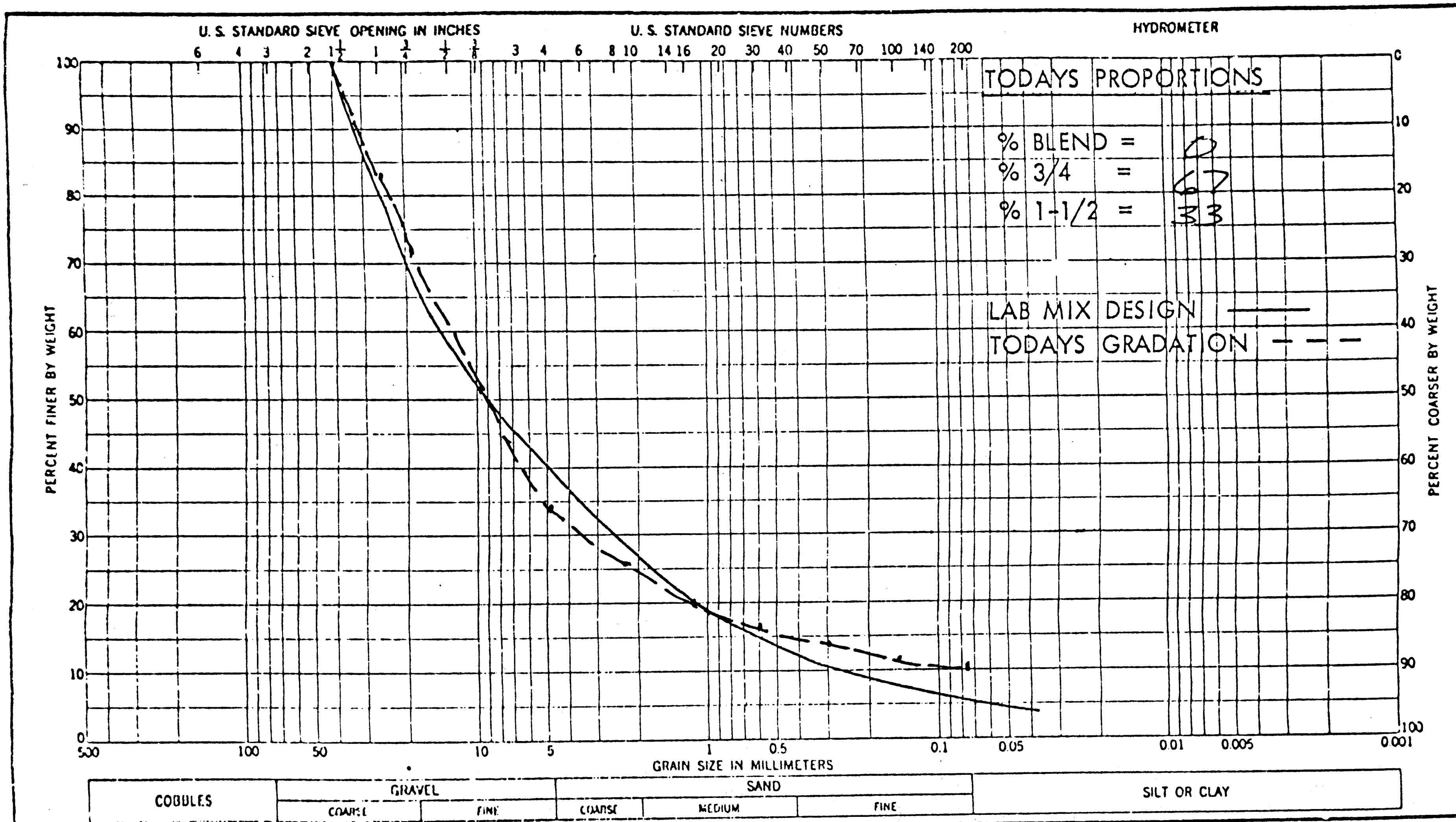
Boring No.

Date 8-2-82

GRADATION CURVES

ENG FORM 1 MAY 63 2087

EXHIBIT 4.2
Sheet 29 of 50



Sample No	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

1-1/2-INCH COMBINED GRADATION

Area

Boring No.

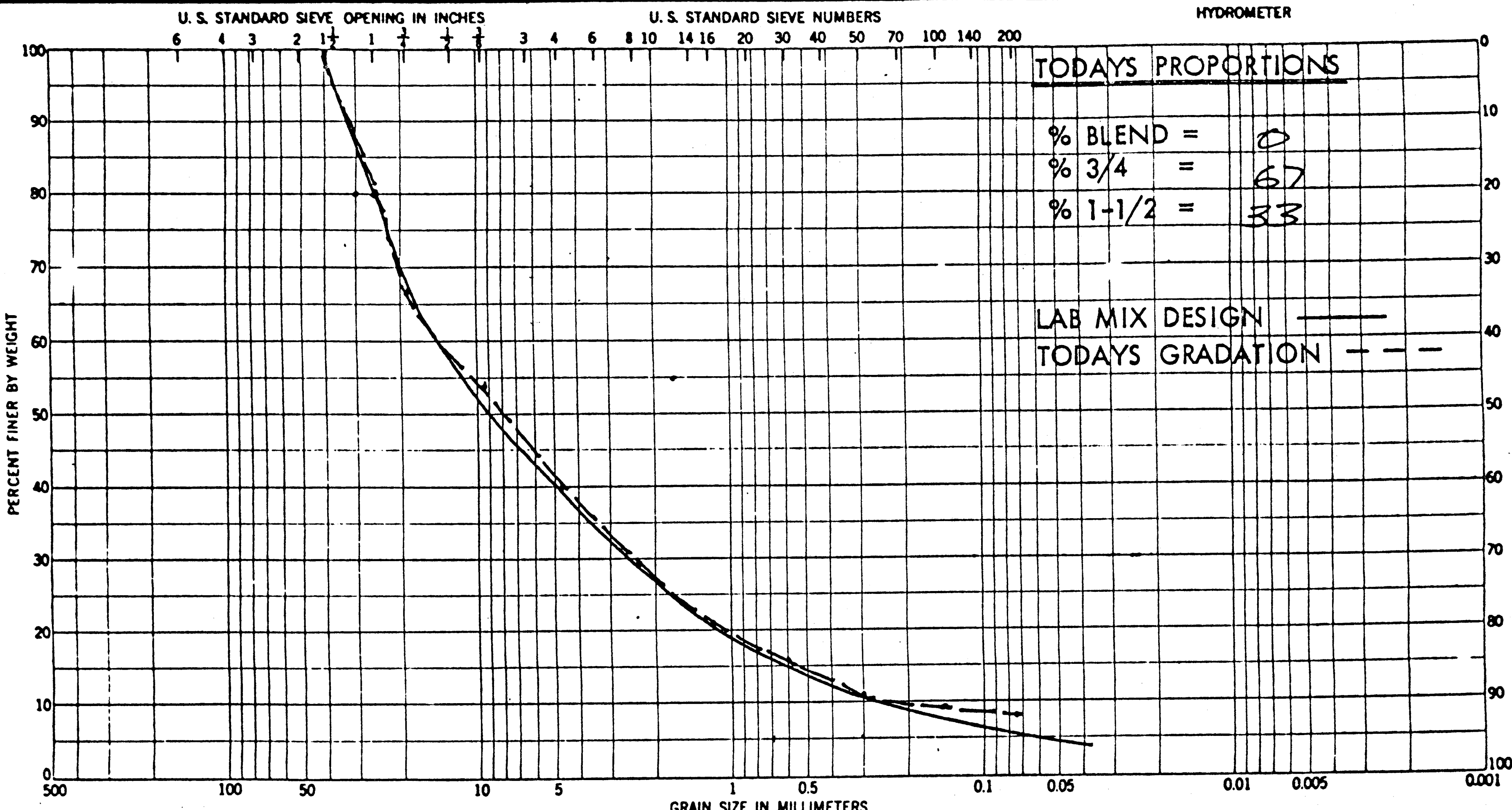
Date 8-9-82

GRADATION CURVES

ENG FORM 1 MAY 63 2087

EXHIBIT 4.2
Sheet 30 of 50

Mix 4



COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

1-1/2-INCH COMBINED GRADATION

Area

Boring No.

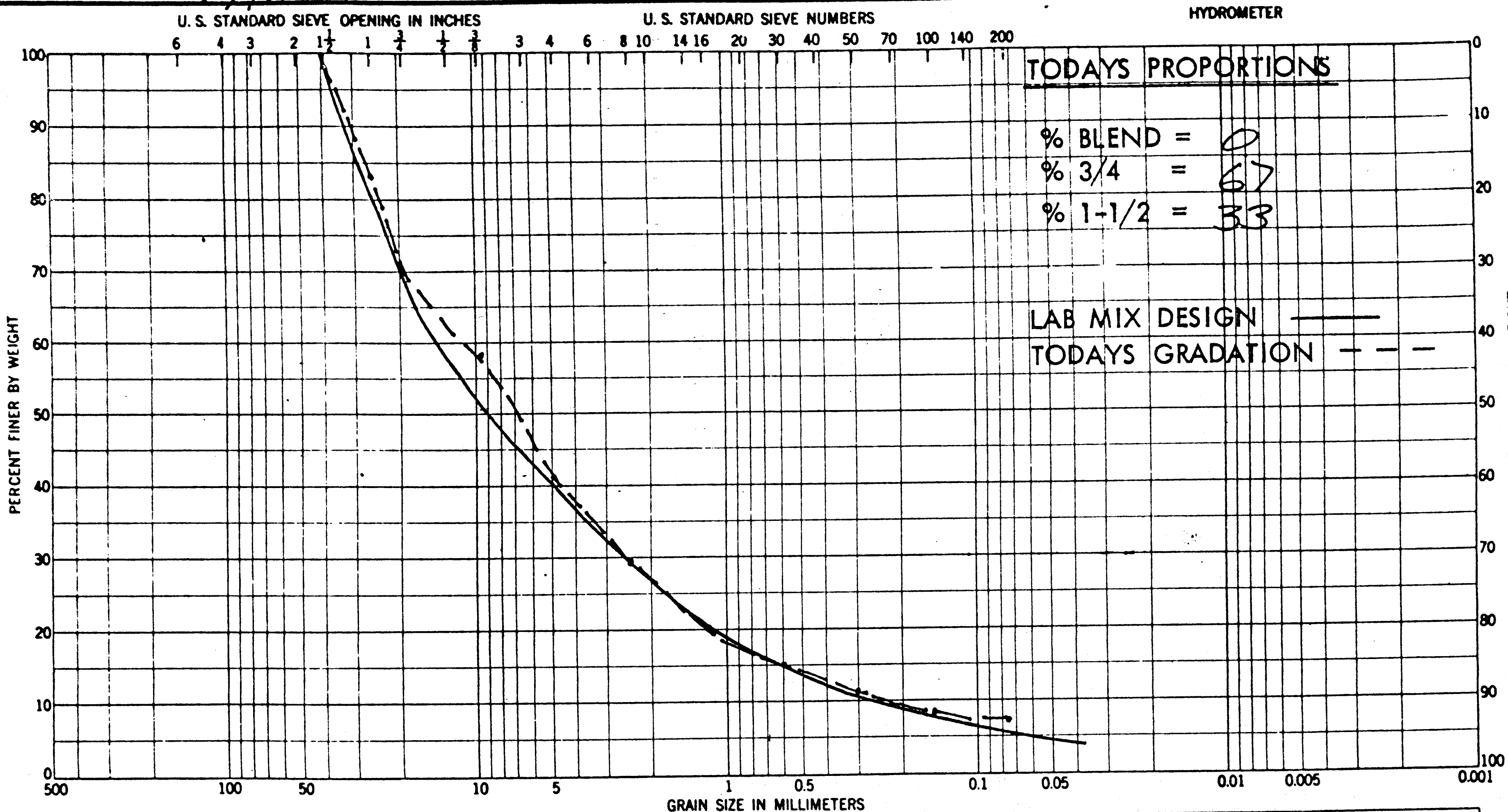
Date 8-16-82

GRADATION CURVES

ENG FORM 1 MAY 63 2087

EXHIBIT 4.2
Sheet 31 of 50

Mix 4



COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

1-1/2-INCH COMBINED GRADATION

Area

Boring No.

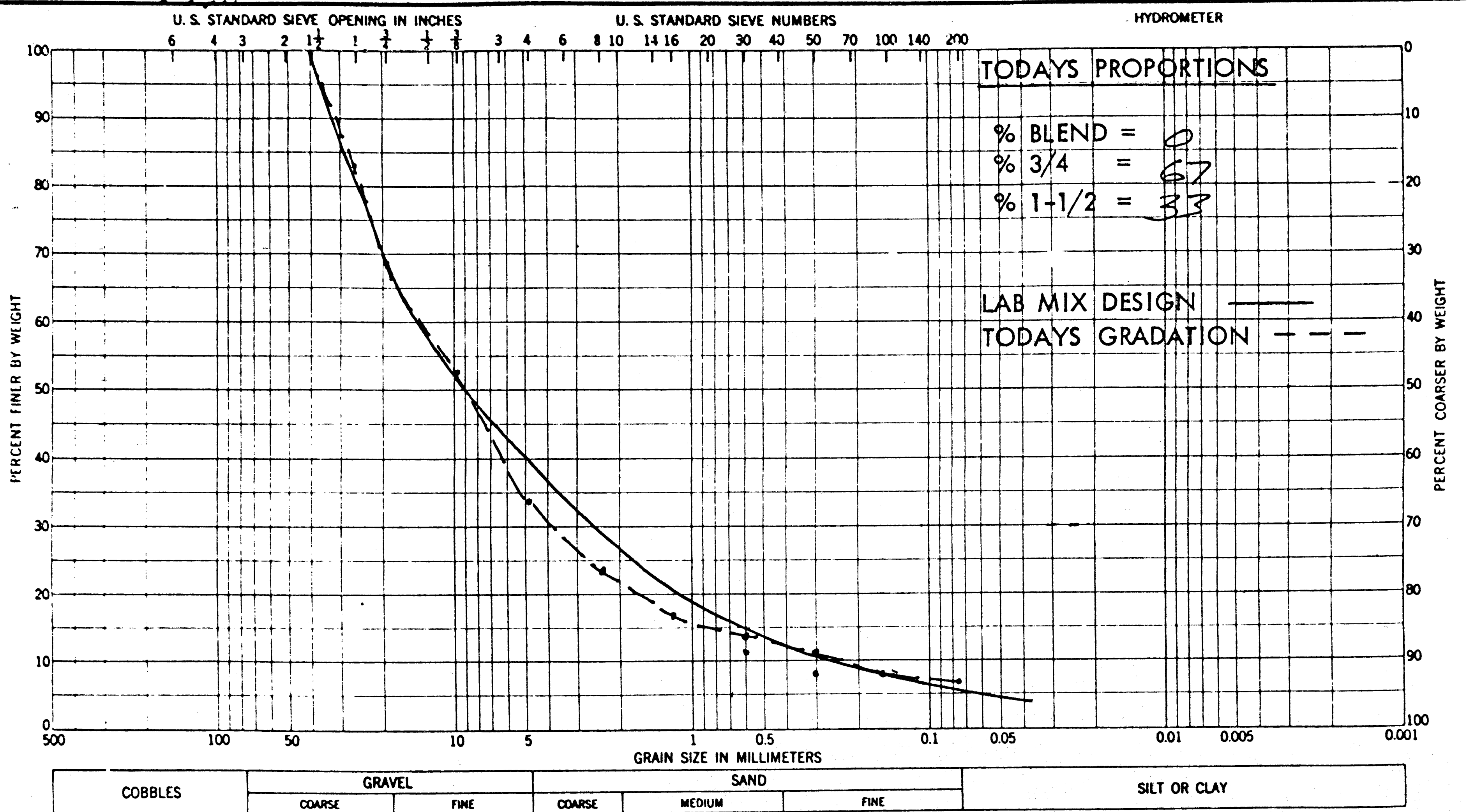
Date 8-23-82

GRADATION CURVES

ENG FORM 1 MAY 63 2087

EXHIBIT 4.2
Sheet 32 of 50

Mix 4



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

1-1/2-INCH COMBINED GRADATION

Area

Boring No.

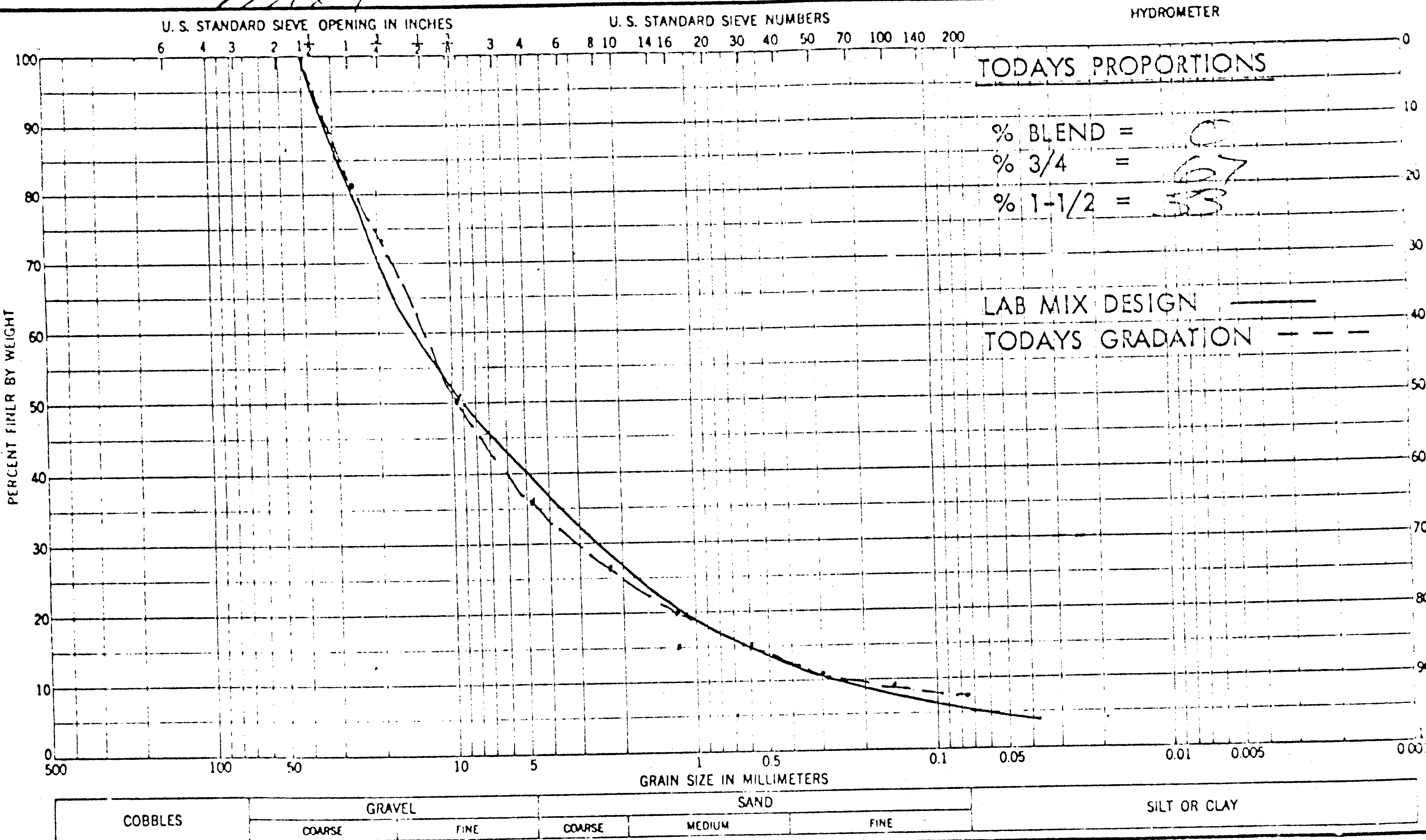
Date 8-30-82

GRADATION CURVES

ENG FORM 1 MAY 63 2087

EXHIBIT 4.2
Sheet 33 of 50

Mix 4



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

1-1/2-INCH COMBINED GRADATION

Area

Boring No.

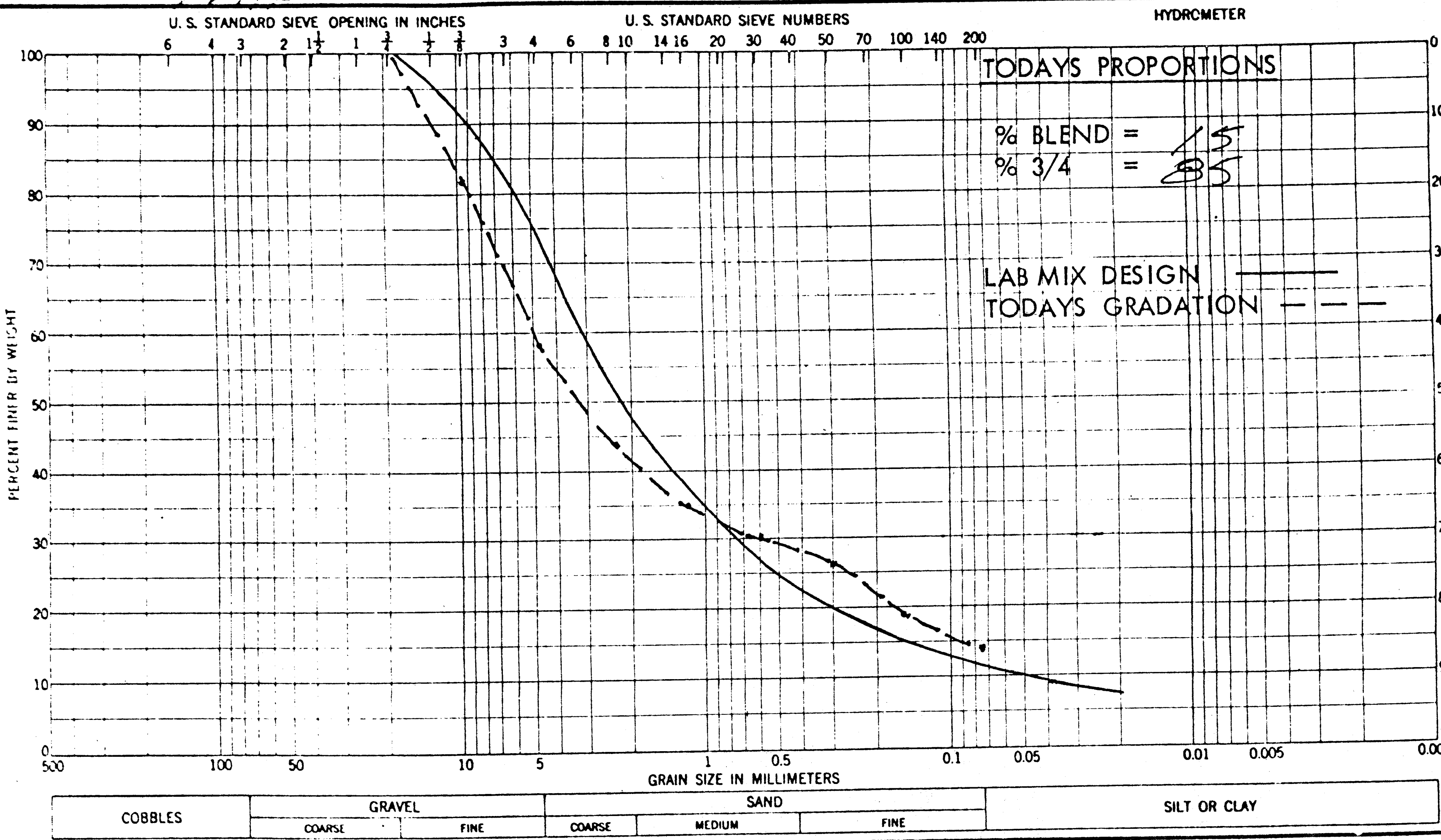
Date 9-13-82

GRADATION CURVES

ENG FORM 1 MAY 63 2087

EXHIBIT 4.2
Sheet 34 of 50

Mix 5



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

3/4-INCH COMBINED GRADATION

Area

Boring No.

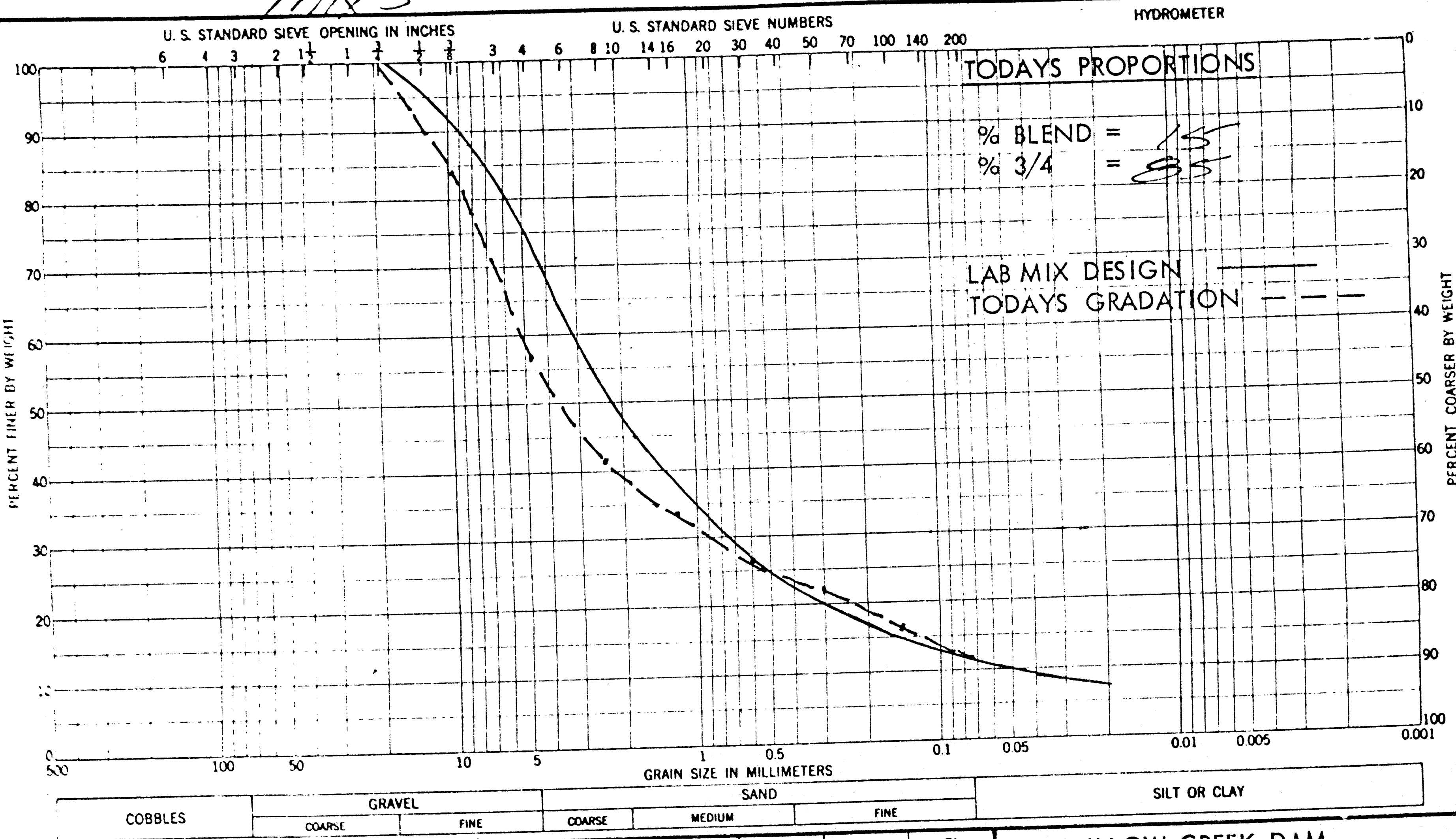
Date 5-10-87

GRADATION CURVES

ENG FORM 1 MAY 63 2087

EXHIBIT 4.2
Sheet 35 of 50

mix 5



Sample No	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

3/4-INCH COMBINED GRADATION

Area

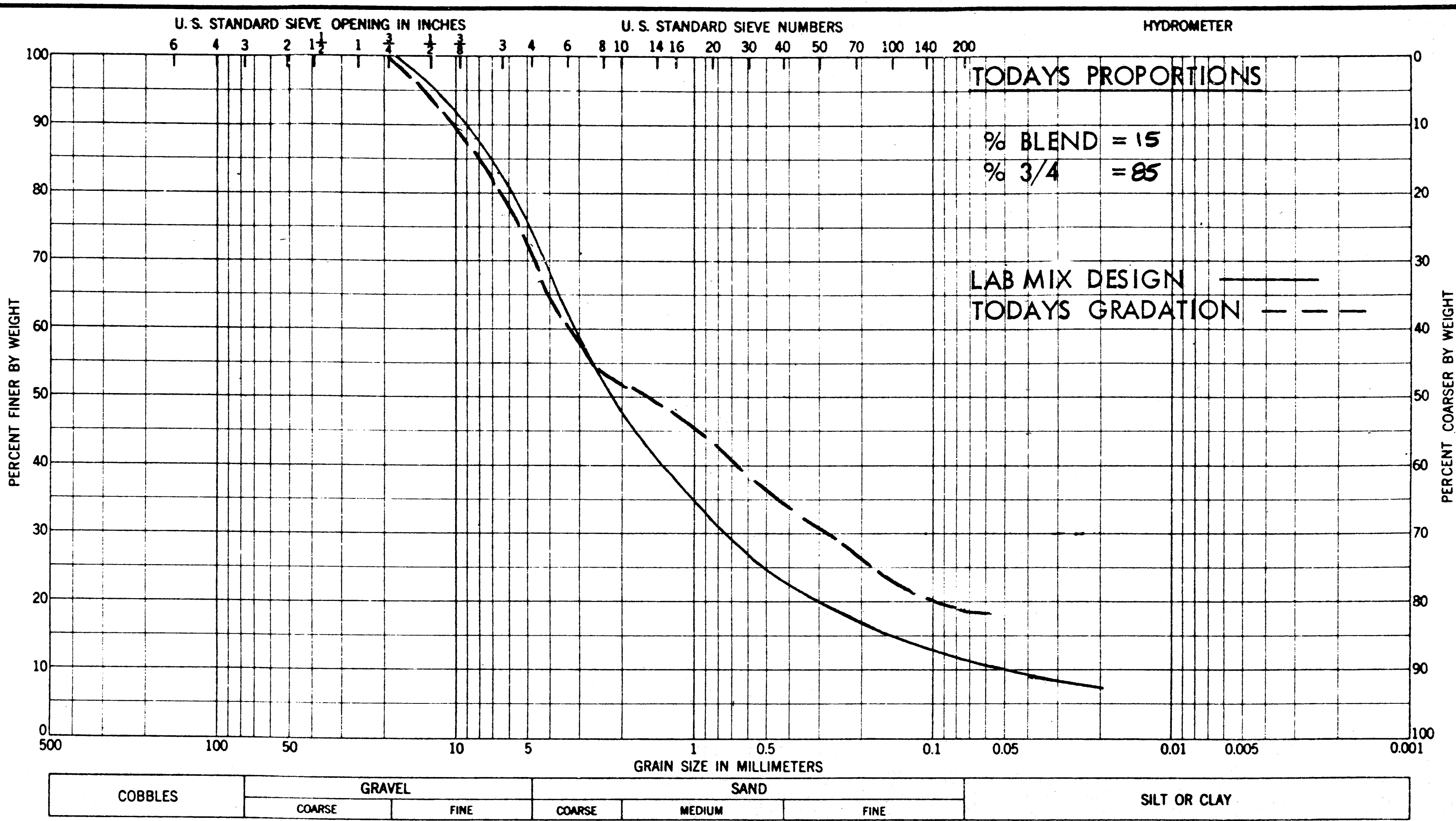
Boring No

Date 5-17-82

GRADATION CURVES

ENG FORM 1 MAY 63 2087

EXHIBIT 4.2
Sheet 36 of 50



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

3/4-INCH COMBINED GRADATION

Area

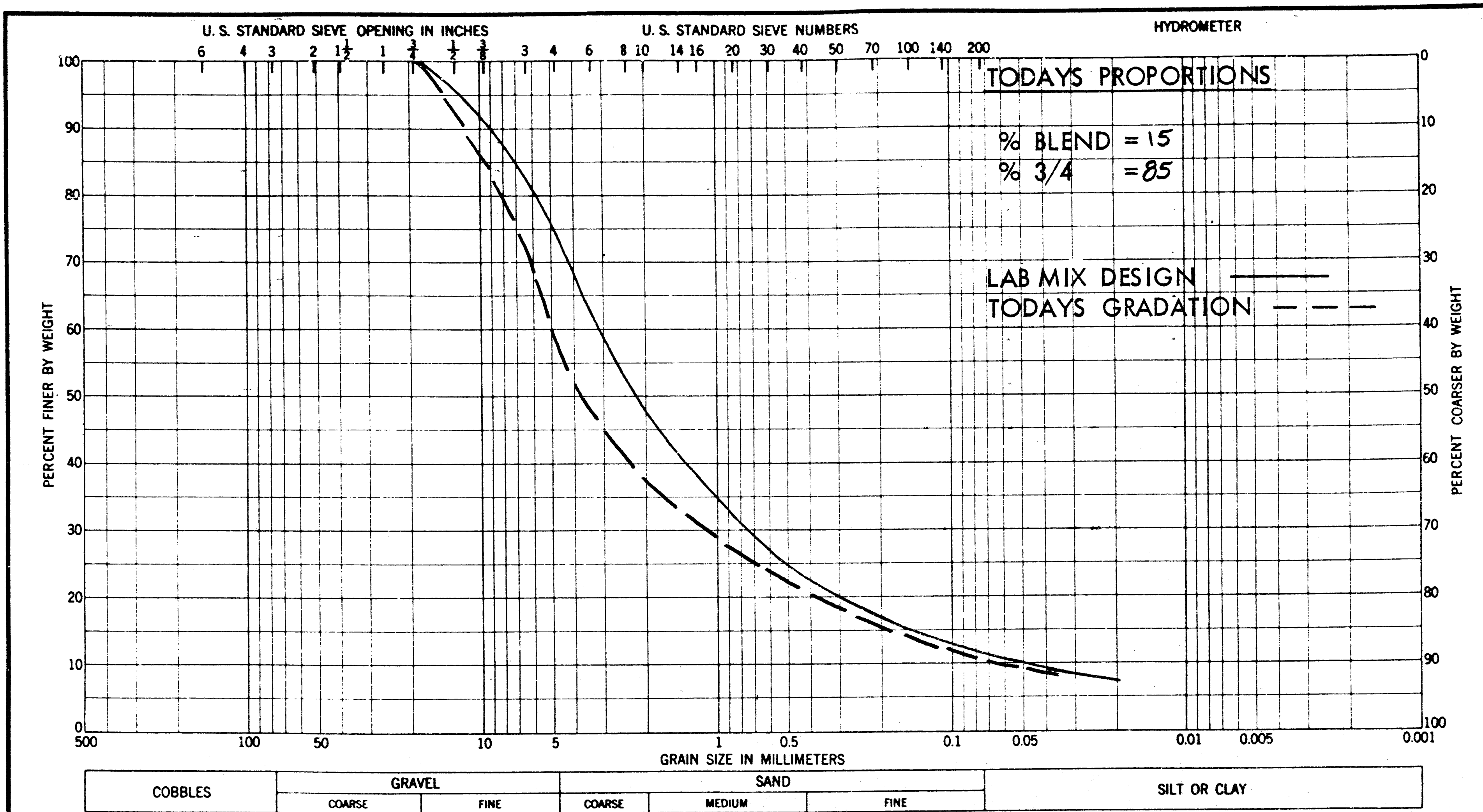
Boring No.

Date 6-7-82

GRADATION CURVES

ENG FORM 1 MAY 63 2087

EXHIBIT 4.2
Sheet 37 of 50



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

3/4-INCH COMBINED GRADATION

Area

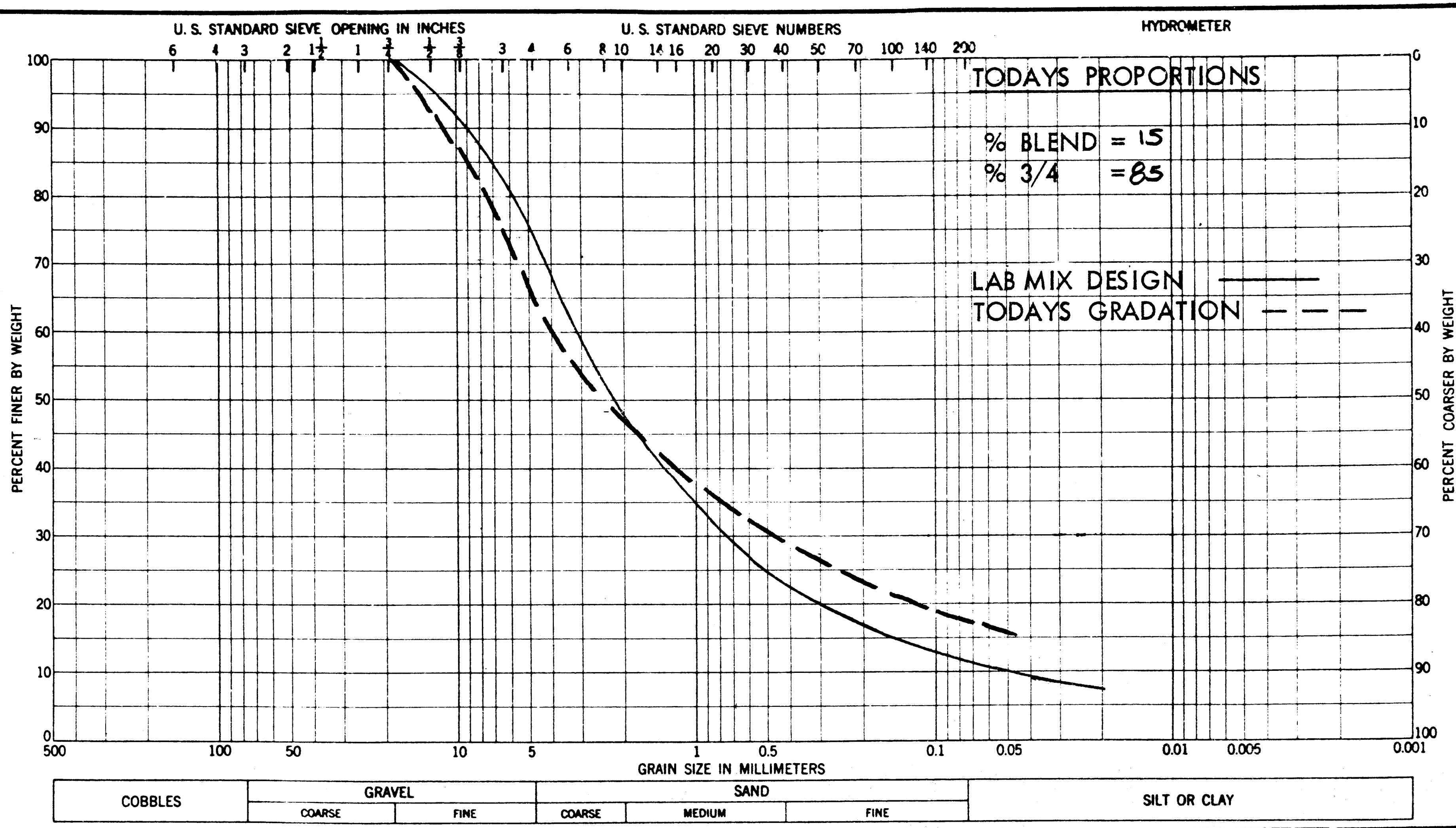
Boring No.

Date 6-14-82

GRADATION CURVES

ENG FORM 1 MAY 63 2087

EXHIBIT 4.2
Sheet 38 of 50



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

GRADATION CURVES

Project WILLOW CREEK DAM

3/4-INCH COMBINED GRADATION

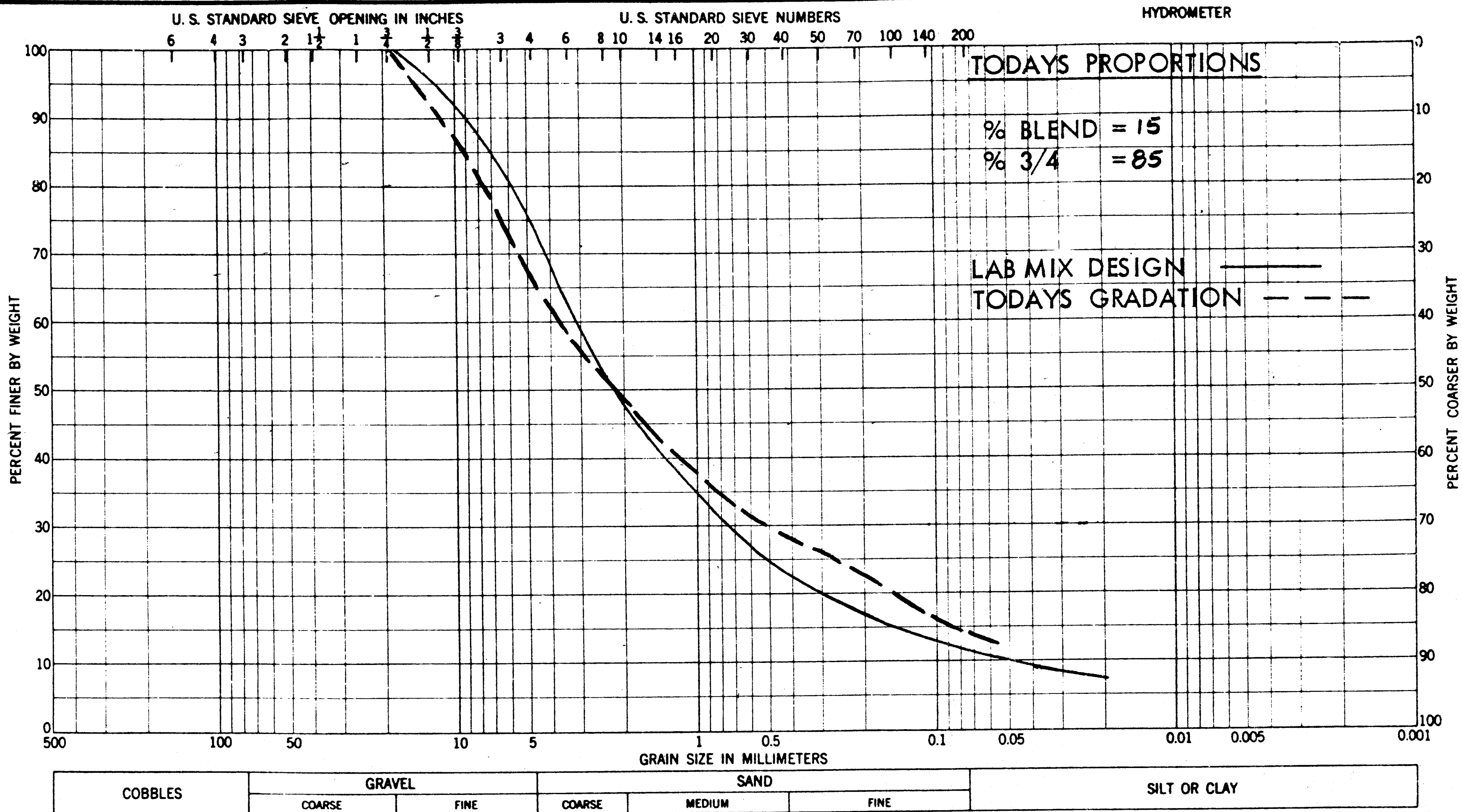
Area

Boring No.

Date 6-21-85

ENG FORM 1 MAY 63 2087

EXHIBIT 4.2
Sheet 39 of 50



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

3/4-INCH COMBINED GRADATION

Area

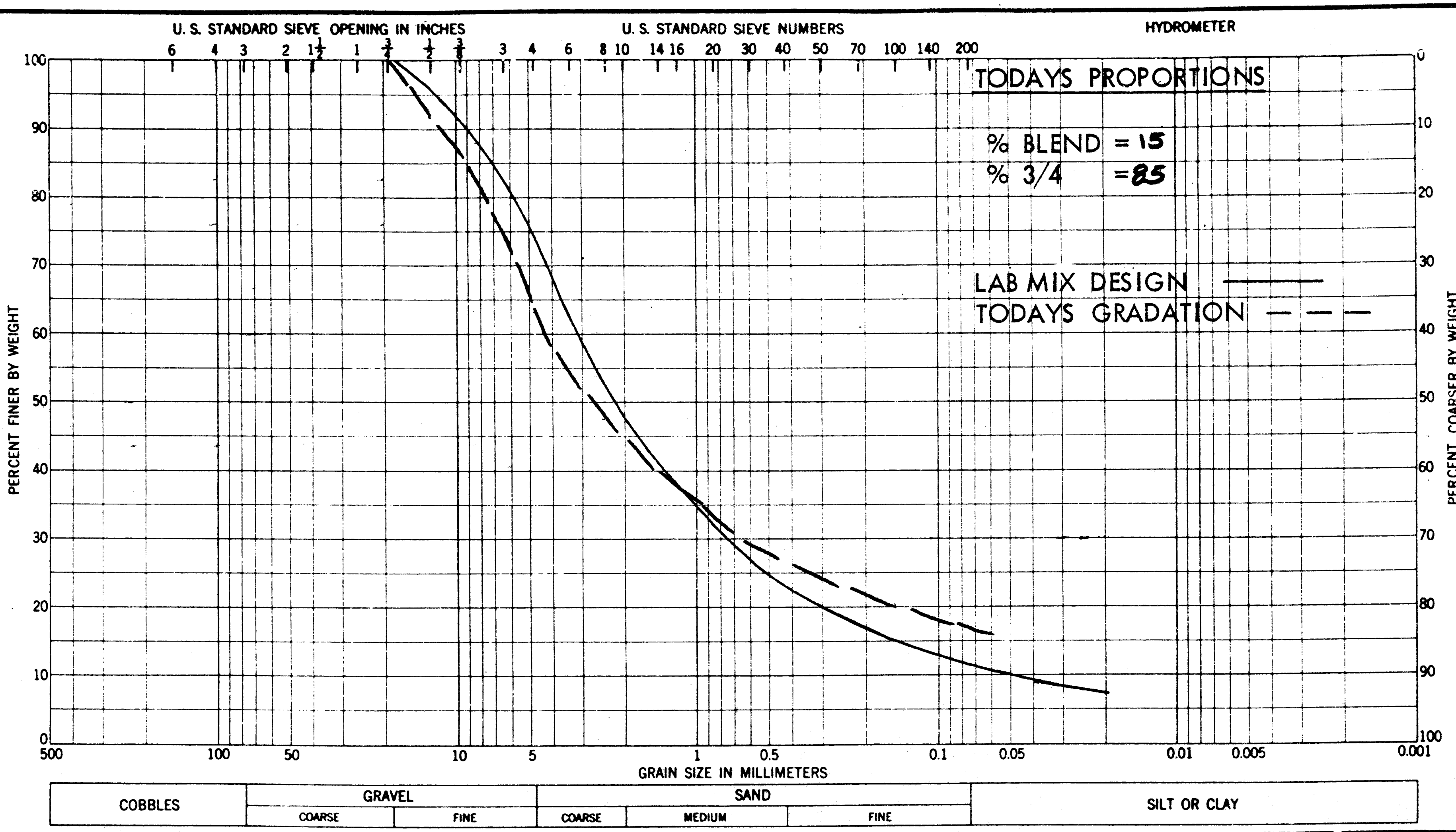
Boring No.

Date 6-28-82

GRADATION CURVES

ENG FORM 1 MAY 63 2087

EXHIBIT 4.2
Sheet 40 of 50



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

GRADATION CURVES

Project WILLOW CREEK DAM

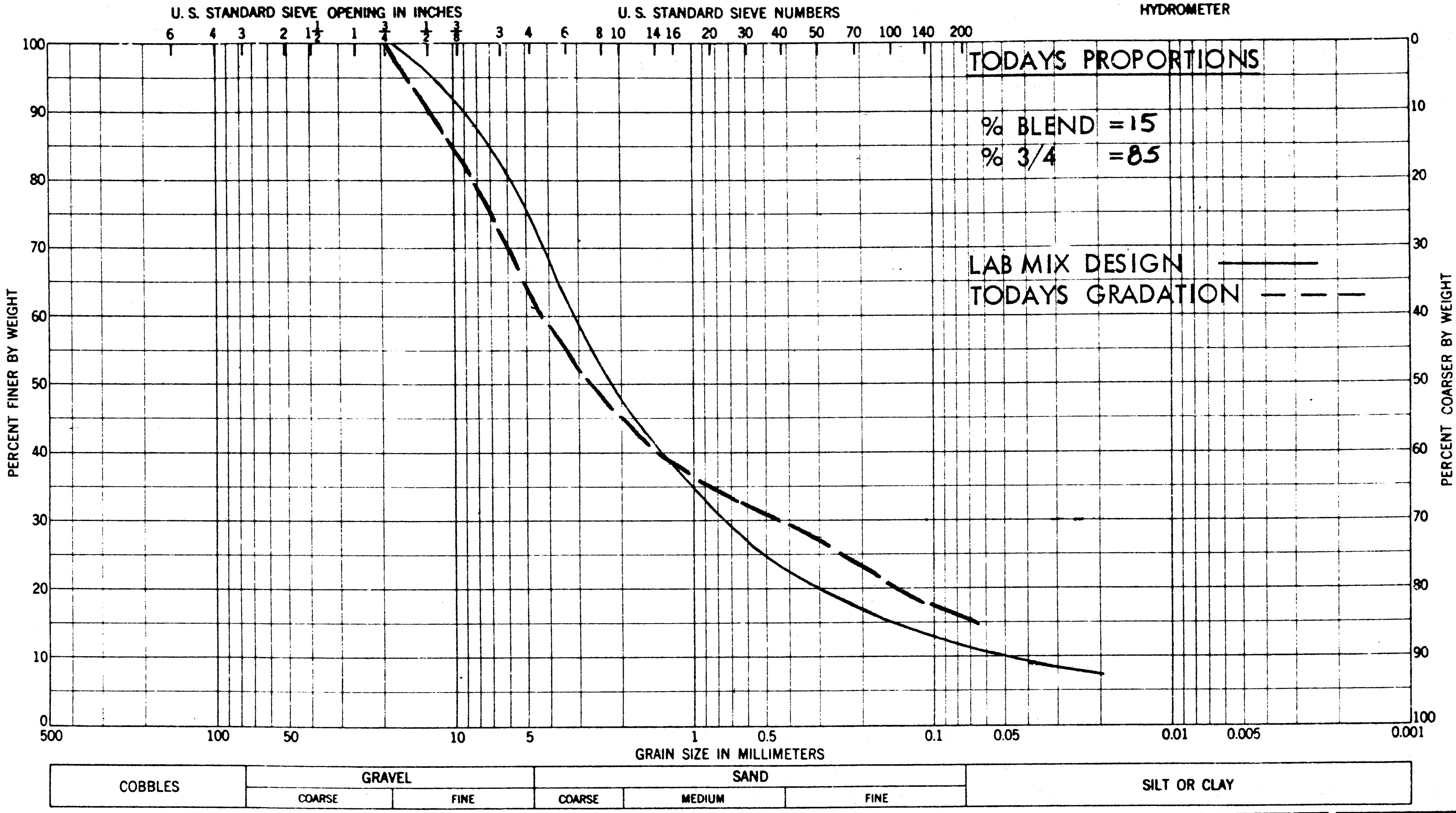
3/4-INCH COMBINED GRADATION

Area

Boring No.

Date 7-12-82

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

3/4-INCH COMBINED GRADATION

Area

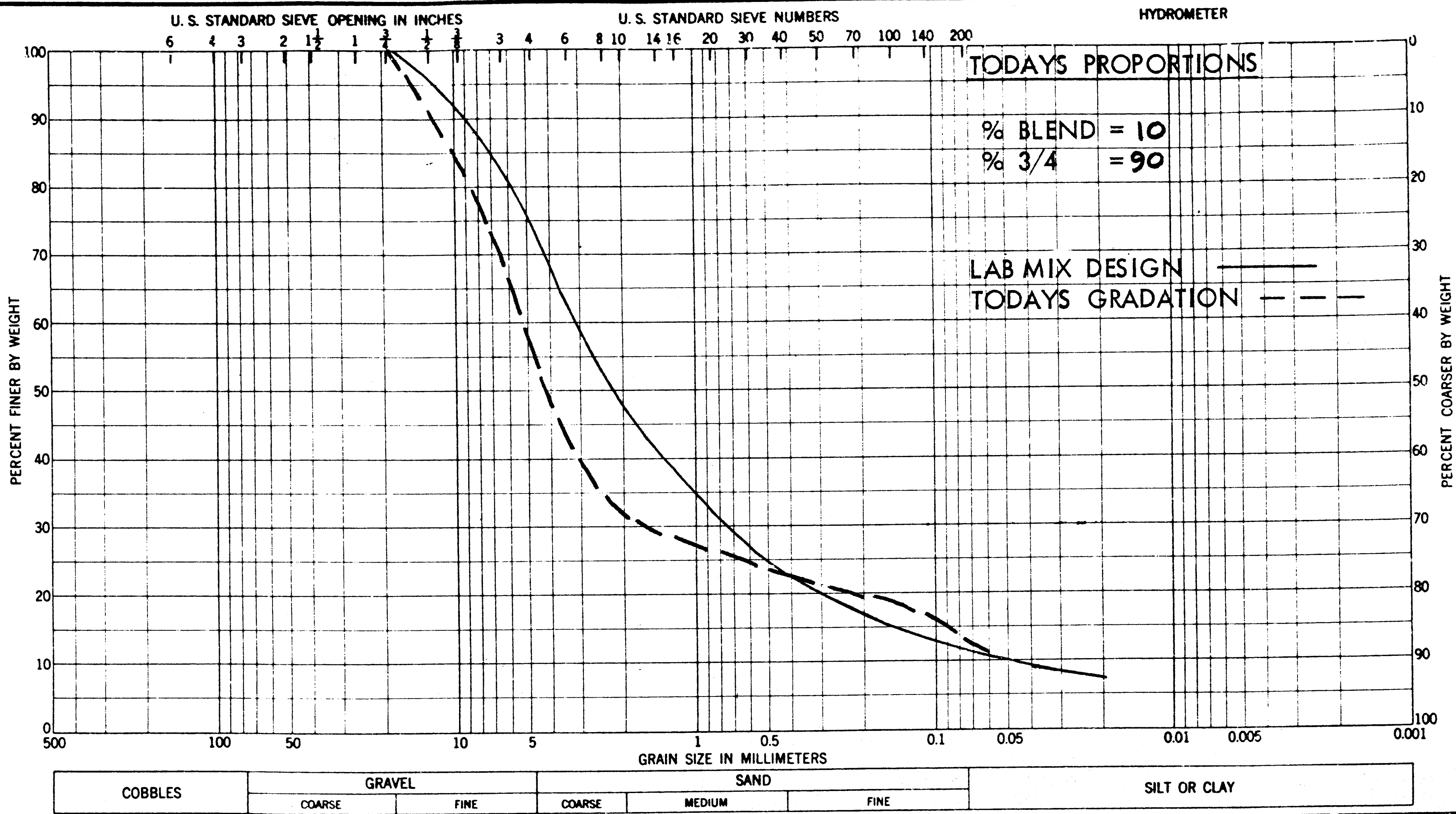
Boring No.

Date 7-19-82

GRADATION CURVES

ENG FORM 1 MAY 63 2087

EXHIBIT 4.2
Sheet 42 of 50



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

3/4-INCH COMBINED GRADATION

Area

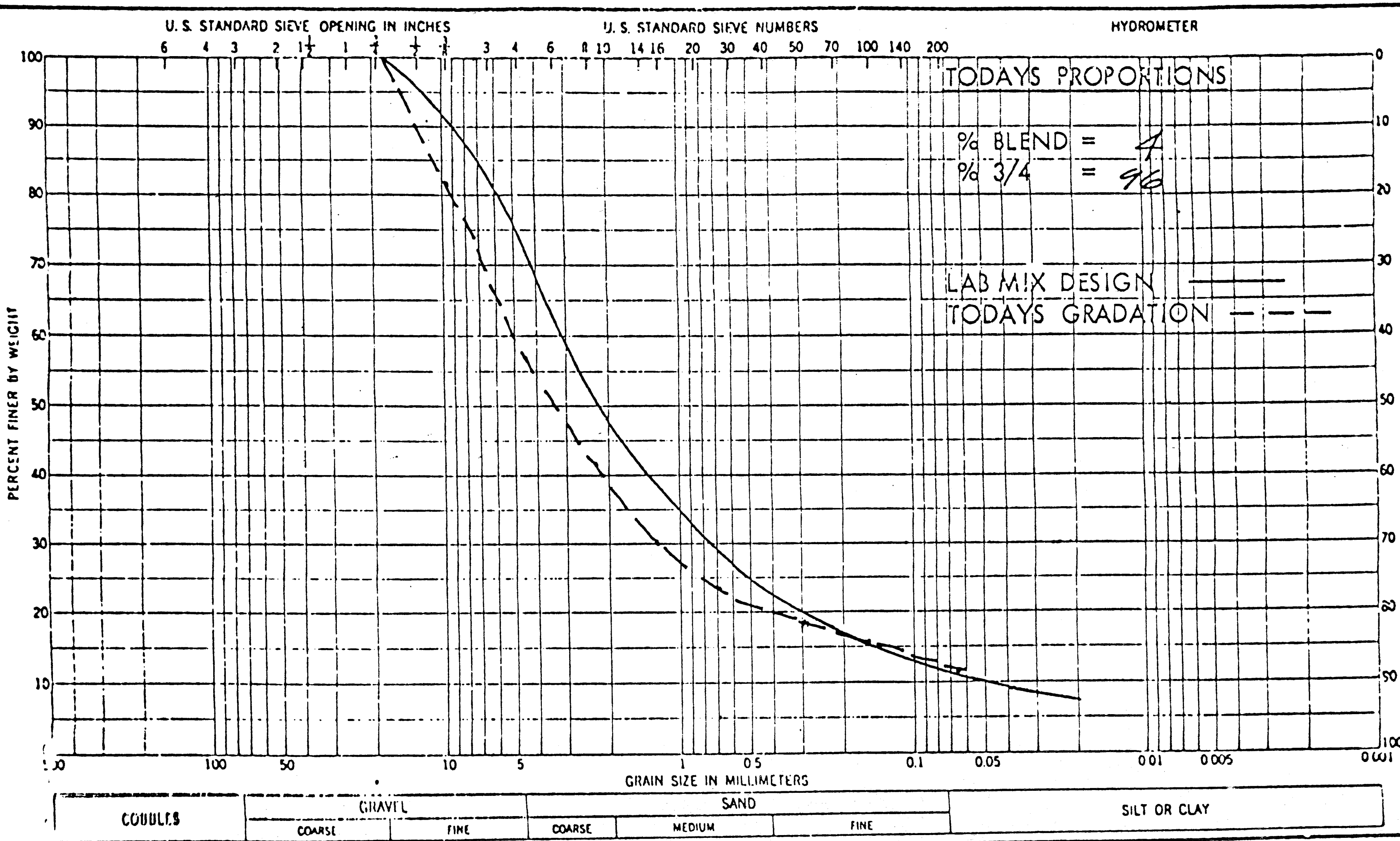
Boring No.

Date 7-26-82

GRADATION CURVES

ENG FORM 1 MAY 63 2087

EXHIBIT 4.2
Sheet 43 of 50



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

3/4-INCH COMBINED GRADATION

Area

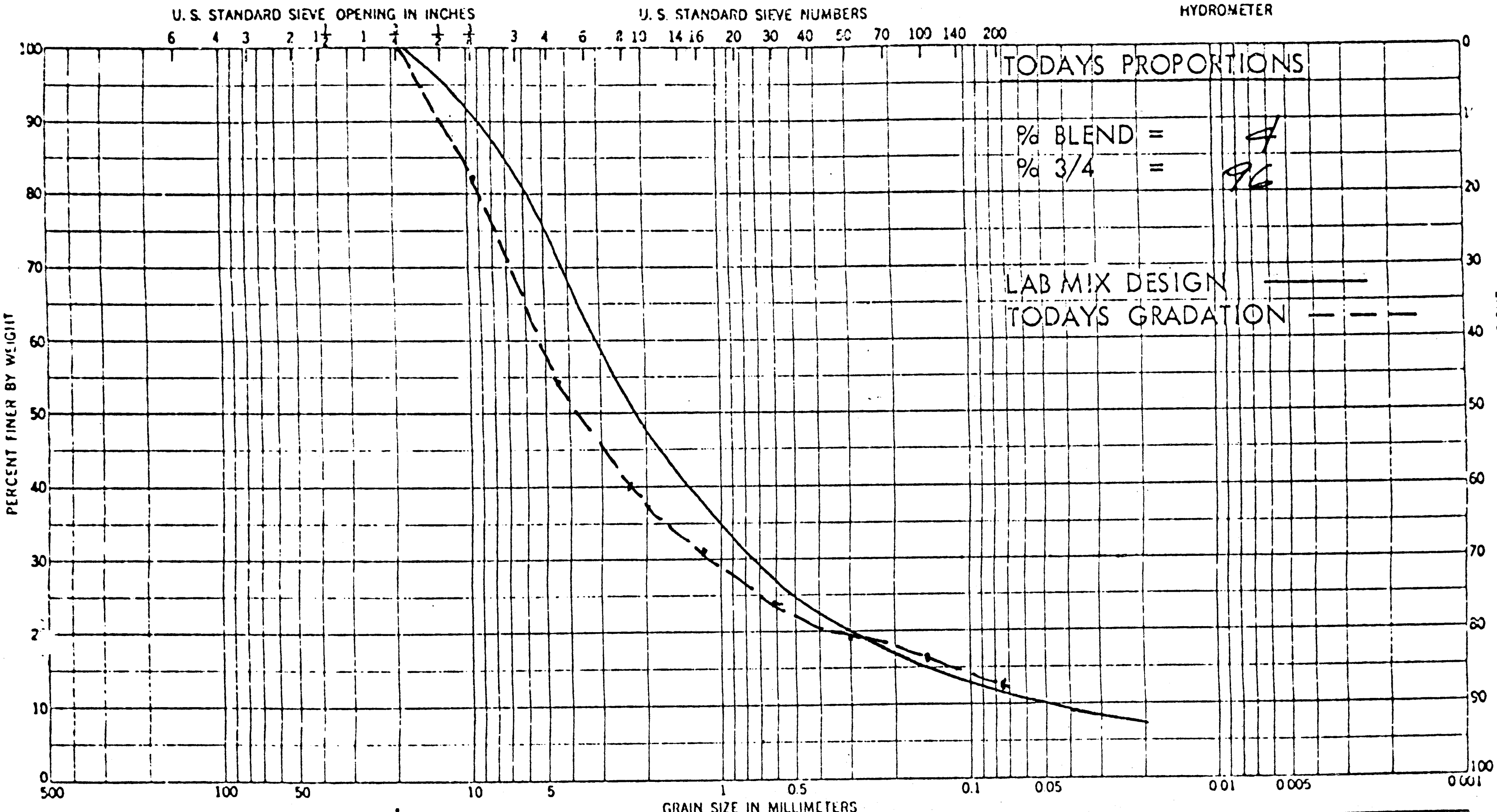
Boring No.

Date 8-2-82

GRADATION CURVES

ENG FORM 1 MAY 63 2087

EXHIBIT 4.2
Sheet 44 of 50



COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

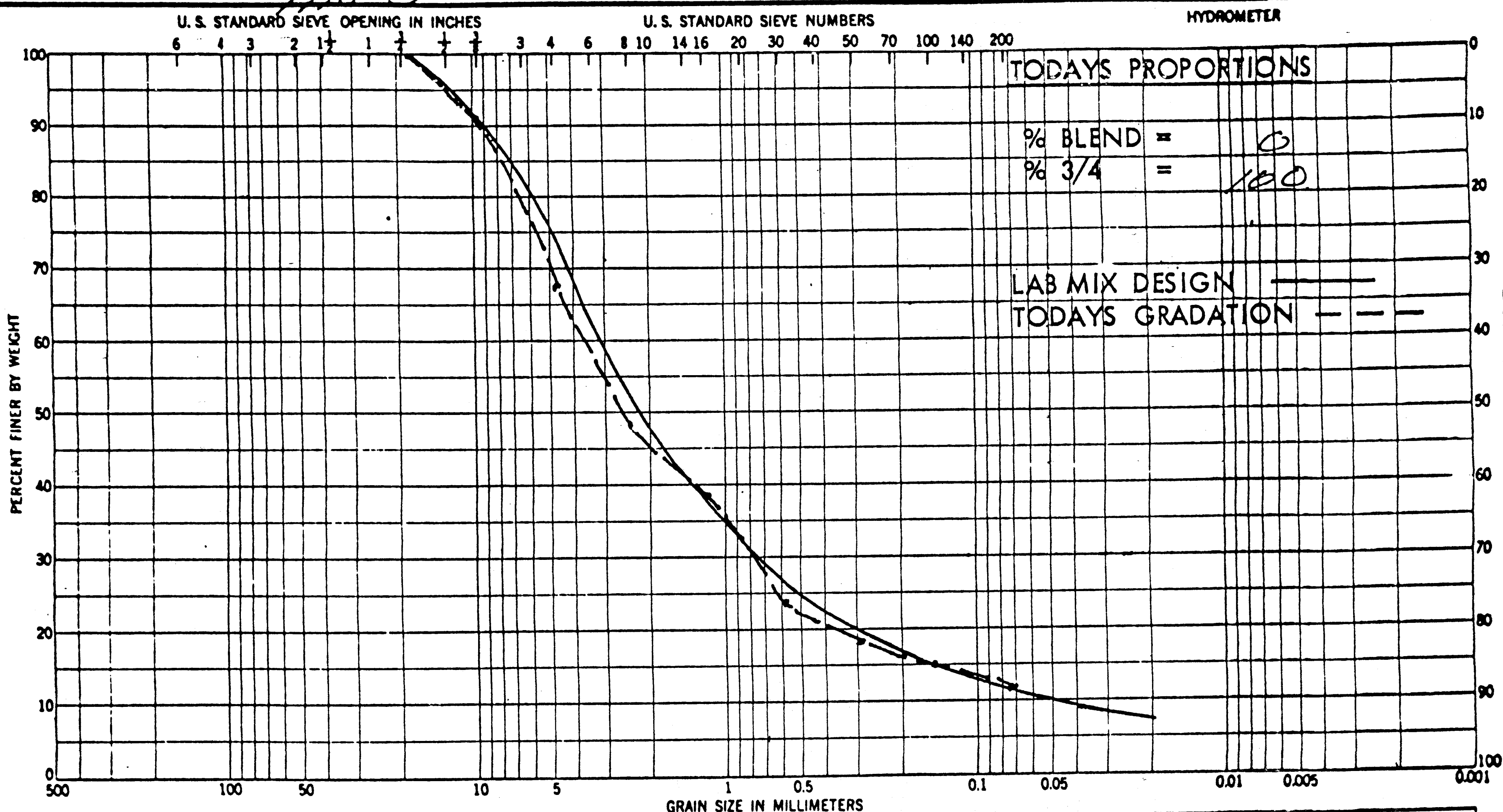
Project WILLOW CREEK DAM
3/4-INCH COMBINED GRADATION
Area
Boring No.
Date 8-9-87

GRADATION CURVES

ENG FORM 1 MAY 63 2087

EXHIBIT 4.2
Sheet 45 of 50

Mix 5



COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

3/4-INCH COMBINED GRADATION

Area

Boring No.

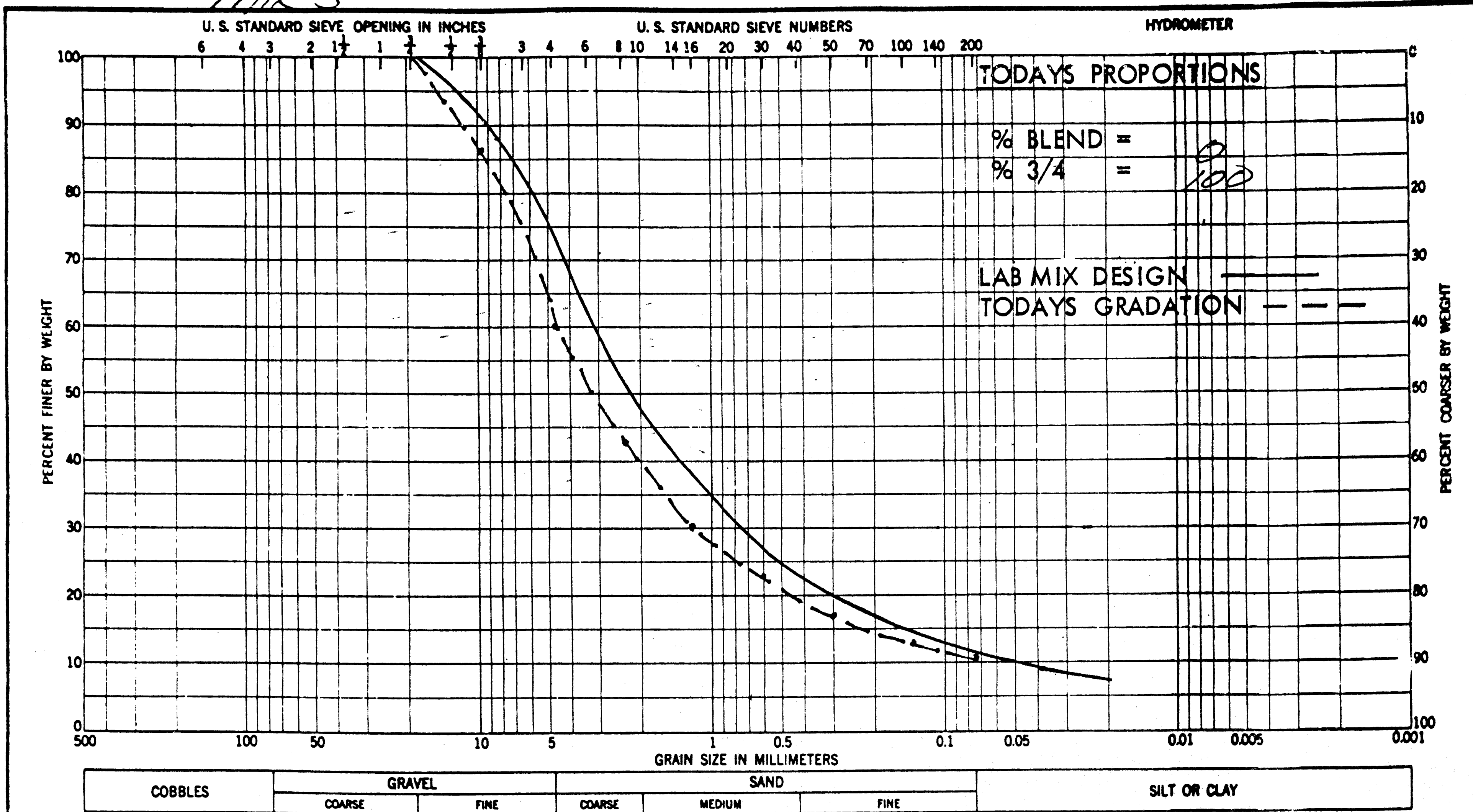
Date 8-16-82

GRADATION CURVES

ENG FORM 1 MAY 63 2087

EXHIBIT 4.2
Sheet 46 of 50

Mix 5



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

GRADATION CURVES

Project WILLOW CREEK DAM

3/4-INCH COMBINED GRADATION

Area

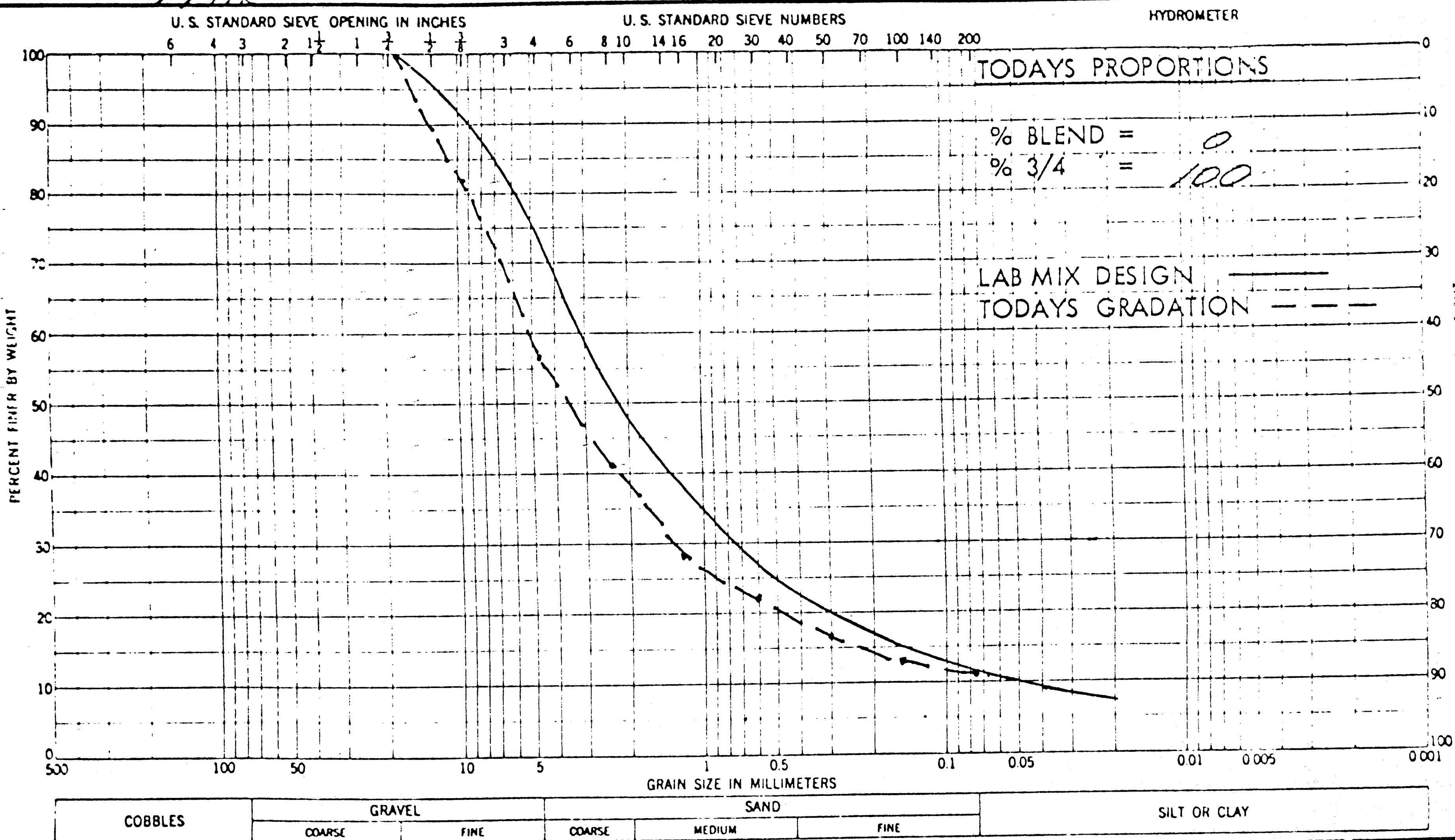
Boring No.

Date 8-23-89

EXHIBIT 4.2
Sheet 47 of 50

ENG FORM 1 MAY 63 2087

Mix 5



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

3/4-INCH COMBINED GRADATION

Area

Boring No.

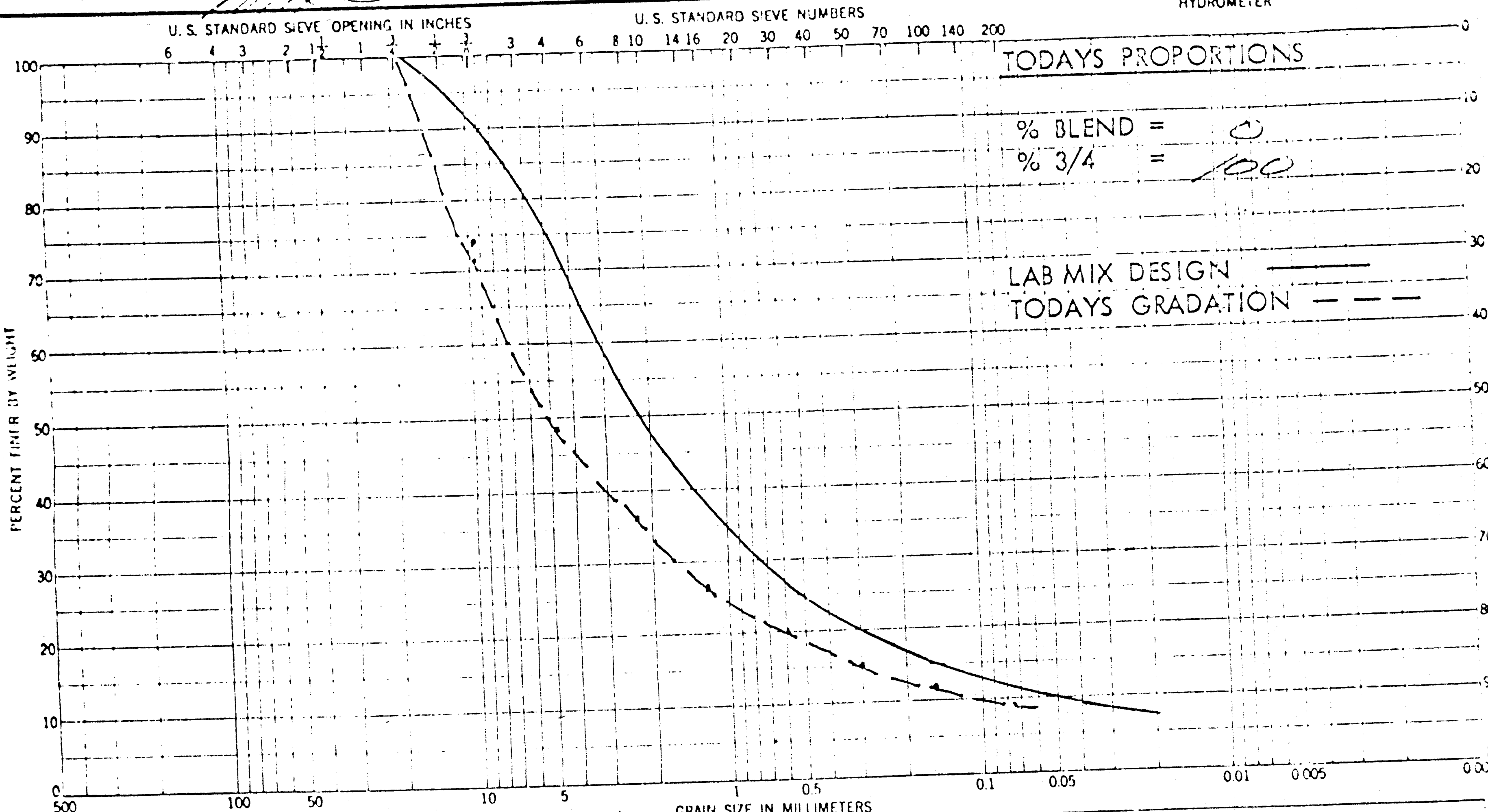
Date 8-30-82

GRADATION CURVES

ENG FORM 1 MAY 63 2087

EXHIBIT 4.2
Sheet 48 of 50

Mix 5



COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM
3/4-INCH COMBINED GRADATION

Area

Boring No.

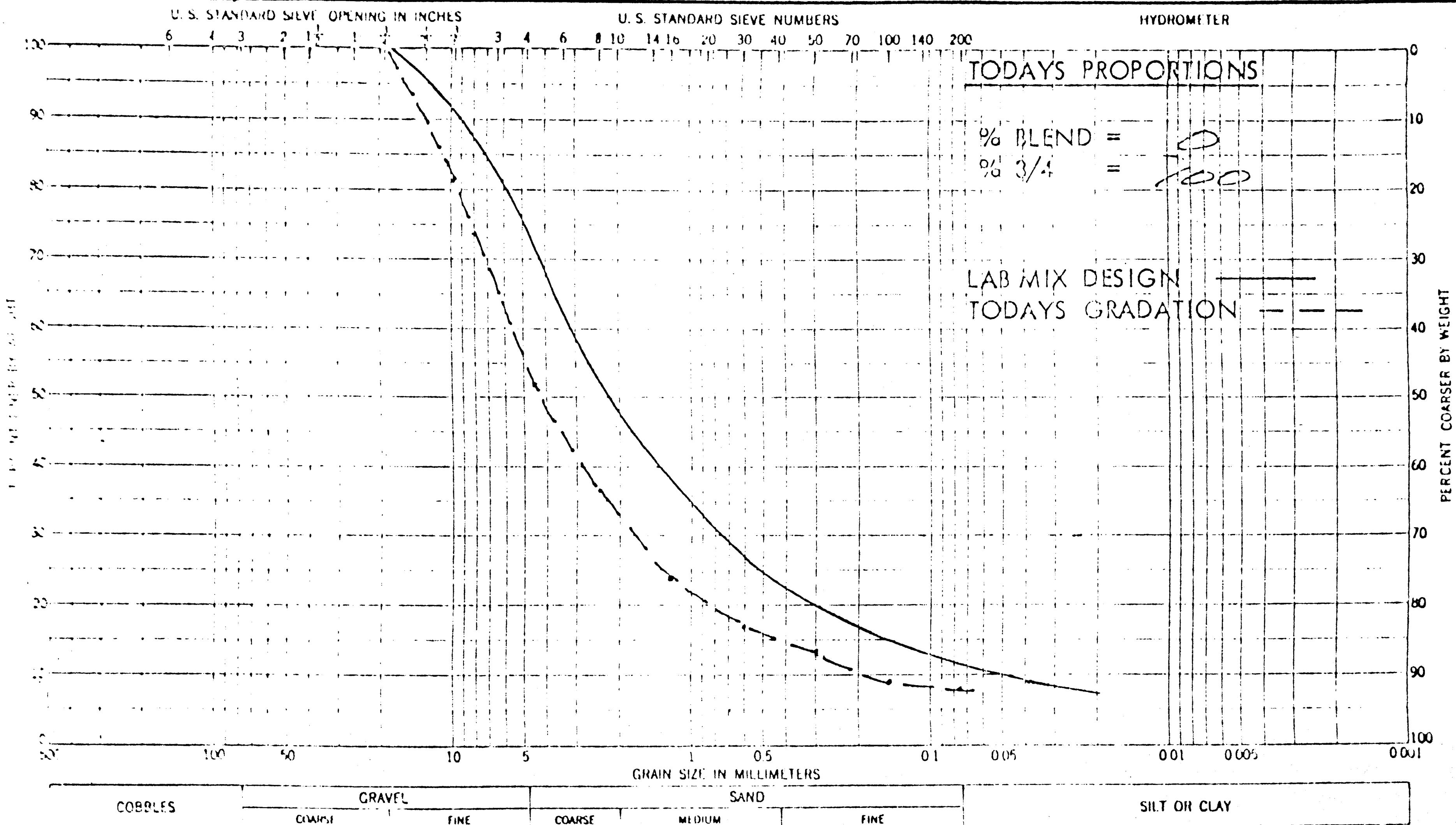
Date 9-15-82

GRADATION CURVES

EXHIBIT 4.2
Sheet 49 of 50

ENG FORM 1 MAY 63 2087

Mix 5



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project WILLOW CREEK DAM

3/4-INCH COMBINED GRADATION

Area

Boring No

Date 9-20-87

GRADATION CURVES

ENG FORM 2087

EXHIBIT 4.2
Sheet 50 of 50

CHAPTER 5

ROLLER-COMPACTED CONCRETE PRODUCTION AND PLANT CAPACITY

REQUIREMENTS

Contract specifications allowed the use of a continuous mix drum or conventional batch-type plant. Pug mill plants were not allowed, primarily because they had not been proven for use in RCC on a high production basis requiring low maintenance and downtime. Also, the 3-inch maximum size aggregate made from crushed high strength, high density basalt was thought to provide a mix very hard on pug mill paddles. At this point, the feeling is that there is sufficient experience with RCC mixes to know their behavior and characteristics well enough so that a suitable pug mill could be developed.

The plant was required to have the capability of producing 400 cubic yards per hour. This was based on a detailed study of placing requirements necessary to meet the schedule as dictated by the thermal studies. It takes into account inefficiency, expected downtime, and the slower placing rate that access and dam shape constraints caused during placing operations.

The contract specifications described requirements for both continuous and batch-type plants in detail including operation, layout, capacity, dispensers, bins, sampling, accuracy, mixing, etc. The major difference allowed for the rolled concrete as compared to conventional concrete was the following significant reduction in the accuracy of batching or charging, and in the within-batch variability allowed after mixing as shown below.

	Batching Variation Allowed	
Material	RCC	Conventional (Semi-Automatic Plant)
Pozzolan and Cement	± 4%	± 1%
Water	± 4%	± 1%
Coarse Aggregate (Plus 3/4)	± 4%	± 2%
Finer Aggregate (Minus 3/4)	± 5%	± 2%
Admixture	± 6%	± 3%

	Minimum Variability Index	
Test	RCC	Conventional (Semi-Automatic Plant)
Water Content of Mortar	85	91.5
Coarse Aggregate	90	90.5
Unit Weight of Air-Free Mortar	96	98.5
Cement Content of Mortar	80	82.5

DETAILED PLANT DESCRIPTION

The contractor elected to use a horizontal (low profile) conventional batch-type plant. This decision was mostly influenced by the availability and relatively low cost of a used paving plant which was then rebuilt and automated for the job. The basic plant was a Noble mobile plant, Model 600. Plate 5.1 shows photographs of the plant, and Plates 1.5 through 1.11 of the introduction show aerial photos of its location in relationship to the dam and aggregate stockpiles. Plate 5.2 shows variations of the basic plant layout used throughout the job. A detailed description of each one follows:

Layout No. 1 (29 April - 30 May):

The plant was fed by two Caterpillar Model 966 front-end loaders, tramming material from stockpile to the 28-ton, three-compartment mobile aggregate batching unit, with three 12-inch x 30-inch double clamshell-type bin gates and automatic ram control, with level indicators to control the bin charging conveyors. There also was a 36-inch belt feeder. From each of the three aggregate bins and from the belt feeder ran 30-inch x 60-foot-long conveyor belts traveling to the 8-cubic yard batching system consisting of four separate aggregate batchers and two cement batchers. The batchers were complete with one dial scale for each batcher, air rams, valves, gages, fittings, moisture traps, regulators, air vibrators, air line lubricators, and batch, start, and dump interlocks. Material went from the batcher to a 48-inch heavy duty belt conveyor with 45-degree troughing idlers and a 25-HP motor and drive, crowned head and tail pulleys with the head pulley lagged, antifriction troughing and return rolls, screw-type takeup and full length skirt boards. From there, materials went to a mobile 48-inch truss-type conveyor, 56 feet long, complete with discharge chute, 75-HP motor and drive, crowned head with tail pulleys with lagged head pulley, 45-degree antifriction troughing rolls, return rolls, screw-type takeup, full length skirt boards, and metal cover including a support frame with two wheels, tires, 10-HP traverse motor and drive with guard and controls to move the conveyor for alternate charging of the two mixers to two Erie Strayer

8-yard tilt-type mixers, each powered by two 50-HP electric motors. The mix was discharged onto a 42-inch x 50-foot-long horizontal conveyor which conveyed the material to a 30-inch x 125-foot-long radial stacker into one of two 50-cubic yard gob hoppers. During the first 2 days of production, material was taken from the gob hoppers by highway-type dump trucks to the placement area. After that time, the material was taken from the gob hopper to the placement area by two Fiat Allis Model 460B scrapers. Other features in the batch plant not previously mentioned were the cement silos. There were two 1,800-cubic-foot horizontal mobile bulk cement silos and one 100-ton guppy. The cement was moved from the guppy to the silos pneumatically and from the silos to the batching unit by a 14-inch cement screw with a 25-HP electric motor. The fly ash was moved by a 14-inch cement screw with a 25-HP motor also. The water pump was a 25-HP centrifugal pump, and an Alkon Compu/key 20 CRT computer with printer was installed in the control unit.

Layout No. 2 (1 June - 2 August):

The basic plant remained unchanged except that it was fed by two Caterpillar 980 front-end loaders. The 30-inch x 125-foot radial stacker was eliminated. Concrete was loaded directly from the 42-inch horizontal belt into Fiat Allis Model 460B scrapers.

Layout No. 3 (3 August - 26 August):

The only changes made in the plant were to install an aggregate cold feed unit consisting of three aggregate bins controlled by SCR drive variable speed belts and approximately 400 feet of 30-inch conveyor belt to the 125-foot x 30-inch stacking conveyor. From the stacking conveyor, material went to a 36-inch belt feeder with surge pile and from that surge pile by means of a 30-inch x 60-foot-long conveyor belt into the 3/4-inch aggregate bin. A very small amount of fine blend sand was added to the 3/4-inch product at the cold feed unit and transferred from there to the plant by means of a conveyor system. Since the No. 4 mix required no blend, a 36-inch belt feeder was added, discharging directly onto the 30-inch x 60-foot-long conveyor that fed into the 3/4-inch aggregate bin so that it could feed 3/4-inch material with no blend from that point. The rest of the plant remained unchanged.

Layout No. 4 (27 August - 24 September):

This was exactly the same as layout No. 3 with the elimination of the cold feed unit, the 400 feet of 30-inch conveyor belt, and the radial stacker. A surge pile and one 36-inch belt fed material onto the 30-inch x 60-foot-long conveyor into the 3/4-inch aggregate bin. Two 980 front-end loaders supplemented partially by a 966 front-end loader were used to feed the plant.

PLANT OPERATION COMMENTS

A few situations relative to operation of the RCC plant at Willow Creek should be noted.

The batching sequence was extremely critical. For instance, adding blend sand to the tail end of the fine charging belt followed by dumping the other aggregate onto it resulted in failing mixer proficiency tests and excess buildup in the mixer drum. Changing the timing and/or opening of the aggregate weigh bin gates by a few seconds also meant the difference between passing and failing tests. The timing and angle of injection of water to the drum was equally important. With the wrong sequence of batching, buildup in the drums got as bad as one full cubic yard after two shifts of operation, while with a slightly different sequence almost no buildup developed with weeks of use.

It is worth commenting that the "blend sand" was actually a very fine natural grainy textured nonplastic material with usually 75 percent to 95 percent passing the No. 200 sieve. It was only needed during the time that production of aggregate failed to include sufficient overburden. Generally it was added at a rate of only 1 percent to 4 percent.

Another important comment pertinent to RCC is the "bulking" effect. Because it contains no paste, the loose material "bulks" while mixing. The 9-cubic-yard drums of the batch plant could hold and effectively mix only 8 cubic yards of loose RCC.

PRODUCTIVITY AND MIXER PROFICIENCY TESTS

The overall production history shown as cumulative yards placed versus calendar date and how that compared to predicted productivity during design is shown on Plate 5.3. Plate 5.4 shows productivity in cubic yards per hour based on theoretical capacity, average normal production, and overall average per shift throughout the job. Plate 5.5 shows the individual and cumulative yardage of each RCC mix in each layer or lift.

The requirement for 400 cubic yards per hour capability was not met until mid-June, 6 weeks after the start of placing. Fortunately, the total required capacity was not practically usable until about that time so there was little actual effect or delay in the construction rate. Until that time, the area was too confined or inaccessible to place much faster and thermal design constraints prohibited putting in more than three lifts in any two shifts regardless of the volume involved.

Because the effectiveness of the mixers with the RCC materials was so very dependent upon the batching sequence and timing, and because the high productivity requirements pushed the mixer to its limits, many mixer proficiency tests were necessary. Basically, a trial and error procedure had to be used to determine the best method of batching, after which successive tests were run to determine the minimum allowable mix time. If a 3-inch aggregate mix design passed the test with the leanest cement plus fly ash content, the richer mixes with the same gradation and aggregate size were considered acceptable at the same mix time. However, separate tests were made for each of the mixes using different gradations and maximum aggregate size. As a general rule only a few seconds difference in mix time would make the difference between a passing and failing test.

Typically, a conventional mass concrete project will require only a few tests. At Willow Creek, 25 tests were necessary. Personnel requirements for these tests included all Resident Office laboratory personnel plus several select and conscientious laborers supplied by the contractor.

There were three significant differences between standard mixer proficiency test procedures and those used at Willow Creek Dam. Discussion of each of these follows. Exhibit 5.1 contains typical results of mixer proficiency tests.

(1) After production was underway, it was evident that considerable mixing/remixing occurred during the conveying-dumping-spreading operation. On the other hand, these operations could be damaging if not properly controlled. Normally, samples are taken from the first, middle, and last third of a single-mix batch. If the variability between the samples was too high when sampled this way but the variability was acceptable after conveying, dumping, and spreading, it was considered to be appropriate to allow the material in construction. It was agreed between the contractor and the Corps to take three random samples from the placement for testing rather than test each third of an individual batch. It was also agreed that when using this sampling technique, allowance should be made for batch-to-batch variability. Accordingly, the minimum acceptable values for variability index were reduced by 10.8 percent of their within-batch values to the following.

	Minimum Allowable Variability Index	
	Within-Batch Sampling	Random Sampling from Placement
Cement	80	71.4
Water	85	75.8
Unit Wt. of Air-Free Mortar	96	85.6
Coarse Aggregate Fraction	90	80.2

In addition to the benefit from remixing while spreading and handling, another benefit from taking samples from the placement was gained from the fact that each sample was obtained fresh. The new sample was obtained after the previous sample had been completely processed. With the normal procedure, many hours pass between testing of the sample in the first and last third obtained from a single batch, and the results can be adversely affected. From an owner's standpoint, the random sample procedure is better because it checks batch-to-batch as well as within-batch variations and it can detect problems from improper handling. From the contractor's standpoint, it is easier to pass because of the benefit from additional mixing while handling. In a continuous mix operation, it is the only reasonable approach. In future work, it is suggested that several trials be made using the normal procedure in wasted batches before routine production begins. A reasonable batching procedure and safe (but probably excessively long) mix time can be established for the start of production. Each subsequent day of production can be used to systematically trim 5 or 10 seconds off the previously accepted mix time, allowing a full day's production at that time while the tests are evaluated until the minimum acceptable time is determined.

(2) The concrete quality monitor (CQM) method was used to determine cement and water contents. The equipment and procedure are described in Chapter 19, "Concrete Quality Monitor," of this report. Basically it is a method of rapidly determining the cement content so that full results of the entire mixer proficiency tests are known the same day. Without the CQM method, mixer proficiency tests could not be used to evaluate mixer performance without causing an unacceptable delay to productivity because of the time required for test evaluation. The normal time to get results using the precipitate chemical process for cement content evaluations is a full week. Assuming that the results of one test are needed before proceeding with the subsequent tests at an additional reduction in mix time, this would have meant that Willow Creek Dam would have been finished before the minimum acceptable mix time was established.

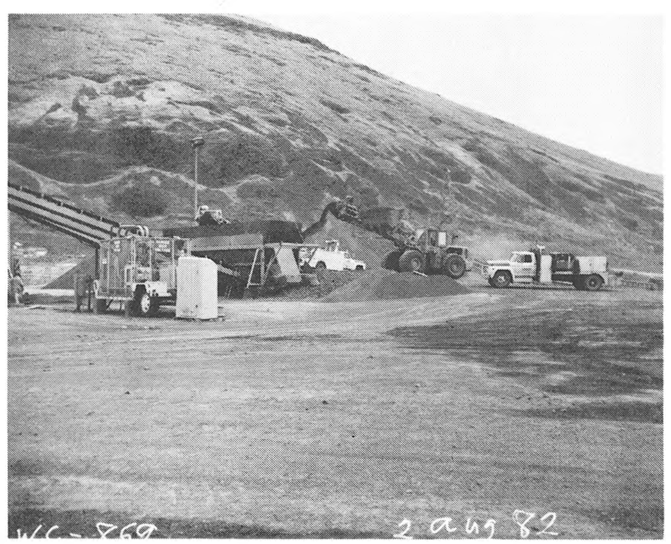
(3) Tests for water content and cement content were performed on both the full mix and the minus No. 4 fraction of the mix. Without the CQM equipment it is not possible to test the full mix, so only results of the minus No. 4 fraction are used. In reality, it is variability of the full mix that is of concern. If tests on the full mix passed but the minus No. 4 results were marginal, the test was considered acceptable.

It is worth noting that after considerable effort to find the origin of the standard for acceptable variability values and how the minus No. 4 portion is supposed to relate to full mix values, nothing was found in either documented written form or from memory of those who have used it for years.

— CONCRETE PLANT

WILLOW CREEK DAM ON 20 JULY 1982.

CONCRETE PLANT.

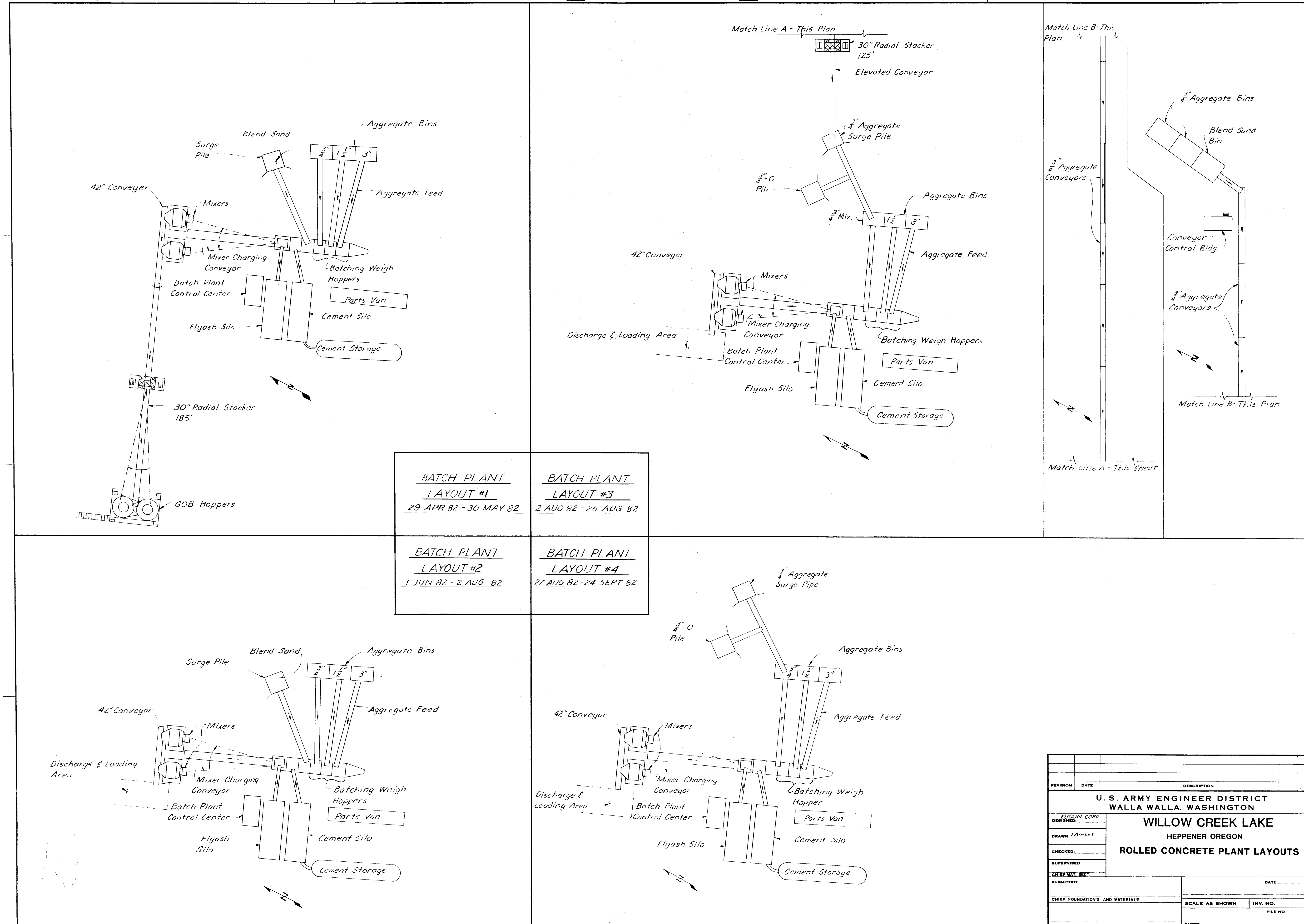


CHARGING AGGREGATES USING A FRONT END LOADER AND CONVEYOR THAT FEEDS THE WEIGH BINS.

LOADING A SCRAPER WITH RCC AT THE PLANT.

ROLLED CONCRETE PLANT

PLATE 5.1


Blend Sand
Aggregate Bins
Surge Pile
42" Conveyer
Mixers
Aggregate Feed
Mixer Charging Conveyor
Batching Weigh Hoppers
Batch Plant Control Center
Parts Van
Flyash Silo
Cement Silo
Cement Storage
30" Radial Stacker 185'
GOB Hoppers
Match Line A - This Plan
30" Radial Stacker 125'
Elevated Conveyor
3/4" Aggregate Surge Pile
3/4"-0 Pile
3/4" Mix
42" Conveyor
Discharge & Loading Area
Match Line B - This Plan
3/4" Aggregate Conveyors
3/4" Aggregate Bins
Blend Sand Bin
Conveyor Control Bldg.
Match Line B - This Plan
Match Line A - This Sheet
BATCH PLANT LAYOUT #1
29 APR 82 - 30 MAY 82
BATCH PLANT LAYOUT #3
2 AUG 82 - 26 AUG 82
BATCH PLANT LAYOUT #2
1 JUN 82 - 2 AUG 82
BATCH PLANT LAYOUT #4
27 AUG 82 - 24 SEPT 82
3/4" Aggregate Surge Pipe
Batching Weigh Hopper
REVISION DATE DESCRIPTION BY
U. S. ARMY ENGINEER DISTRICT
WALLA WALLA, WASHINGTON
DESIGNED: EUCON CORP
DRAWN: FAIRLEY
CHECKED:
SUPERVISED:
CHIEF MAT. SECT.
SUBMITTED:
CHIEF, FOUNDATIONS AND MATERIALS
WILLOW CREEK LAKE
HEPPENER OREGON
ROLLED CONCRETE PLANT LAYOUTS
DATE
SCALE AS SHOWN
INV. NO.
FILE NO.
SHEET

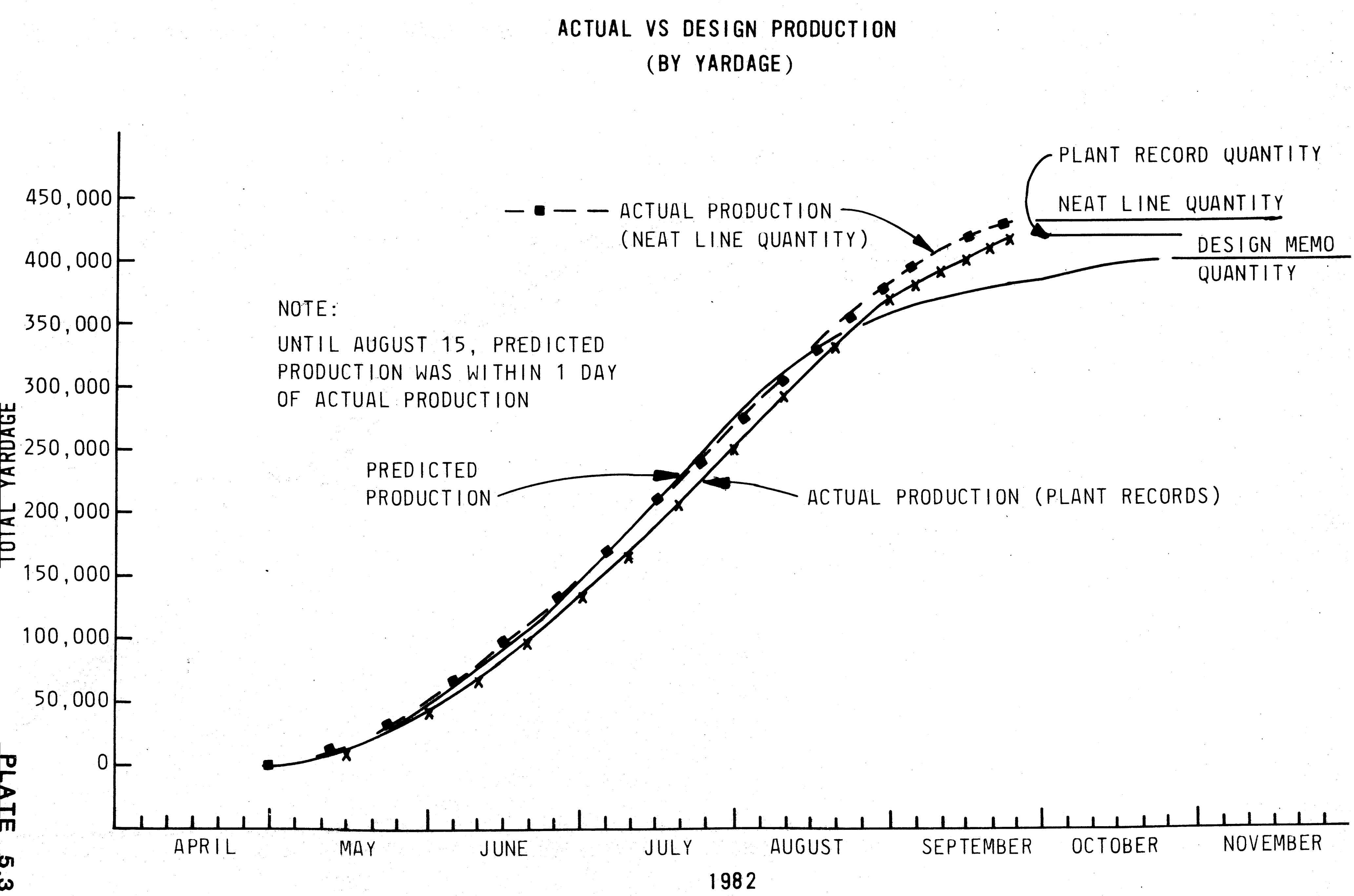
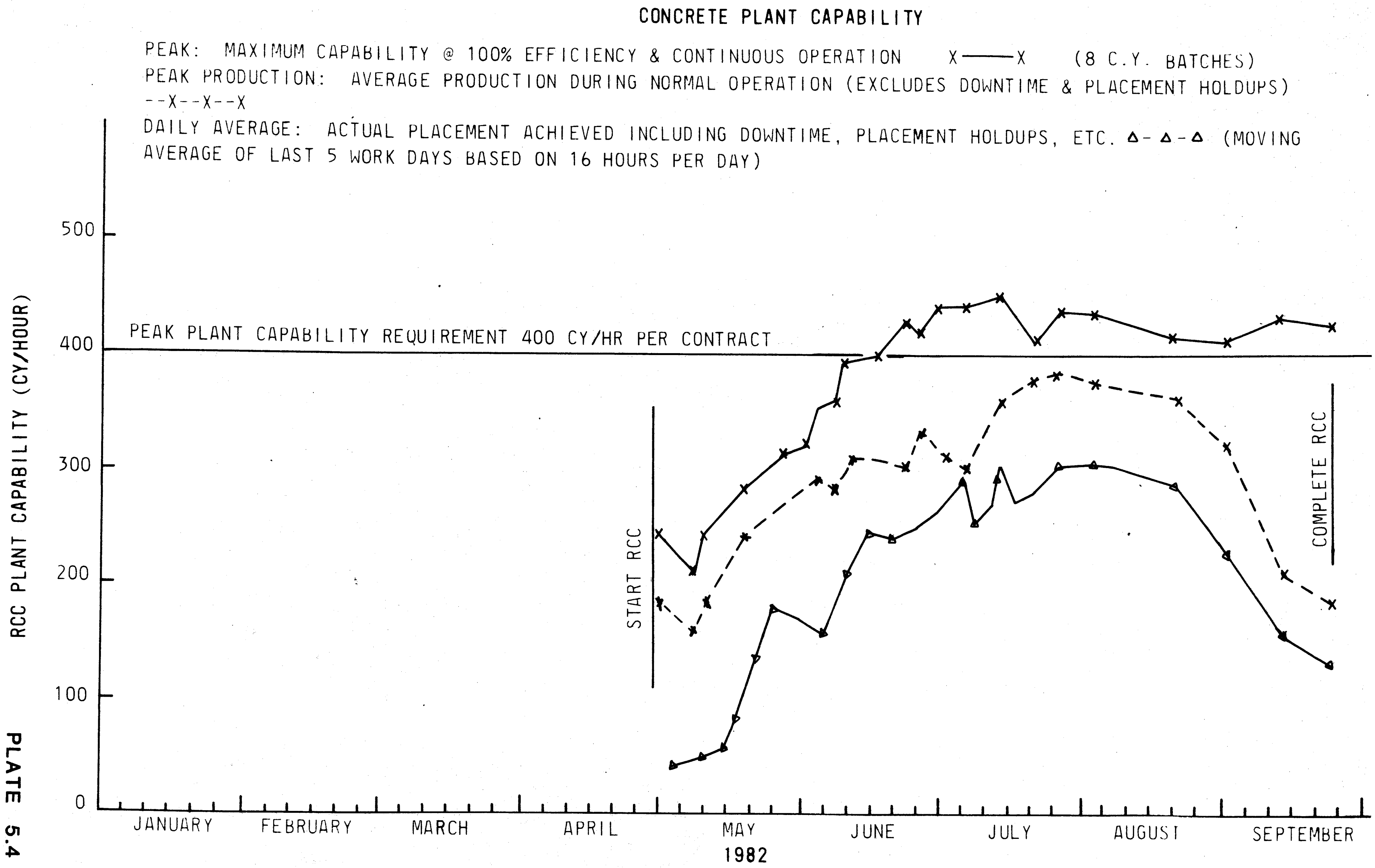

ACTUAL VS DESIGN PRODUCTION
(BY YARDAGE)
TOTAL YARDAGE
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
1982
ACTUAL PRODUCTION (NEAT LINE QUANTITY)
PLANT RECORD QUANTITY
NEAT LINE QUANTITY
DESIGN MEMO QUANTITY
NOTE:
UNTIL AUGUST 15, PREDICTED PRODUCTION WAS WITHIN 1 DAY OF ACTUAL PRODUCTION
PREDICTED PRODUCTION
ACTUAL PRODUCTION (PLANT RECORDS)

PLATE 5.3



CONCRETE PLANT CAPABILITY
PEAK: MAXIMUM CAPABILITY @ 100% EFFICIENCY & CONTINUOUS OPERATION X——X (8 C.Y. BATCHES)
PEAK PRODUCTION: AVERAGE PRODUCTION DURING NORMAL OPERATION (EXCLUDES DOWNTIME & PLACEMENT HOLDUPS) --X--X--X
DAILY AVERAGE: ACTUAL PLACEMENT ACHIEVED INCLUDING DOWNTIME, PLACEMENT HOLDUPS, ETC. Δ-Δ-Δ (MOVING AVERAGE OF LAST 5 WORK DAYS BASED ON 16 HOURS PER DAY)
PEAK PLANT CAPABILITY REQUIREMENT 400 CY/HR PER CONTRACT
RCC PLANT CAPABILITY (CY/HOUR)
500
400
300
200
100
0
START RCC
COMPLETE RCC
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
1982

PLATE 5.4

LIFT ELEV	RCC-1 CY	RCC-2 CY	RCC-3 CY	RCC-4 CY	RCC-1 ACC CY	RCC-2 ACC CY	RCC-3 ACC CY	RCC-4 ACC CY	ACCUM TOTAL
2128.00	0	0	0	0	307787	54705	42252	26667	431411
2127.00	0	0	735	0	307787	54705	42252	26667	431411
2126.00	0	0	863	0	307787	54705	41517	26667	430676
2125.00	0	0	821	0	307787	54705	40654	26667	429813
2124.00	0	0	848	0	307787	54705	39833	26667	428992
2123.00	0	442	407	0	307787	54705	38985	26667	428144
2122.00	0	425	468	0	307787	54263	38578	26667	427295
2121.00	0	428	482	0	307787	53838	38110	26667	426402
2120.00	0	416	481	0	307787	53410	37628	26667	425492
2118.75	0	376	512	0	307787	52994	37147	26667	424595
2117.75	0	375	544	0	307787	52618	36635	26667	423707
2116.75	0	375	575	0	307787	52243	36091	26667	422788
2115.75	0	376	606	0	307787	51868	35516	26667	421838
2114.75	0	375	636	0	307787	51492	34910	26667	420856
2113.75	0	376	667	0	307787	51117	34274	26667	419845
2112.75	194	375	505	0	307787	50741	33607	26667	418802
2111.75	367	375	362	0	307593	50366	33102	26667	417728
2110.75	398	393	362	4	307226	49991	32740	26667	416624
2109.75	419	366	338	65	306828	49598	32378	26663	415467
2108.75	450	366	354	113	306409	49232	32040	26598	414279
2107.75	477	367	354	169	305959	48866	31686	26485	412996
2106.75	505	365	353	188	305482	48499	31332	26316	411629
2105.75	533	365	351	204	304977	48134	30979	26128	410218
2104.75	560	444	348	164	304444	47769	30628	25924	408765
2103.75	588	489	331	114	303884	47325	30280	25760	407249
2102.75	613	489	344	126	303296	46836	29949	25646	405727
2101.75	639	484	343	142	302683	46347	29605	25520	404155
2100.75	666	479	341	160	302044	45863	29262	25378	402547
2099.75	724	477	339	167	301378	45384	28921	25218	400901
2098.75	717	476	338	188	300654	44907	28582	25051	399194
2097.75	745	473	337	187	299937	44431	28244	24863	397475
2096.75	767	513	338	200	299192	43958	27907	24676	395733
2095.75	780	467	312	217	298425	43445	27569	24476	393915
2094.75	798	466	330	245	297645	42978	27257	24259	392139
2093.75	944	462	328	125	296847	42512	26927	24014	390300
2092.75	1065	428	327	125	295903	42050	26599	23889	388441
2091.75	961	426	325	125	294838	41622	26272	23764	386496
2090.75	994	426	324	125	293877	41196	25947	23639	384659
2089.75	1026	425	316	125	292883	40770	25623	23514	382790
2088.75	1059	424	286	125	291857	40345	25307	23389	380898
2087.75	1092	424	284	125	290798	39921	25021	23264	379004
2086.75	1124	422	283	125	289706	39497	24737	23139	377079
2085.75	1156	423	282	125	288582	39075	24454	23014	375125
2084.75	1188	423	280	125	287426	38652	24172	22889	373139
2083.75	1220	421	280	125	286238	38229	23892	22764	371123
2082.75	1252	419	280	125	285018	37808	23612	22639	369077
2081.75	1281	419	280	125	283766	37389	23332	22514	367001
2080.75	1312	420	280	125	282485	36970	23052	22389	364896
2079.75	1362	423	280	125	281173	36550	22772	22264	362759
2078.75	1382	425	283	125	279811	36127	22492	22139	360569
2077.75	1406	415	275	125	278429	35702	22209	22014	358354
2076.75	1430	413	274	125	277023	35287	21934	21889	356133
2075.75	1457	413	273	125	275593	34874	21660	21764	353891
2074.75	1483	411	272	125	274136	34461	21387	21639	351623
2073.75	1509	411	271	125	272653	34050	21115	21514	349332
2072.75	1544	409	271	125	271144	33639	20844	21389	347016
2071.75	1577	409	269	125	269600	33230	20573	21264	344667
2070.75	1611	407	268	125	268023	32821	20304	21139	342287
2069.75	1645	406	266	125	266412	32414	20036	21014	339876
2068.75	1678	408	265	125	264767	32008	19770	20889	337434
2067.75	1712	403	264	125	263089	31600	19505	20764	334958
2066.75	1719	411	263	125	261377	31197	19241	20639	332454
2065.75	1744	400	263	125	259658	30786	18978	20514	329936
2064.75	1774	399	263	125	257914	30386	18715	20389	327404
2063.75	1803	399	262	125	256140	29987	18452	20264	324843
2062.75	1827	398	261	125	254337	29588	18190	20139	322254
2061.75	1860	398	259	125	252510	29190	17929	20014	319643
2060.75	1887	396	258	125	250650	28792	17670	19889	317001
2059.75	1918	396	257	125	248763	28396	17412	19764	314335
2058.75	1948	397	258	125	246845	28000	17155	19639	311639
2057.75	1978	395	257	125	244897	27603	16897	19514	308911
2056.75	2009	396	257	125	242919	27208	16640	19389	306156
2055.75	2039	395	257	125	240910	26812	16383	19264	303369
2054.75	2070	403	265	125	238871	26417	16126	19139	300553
2053.75	2119	395	256	125	236801	26014	15861	19014	297690
2052.75	2132	393	256	125	234682	25619	15605	18889	294795
2051.75	2165	393	256	125	232550	25226	15349	18764	291889
2050.75	2194	391	255	125	230385	24833	15093	18639	288950
2049.75	2223	390	255	125	228191	24442	14838	18514	285985
2048.75	2252	390	255	125	225968	24052	14583	18389	282992
2047.75	2281	388	255	125	223716	23662	14328	18264	279970
2046.75	2310	388	254	125	221435	23274	14073	18139	276921
2045.75	2339	386	254	125	219125	22886	13819	18014	273844
2044.75	2367	385	253	125	216786	22500	13565	17889	270740
2043.75	2396	392	253	125	214419	22115	13312	17764	267610
2042.75	2425	401	254	125	212023	21723	13059	17639	264444
2041.75	2355	370	240	125	209598	21322	12805	17514	261239
2040.75	2625	370	240	125	207243	20952	12565	17389	258149
2039.75	2394	369	239	125	204618	20582	12325	17264	254789
2038.75	2425	370	238	125	202224	20213	12086	17139	251662
2037.75	2456	369	238	125	199799	19843	11848	17014	248504
2036.75	2485	368	237	125	197343	19474	11610	16889	245316
2035.75	2515	369	236	125	194858	19106	11373	16764	242101
2034.75	2544	368	236	125	192343	18737	11137	16639	238856
2033.75	2573	368	235	125	189799	18369	10901	16514	235583
2032.75	2603	368	234	125	187226	18001	10666	16389	232282
2031.75	2631	367	234	125	184623	17633	10432	16264	228952
2030.75	2660	368	234	125	181992	17266	10198	16139	225595
2029.75	2690	366	233	125	179332	16898	9964	16014	222208
2028.75	2719	366	233	125	176642	16532	9731	15889	218794
2027.75	2747	367	233	125	173923	16166	9498	15764	215351
2026.75	2759	365	232	125	171176	15799	9265	15639	211879
2025.75	2788	364	232	125	168417	15434	9033	15514	208398
2024.75	2817	364	231	125	165629	15070	8801	15389	204889
2023.75	2846	363	231	125	162812	14706	8570	15264	201352
2022.75	2863	370	231	125	159966	14343	8339	15139	197787
2021.75	2880	361	227	125	157103	13973	8108	15014	194198
2020.75	2897	369	226	125	154223	13612	7881	14889	190605
2019.75	3041	361	226	125	151326	13243	7655	14764	186988
2018.75	2941	359	225	125	148285	12882	7429	14639	183235
2017.75	2971	359	225	125	145344	12523	7204	14514	179585
2016.75	3001	359	225	125	142373	12164	6979	14389	175905
2015.75	3014	355	224	125	139372	11805	6754	14264	172195
2014.75	3029	364	225	125	136358	11450	6530	14139	168477
2013.75	2882	341	205	125	133329	11086	6305	14014	164734
2012.75	3049	345	212	125	130447	10745	6100	13889	161181
2011.75	2968	335	210	125	127398	10400	5888	13764	157450
2010.75	2933	342	209	125	124430	10065	5678	13639	153812
2009.75	2945	330	208	125	121497	9723	5469	13514	150203
2008.75	2972	337	207	125	118552	9393	5261	13389	146595
2007.75	2983	317	199	125	115580	9056	5054	13264	142954
2006.75	3211	308	191	125	112597	8739	4855	13139	139330
2005.75	2976	286	190	125	109386	8431	4664	13014	135495
2004.75	2975	290	201	125	106410	8145	4474	12889	131918
2003.75	3235	286	199	125	103435	7855	4273	12764	128327
2002.75	2949	285	196	125	100200	7569	4074	12639	124482
2001.75	2665	283	185	125	97251	7284	3878	12514	120927
2000.75	2675	279	158	125	94586	7001	3693	12389	117669
1999.75	2684	277	157	125	91911	6722	3535	12264	114432
1998.75	2692	276	153	125	89227	6445	3378	12139	111189
1997.75	2763	276	150	125	86535	6169	3225	12014	107943
1996.75	2707	274	147	125	83772	5893	3075	11889	104629
1995.75	2714	273	144	125	81065	5619	2928	11764	101376
1994.75	2722	272	142	125	78351	5346	2784	11639	98120
1993.75	2728	271	140	125	75629	5074	2642	11514	94859
1992.75	2735	268	146	125	72901	4803	2502	11389	91595
1991.75	2741	266	145	125	70166	4535	2356	11264	88321
1990.75	2668	277	155	125	67425	4269	2211	11139	85044
1990.00	3165	281	143	143	64757	3992	2056	11014	81819
1989.00	3262	270	141	125	61592	3711	1913	10871	78087
1988.00	3193	264	136	125	58330	3441	1772	10746	74289
1987.00	3729	262	178	125	55137	3177	1636	10621	70571
1986.00	2953	200	118	125	51408	2915	1458	10496	66277
1985.00	2921	227	115	125	48455	2715	1340	10371	62881
1984.00	2860	182	114	161	45534	2488	1225	10246	59493
1983.00	2797	175	122	178	42674	2306	1111	10085	56176
1982.00	2809	169	99	183	39877	2131	989	9907	52904
1981.00	2619	164	108	187	37068	1962	890	9724	49644
1980.00	2554	162	102	192	34449	1798	782	9537	46566
1979.00	3451	176	97	196	31895	1636	680	9345	43556
1978.00	2354	151	79	201	28444	1460	583	9149	39636
1977.00	2281	151	53	205	26090	1309	504	8948	36851
1976.00	2259	137	54	204	23809	1158	451	8743	34161
1975.00	1478	129	50	208	21550	1021	397	8539	31507
1974.00	2059	128	49	204	20072	892	347	8331	29642
1973.00	2186	127	45	189	18013	764	298	8127	27202
1972.00	1921	127	39	185	15827	637	253	7938	24655
1971.00	1914	123	35	181	13906	510	214	7753	22383
1970.00	1392	123	32	179	11992	387	179	7572	20130
1974.75	1970	130	30	203	10600	264	147	7393	18404
1973.75	1907	48	27	179	8630	134	117	7190	16071
1972.75	1626	38	24	176	6723	86	90	7011	13910
1971.75	1301	26	18	173	5097	48	66	6835	12046
1970.75	1352	21	11	171	3796	22	48	6662	10528
1969.75	703	1	7	1063	2444	1	37	6491	8973
1968.75	980	0	6	1050	1741	0	30	5428	7199
1967.75	373	0	5	1037	761	0	24	4378	5163
1966.75	388	0	5	1087	388	0	19	3341	3748
1965.75	0	0	4	1099	0	0	14	2254	2268
1964.75	0	0	4	724	0	0	10	1155	1165
1963.75	0	0	4	372	0	0	6	431	437
1962.75	0	0	2	59	0	0	2	59	61

WILLOW CREEK DAM

RCC MIX QUANTITIES BY LIFT ELEVATION
BASED ON COMPOSITE FOUNDATION GRADES
AND THEORETICAL TEMPLATE GRADES

BASED ON REVISED QUANTITIES 10 MAY 83

SOURCE FILE = RCCTOT3

PLOTTED 23 JUN 1983 - GDPS

PLATE 5.5

EXHIBIT 5.1

TYPICAL MIXER PROFICIENCY
TEST RESULTS

RCC MIXER PROFICIENCY TEST

Date: 20 April 82 Responsible Corps Representative: E. Schrader

Mix: #4 : 315+135 Aggregate Blend: 0 % Blend

Mix Time: 135 seconds 63 % 3/4

Batch Size: 8 C.Y. 37 % 1-1/2

0 % 3

Full Mix

	Sample 1	Sample 2	Sample 3	Variability Index	Minimum Allowed	Result
Cement (lbs/cy)	368	332	275	83	80	Pass
Water (% by OD)	448	415	398	89	85	Pass
Water (% by CQM)	261	166	149	57	85	(Disregard)
Mortar Unit Wt (lbs/cy)	143.1	137.4	137.1	96	96	Pass
Plus #4 Agg (%)	57.0	56.2	58.5	96	90	Pass
Air (%)	1.3	1.1	1.0	76	—	—
Compacted Unit Wt (pcf)	—	—	—	—	—	—

Minus #4 Portion

	Sample 1	Sample 2	Sample 3	Variability Index	Minimum Allowed	Result
Cement (lbs/cy)	304	302	278	91	80	Pass
Water (% OD)	10.1	10.0	9.6	95	85	Pass
Water (% by QCM)	15.6	12.8	10.3	66	85	(Disregard)

Full Mix

	Mix Design	Req'd @ Batcher	Average Actual	Result
Cement (lbs/cy)	315	±4% (302 to 328)	305	OK
Plus #4 Agg (%)	61	±5% (58 to 64)	58	OK

Notes: Samples taken from 1st, middle, and last third of 1 batch in the mixer. CQM H_2O results questionable. Test passes.

EXHIBIT 5.1
Sheet 1 of 6

RCC MIXER PROFICIENCY TEST

Date: 14 MAY 82 Responsible Corps Representative: E. SCHRADER

Mix: #1: 80+32

Mix Time: 120 SECONDS

Batch Size: 8 CY

Aggregate Blend: 4 % Blend
47 % 3/4
23 % 1-1/2
26 % 3

Full Mix

	Sample 1	Sample 2	Sample 3	Variability Index	Minimum Allowed	Result
Cement (lbs/cy)	87	105	98	83	71.4	OK
Water (% by CQM)	6.7	7.2	8.5	79	75.8	ok
Mortar Unit Wt (lbs/cy)	131.8	139.5	142.7	93	85.6	ok
Plus #4 Agg (%)	70.3	58.9	53.1	76	80.2	FAIL
Air (%)	0.7	1.1	1.1	64	—	-
Compacted Unit Wt (pcf)	153.1	153.4	154.3	99	—	-

Minus #4 Portion

	Sample 1	Sample 2	Sample 3	Variability Index	Minimum Allowed	Result
Cement (lbs/cy)	226	260	236	87	71.4	OK
Water (% OD)	12.4	12.0	13.0	92	75.8	OK
Water (% by QCM)	14.3	9.9	13.8	69	75.8	FAIL

Full Mix

	Mix Design	Req'd @ Batcher	Average Actual	Result
Cement (lbs/cy)	80	±4% (77 to 83)	97	HIGH
Plus #4 Agg (%)	63	±5% (61 to 66)	61	OK

Notes: RANDOM Samples From FILL. TEST FAILS.
SUGGEST CHANGING BATCHING SEQUENCE FOR NEXT TEST

RCC MIXER PROFICIENCY TEST

Date: 9 June 82   Responsible Corps Representative: E. Schrader

Mix: #1 : 80+32   Aggregate Blend: 4 % Blend

Mix Time: 80 Seconds (Start Timing After Weigh Bins Emptied)   43 % 3/4

Batch Size: 8 C.Y.   22 % 1-1/2

31 % 3

Full Mix

	Sample 1	Sample 2	Sample 3	Variability Index	Minimum Allowed	Result
Cement (lbs/cy)	83	68	64	77.1	71.4	Pass
Water (% by CQM)	4.2	4.9	4.2	85.7	75.8	Pass
Mortar Unit Wt (lbs/cy)	137.8	144.2	139.9	95.6	85.6	Pass
Plus #4 Agg (%)	66.4	67.2	64.4	95.8	80.2	Pass
Air (%)	1.5	1.5	1.2	80.0	—	—
Compacted Unit Wt (pcf)	154.3	156.2	154.3	98.8	—	—

Minus #4 Portion

	Sample 1	Sample 2	Sample 3	Variability Index	Minimum Allowed	Result
Cement (lbs/cy)	220	220	234	94.0	71.4	Pass
Water (% OD)	12.9	11.1	11.5	86.0	75.8	Pass
Water (% by QCM)	8.3	10.4	8.8	79.8	75.8	Pass

Full Mix

	Mix Design	Req'd @ Batcher	Average Actual	Result
Cement (lbs/cy)	80	±4% (77 to 83)	71.7	Low
Plus #4 Agg (%)	70	±5% (66 to 74)	66.0	OK

Notes: Test Passes   Random Samples From Fill

RCC MIXER PROFICIENCY TEST

Date: 29 April 82 Responsible Corps Representative: E. Schrader

Mix: 80+32 Aggregate Blend: 11 % Blend

Mix Time: 135 Sec 35 % 3/4

Batch Size: 8 CY 26 % 1-1/2

28 % 3

Full Mix

	Sample 1	Sample 2	Sample 3	Variability Index	Minimum Allowed	Result
Cement (lbs/cy)	80	84	81	95	80	Pass
Water (% by CQM)	7.0	6.9	5.8	83	85	Fail
Mortar Unit Wt (lbs/cy)	125.7	120.5	130.6	92	96	Fail
Plus #4 Agg (%)	70.3	61.2	63.0	87	90	Fail
Air (%)	1.6	1.5	1.5	94	—	—
Compacted Unit Wt (pcf)	146.3	142.2	146.3	97	—	—

Minus #4 Portion

	Sample 1	Sample 2	Sample 3	Variability Index	Minimum Allowed	Result
Cement (lbs/cy)	270	236	240	87	80	Pass
Water (% OD)	19.0	18.2	17.1	90	85	Pass
Water (% by QCM)	21.2	20.1	—	—	85	—

Full Mix

	Mix Design	Req'd @ Batcher	Average Actual	Result
Cement (lbs/cy)	80	±4% (77 to 83)	82	OK
Plus #4 Agg (%)	64	±5% (61 to 67)	65	OK

Notes: Test Fails: Samples Taken From First, middle, and Last Thirds of one Batch in Mixer.

EXHIBIT 5.1
Sheet 4 of 6

RCC MIXER PROFICIENCY TEST

Date: 2 July 82 Responsible Corps Representative: Ernie Schrader

Mix: #1 : 80+32 Aggregate Blend: 4 % Blend

Mix Time: 75 Seconds (After emptied Weigh Bins) 47 % 3/4

Batch Size: 8 C.Y. 19 % 1-1/2

30 % 3

Full Mix

	Sample 1	Sample 2	Sample 3	Variability Index	Minimum Allowed	Result
Cement (lbs/cy)	63	112	73	56.2	71.4	Fail
Water (% by CQM)	10.5	6.9	4.3	40.9	75.8	Fail
Mortar Unit Wt (lbs/cy)	136.2	134.5	134.4	98.6	85.6	OK
Plus #4 Agg (%)	60.9	60.8	63.2	96.2	80.2	OK
Air (%)	0.9	1.4	1.1	64.3	-	-
Compacted Unit Wt (pcf)	152.3	147.9	150.7	97.1	-	-

Minus #4 Portion

	Sample 1	Sample 2	Sample 3	Variability Index	Minimum Allowed	Result
Cement (lbs/cy)	200	264	182	68.9	71.4	Fail
Water (% OD)	10.9	14.6	12.7	74.7	75.8	Fail
Water (% by QCM)	10.5	15.8	10.2	64.5	75.8	Fail

Full Mix

	Mix Design	Req'd @ Batcher	Average Actual	Result
Cement (lbs/cy)	80	76.8 to 83.2 (±4%)	82.6	OK
Plus #4 Agg (%)	74	70.3 to 77.7 (±5%)	61.6	Low

Notes: Test Failed: Maintain 80 second mix time previously approved: Random samples from fill

EXHIBIT 5.1
Sheet 5 of 6

RCC MIXER PROFICIENCY TEST

Date: 29 July 82 Responsible Corps Representative: E. Schrader

Mix: #4: 315+135

Mix Time: 90 Sec

Batch Size: 6 C.Y.

Aggregate Blend: 0 % Blend

67 % 3/4

33 % 1-1/2

0 % 3

Full Mix

	Sample 1	Sample 2	Sample 3	Variability Index	Minimum Allowed	Result
Cement (lbs/cy)	380	306	292	76.8	71.4	OK
Water (% by CQM)	7.0	7.4	6.9	93.2	25.8	OK
Mortar Unit Wt (lbs/cy)	142.1	138.1	140.1	97.2	85.6	OK
Plus #4 Agg (%)	55.1	52.4	49.0	88.9	80.2	OK
Air (%)	1.7	1.3	1.9	-	-	-
Compacted Unit Wt (pcf)	156.3	152.3	150.7	-	-	-

Minus #4 Portion

	Sample 1	Sample 2	Sample 3	Variability Index	Minimum Allowed	Result
Cement (lbs/cy)	260	365	342	71.2	71.4	OK
Water (% OD)	9.5	14.8	12.8	64.0	25.8	FAIL
Water (% by QCM)	14.2	11.9	11.4	80.3	25.8	OK

Full Mix

	Mix Design	Req'd @ Batcher	Average Actual	Result
Cement (lbs/cy)	315	302 to 328	326	OK
Plus #4 Agg (%)	66	63 to 70	52.1	Low

Notes: Includes Batch to-Batch Variability. Random Samples from Fill
Mix time Starts After Weigh Bins are Empty.
Water on -#4 Portion Not Critical. Test overall Passes

EXHIBIT 5.1
Sheet 6 of 6

CHAPTER 6

TRANSPORTING AND SPREADING RCC

TRANSPORTING

Contract specifications allowed transporting RCC by haul vehicle or conveyor system. The contractor had equipment readily available for vehicular haul and did not have the necessary conveyor equipment within his inventory. Primarily for this reason, hauling vehicles were used which, as discussed below, had specific problems associated with their use. These problems and associated inspection difficulties should be considered in future projects when deciding if vehicular haul should be prohibited or limited.

The original intent and contract requirements were to deliver the mixes from the plant to two gob hoppers or temporary holding facilities from which haul vehicles would be loaded. Initially, this was done with the hoppers having the specified capacity of 60 cubic yards each. In future work, if the plant can deliver RCC in a reasonably continuous manner, a smaller size of about 30 cubic yards may be more appropriate. The contractor's conveyor did not have capacity to deliver RCC from the mixers to the elevated hoppers at the specified required batch plant capacity of 400 cubic yards per hour. In order to establish the actual batch plant capacity, it was decided to allow the mix to be discharged directly into the haul vehicles from the plant without conveying into the hoppers on a trial basis. The rate of delivery from the plant (discussed in Chapter 5, "Roller-Compacted Concrete Production and Plant Capacity") increased. By properly sizing the haul vehicle fleet, providing access to the loading zone, and coordinating operation between the plant and placing foreman, this system worked well and was allowed to continue throughout the remainder of the project. In retrospect and considering the problems discussed below, it would have been better (although more costly to the contractor) to have reduced the gob hopper size, required that they be located on the placement, and insisted on a conveyor with sufficient capacity to transport the material to the hoppers at the specified rate of 400 cubic yards per hour.

The general hauling and spreading operation can be seen in the aerial photos of Plates 1.5 through 1.11. More specific photos of the equipment are shown on Plates 6.1 and 6.2.

The vast majority (probably 95 percent) of the RCC was delivered in Fiat Allis-Chalmers 580 scrapers loaded with 16 cubic yards (compacted volume) of RCC. This constituted two batches from the plant which bulked to an estimated 17 or 18 cubic yards of loose volume. The scrapers were capable of hauling more volume but because of the relatively high loose density of the RCC, two batches represented about 65,000 pounds and an effective full load by weight.

Until the foundation was covered with enough RCC to provide a large enough and reasonably level working area, RCC was hauled to the stilling basin zone with 10-cubic-yard highway end dumps. Near the top of the dam, where the width across the spillway area was reduced to as low as 15 feet, Peterbilt highway belly dumps with 10-cubic-yard capacity were used. After the spillway had reached the ogee crest height, the dam was split into the north and south nonoverflow sections with no traffic access from one side to the other. Off-highway Caterpillar 769 trucks carrying 16 cubic yards were then used. They had to back out onto the dam, dump, and drive off one at a time.

Segregation during and after dumping needed constant attention and surveillance but did not represent a serious problem - partly because of the attention it was given, partly because the angular aggregate minimized segregation, partly because the scrapers did a good job of spreading while dumping and the "drop" was minimal, and partly because the dozer operator was skillful in his spreading technique. Segregation from belly dumps was minimal, but from end dumps it was worse. When segregation occurred, it usually was caused by 3-inch aggregate rolling down the edge of a freshly spread layer or a dumped pile of RCC, and collecting at the bottom of the edge or pile on top of the previously compacted layer of RCC. The practice on the job was to remove this rock by hand shovel if it nested and would result in a rock pocket. If removed prior to rolling the lift, the stone was simply shoveled onto the top of the lift, broadcasting it over the surface.

The biggest problem with the hauling vehicles, and one which regardless of prompting and persistent reminders was not recognized for its seriousness by either inspectors or placing personnel, was maintaining the compacted RCC surface in an undisturbed condition. Field personnel simply did not appreciate the fact that although RCC looks like embankment material during placing, it is concrete and the surface should be treated with almost the same respect given to conventional concrete. The contract forbade tracking of contamination onto the fill and operating equipment in a manner that damaged the surface (specifically tight turns, etc.). This was routinely disregarded. Typically, scraper operators would make a sharp turn onto the RCC from the haul road while accelerating and shifting, and the tires would tear the top surface. With continued action for many hours at the same location and complicated by repeated rewetting by the water truck, a very thin layer of disturbed damp fine material with little or no cementing value would develop. Seldom was this cleaned off prior to placing the next layer of RCC. The result was a joint with a much poorer integrity, strength, and watertightness than could have been achieved. A similar situation occurred when vehicles turned to leave the fill onto the haul ramps.

A worse surface scuffing situation occurred each time the access ramp at one end or the other of the dam was raised (about once each day on an average). When this happened, the scrapers would discharge, make a sharp U-turn, drive over the loose RCC, and return across the dam to the ramp they had started from.

The worst surface damage was probably done by tracking mud, silt, and fine noncementitious debris onto the RCC from the access ramps. This was prohibited by specification, but again, both inspection and placing personnel refused to appreciate its importance. The result was compaction of the subsequent layer of RCC over the contaminated surface of the previous layer. The degree of contamination may have been tolerable in an embankment structure but the material at the joint interface was of little or no cementing value, resulting in a more permeable joint in the RCC. The problem became especially bad when the ramps were raised using adjacent overburden material consisting of almost all silt. It was not as bad when the contractor used 3-inch aggregate or shotrock for at least the last 50 feet of the ramp in front of the dam.

Another problem occasionally developed because of hauling equipment driving over an RCC mix which had been successfully compacted and that would have been quite acceptable if left undisturbed, but which had a moisture content slightly too wet. Under these circumstances, repeatedly driving over the mix would cause rutting to begin, continuous disturbance and redistribution of the aggregate-paste material while it was trying to develop initial set and strength, and ultimate pumping of water to the surface which subsequently caused a problem with tacking and surface contamination. Both the strength of the RCC mass and the integrity of the joint were affected.

A routine problem because of traffic on the fill was the result of the simultaneous requirement to maintain the surface in a continuously moist condition. This was almost exclusively done with a water truck continually misting the surface. For various reasons (rain, overwatering by the truck operator, mechanical breakdown, winds drying one side of the dam faster than the other, etc.) large portions of the compacted RCC surface would frequently have free surface water and temporary ponded water. This condition would have been acceptable if the surface was not mechanically aggravated. However, when hauling equipment drove over the surface while it had free surface moisture, a thin layer of muddy paste containing some cement resulted. By the time it was covered with the next layer of RCC, it frequently went through cycles of wet/dry and was periodically disturbed. The result was a joint with little strength and with reduced impermeability.

SPREADING

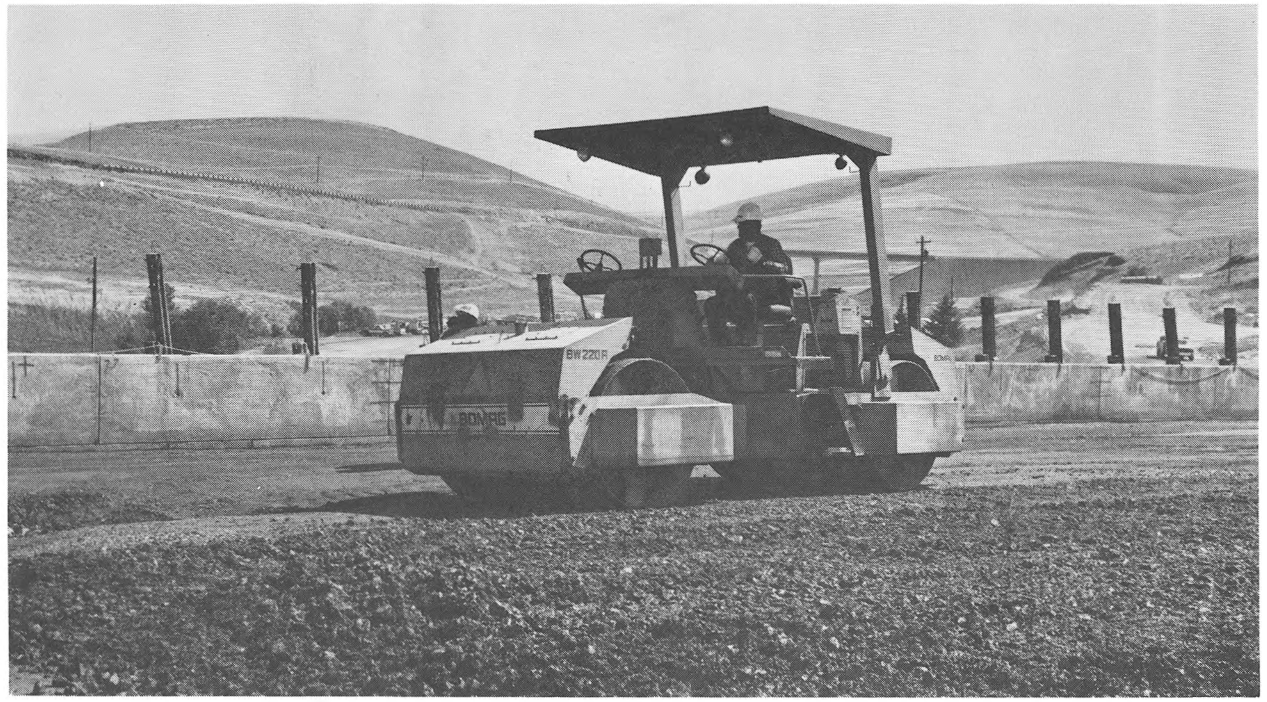
Most rough spreading was accomplished during discharge from the scrapers. A Caterpillar D-6 dozer was used for most of the final spreading. This consisted of leveling the rough spread material, pushing it short distances into tight corners and areas not accessible by the scrapers, and spreading piles left by the end-dump trucks. A small Caterpillar D-3 dozer with angle blade was used initially (about the first 10 days) until a large enough area and faster production were available for the larger dozer. The D-3 dozer was used again in the confined area at the top of the dam. A D-8 dozer was tried and found to be too large. It lacked maneuverability and caused significant damage to the RCC surface.

All tracked equipment caused some undesirable surface damage when crabbing and could cause significant damage by tearing the surface of previously compacted RCC if the operator made tight turns or was not careful.

As a general rule the dozer minimized damage when always pushing in the same direction and turning only on uncompacted material. Attentive roller operators usually and quickly rolled out track marks when they did occur on an already compacted surface. In future work, street pads or worn grousers should be specified for RCC spreading equipment.

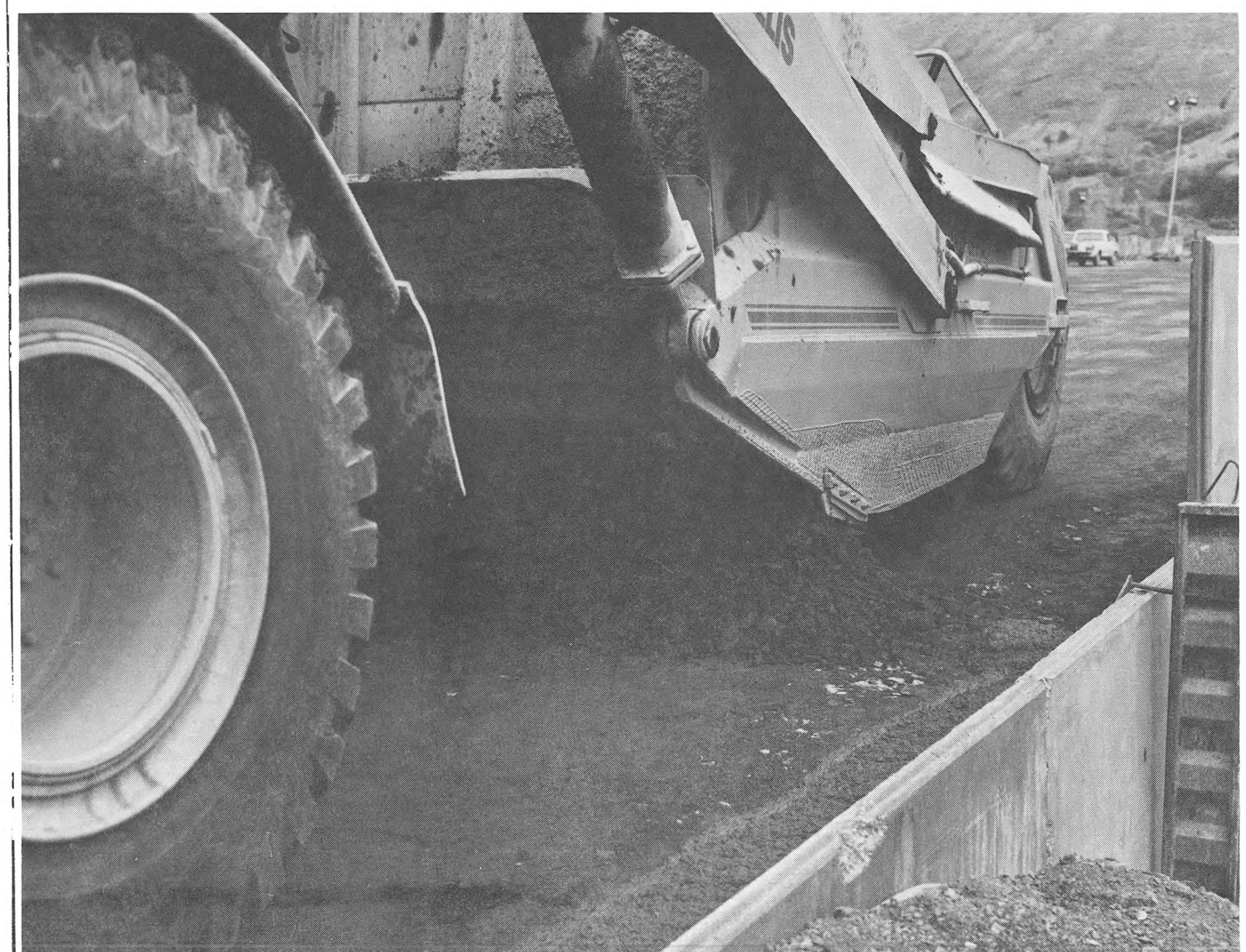
Specifications generally prohibited rubber-tired spreading equipment. Previous experience has shown that it is easy to spin the tires when trying to push any amount of RCC with it and that the slightest slip can cause substantial surface damage. During the test fill, a Caterpillar 966 front-end loader was used for spreading and again demonstrated this problem. A motor grader was available at the jobsite primarily to maintain haul roads. It was kept on the RCC fill during much of the placement and occasionally used for trimming, final grading, or to supplement other spreading equipment. When used in this capacity, the tires did not spin, but it was cumbersome to maneuver and would tear the surface when turned in the tight area available.

Grade control for spreading was achieved through use of a laser beam and movable target. The placing foreman made periodic checks of grade, and with little guidance the operators were able to maintain the lift level within a liberal but tolerable tolerance of about plus or minus 2 inches.

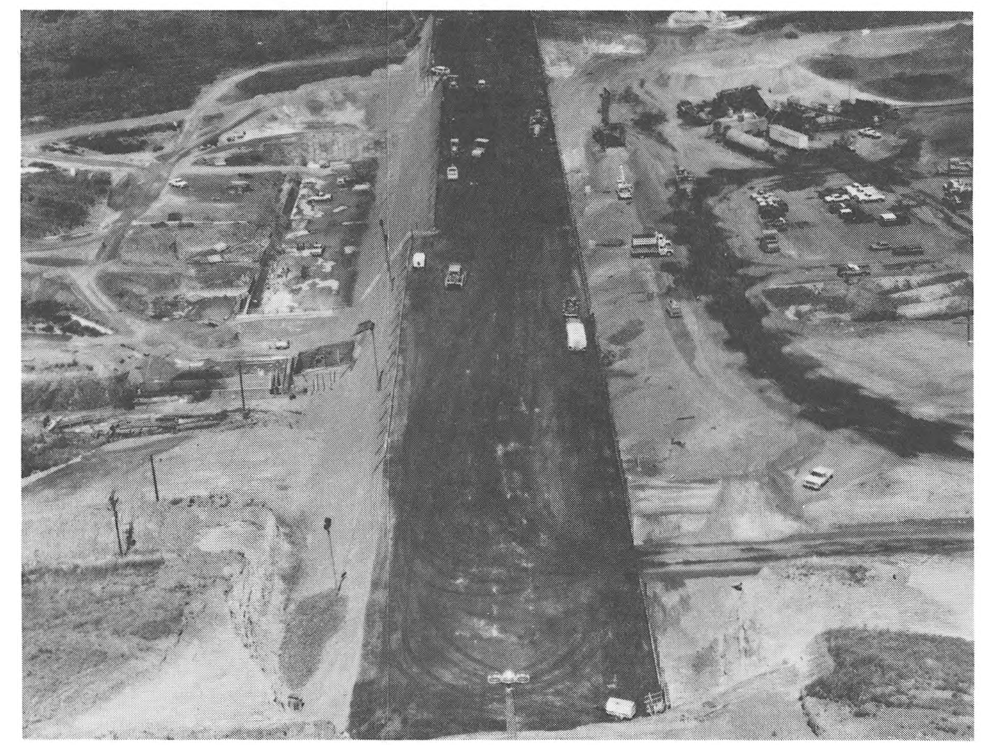


COMPACT WITH A 10 TON BOMAG DUAL DRUM VIBRATORY ROLLER.

SPREAD WITH A D-6 DOZER.



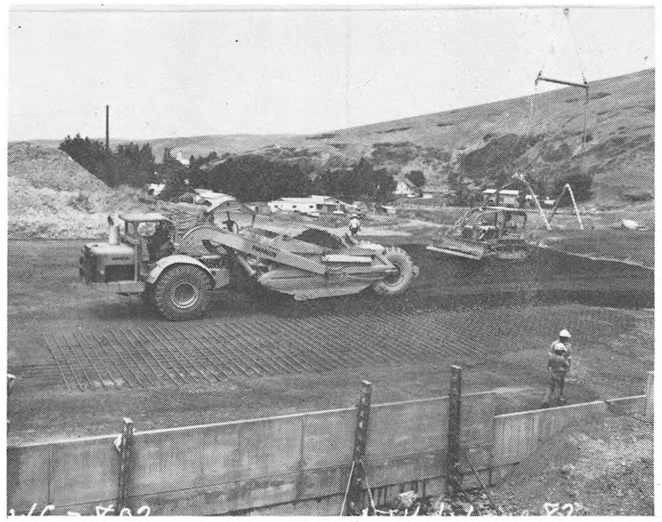
DUMPING FROM A SCRAPER HOLDING 16 CUBIC YARDS.



OVERALL VIEW OF THE EQUIPMENT SPREAD. JULY 20, 1982. NOTE THE UNDESIRED EQUIPMENT TIRE TRACKS. ALSO NOTE THE MINIMAL EQUIPMENT AND PERSONNEL REQUIREMENTS DURING PEAK PRODUCTION.

NORMAL DUMP, SPREAD, AND ROLL OPERATION

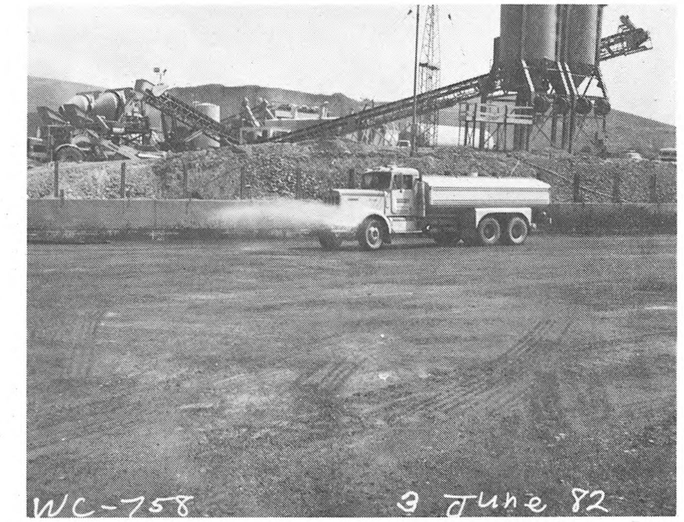
PLATE 6.1



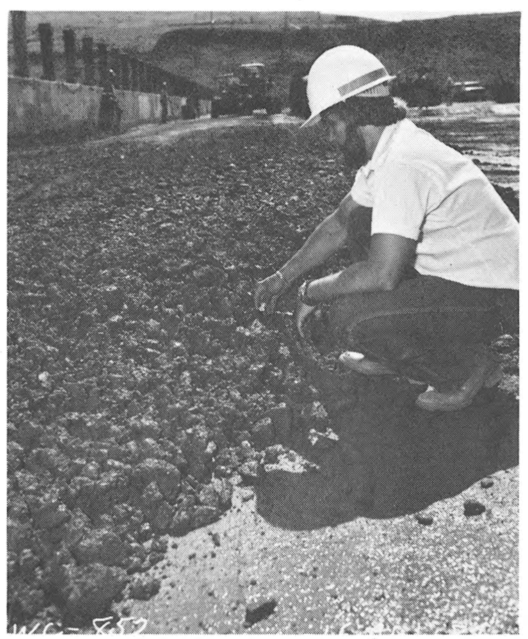
DUMPING AND SPREADING AT A REBAR MAT PLACED AT THE FLOOR OF THE GALLEY.

SPREADING AND ROLLING RCC OVER REBAR.

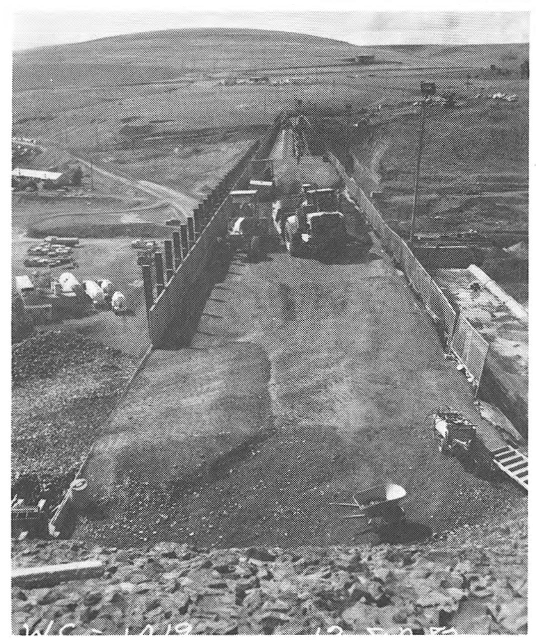
PLACING RCC BEHIND THE RIGHT TRAINING WALL.



WATER TRUCK MISTING THE SURFACE TO KEEP THE LIFT SURFACE DAMP.



RCC INTERIOR MIX AFTER SPREADING. THE MIX HERE IS SLIGHTLY TOO WET.



NARROW WORK AREA NEAR THE TOP OF THE DAM.

DUMP TRUCK USED IN NARROW AREAS AT THE TOP OF THE DAM.

PNEUMATIC ROLLER USED IN A TRIAL AREA.

RCC PLACING OPERATIONS

CHAPTER 7

COMPACTION OF ROLLER-COMPACTED CONCRETE

EQUIPMENT AND METHODS

RCC was consolidated into 12-inch lifts using smooth dual steel drum vibratory rollers. Because some compaction occurred from hauling and spreading equipment prior to the first pass of the vibratory roller, it was not possible to determine an accurate difference between the loose and compacted layer thickness, but estimates are that about 13 inches of loose RCC provided a 12-inch compacted layer.

A minimum of four passes (A to B being one pass and B to A being another pass) were provided. The contractor was not required to achieve a specified density, but to follow the "method" specifications. Roller requirements were:

Drum Width	66 inches to 96 inches
Drum Diameter	48 inches to 66 inches
Static Weight	21,000 pounds minimum
Dynamic Force	350-550 pounds per inch of drum width
Speed	1.5 mph maximum
Power to Eccentric Mass	125 horsepower minimum
Frequency	1,800 vpm minimum

The contractor used two models of roller with the following capabilities:

	Bomag BW 220A	DynaPac C50A
Drum Width	80 inches	84 inches
Drum Diameter	48 inches	60 inches
Static Weight	25,000 pounds	29,400 pounds
Dynamic Force	375 pounds/inch	429 pounds/inch
Speed	1.5 mph	1.5 mph
Power	150 horsepower	155 horsepower
Frequency	2,400 vpm	2,400 vpm
Amplitude	0.023-0.082 inch	0.032 inch

As required by contract, two operational rollers (with operators) were kept on the placement during RCC construction. A third roller was kept on standby at the project. This provided more rolling capacity than theoretically necessary, but under actual construction conditions was appropriate. With all equipment functional and at normal placing rates, the rollers were theoretically functional for about 45 percent of the time. This allowed for the rollers to comfortably be able to roll the mix immediately after spreading. It also allowed for production to continue uninterrupted with just one roller while getting the standby roller during times when one of the rollers on the fill broke down. The two rollers were also needed so that one roller could finish compaction of a lift at one end of the dam while the other roller compacted material being placed for the start of the next layer at the other end of the dam.

Compaction was usually accomplished within a few minutes of when the material was dumped and spread. Specifications required rolling within 10 minutes of spreading. In reality it was impractical or impossible to get this accomplished in some of the confined depressions of the foundation at the start of the job. Occasionally material would be in place as long as 25 minutes before being compacted, at which time it could be as much as 45 minutes since being batched. In these areas the problem was typically one of bringing in small truckloads of material over the irregular foundation terrain, spreading it with a small dozer and by hand, and then bringing in both small and large rollers. This very undesirable situation occurred until depressions and rough areas in the foundation were filled to a level that allowed a reasonably flat, accessible, and sizable work area. Fortunately, this condition occurred at the start of construction, early in the spring, when temperatures were cool and the adverse effects of delays were minimized.

Plates 6.1, 6.2, and 20.1 show compaction with the various pieces of equipment at different locations.

Densities achieved and the methods of determining densities are discussed in Chapter 10, "Density and Void Space," of this report. In general, unit weights on the order of 150 to 155 pounds per cubic foot were achieved, and about 98 percent of the compaction occurred within the first two or three passes of the roller.

Maintenance of the rollers was an ongoing chore. Hydraulic line leaks and occasional ruptures while operating on the RCC required cleanup to remove spilled oil that could act as a bond breaker between lifts. Because the compacted surface was very tight and hydrated into a solid mass, the rollers were subjected to much harsher pounding and impact than occurs on asphalt and softer soil materials. The hardest thing on equipment was rolling edges of the RCC, which twisted the rollers at the articulated hinge point.

MODIFIED COMPACTION METHODS

A series of lifts was compacted in portions of the dam using a rubber tire (pneumatic) roller, and the rubber tire roller in conjunction with the vibratory roller. These trials were made to demonstrate what could be achieved with other compaction equipment under production situations. The pneumatic roller was a Hyster Model C500A with a gross weight of 15 tons and a tire pressure of 90 to 100 psi. Adjacent areas of the same mix in the same lifts were compacted with the standard four passes of the vibratory roller for comparison. The following data summarizes results of this work based on nuclear density tests of the freshly compacted mix. More conclusive information, including any differences in lift joint quality, will be obtained from cores scheduled to be taken from the trial areas in the summer of 1983.

Mix	Modified Compaction Method	Average Density	Average Density with 4 Passes of Vibratory Roller
1	2 Passes-Pneumatic Roller	146.0 pcf	151.7 pcf
1	4 Passes-Pneumatic Roller	149.0 pcf	151.7 pcf
1	6 Passes Pneumatic Roller	151.8 pcf	151.7 pcf
3	2 Passes-Pneumatic Roller	149.4 pcf	152.8 pcf
3	4 Passes-Pneumatic Roller	151.9 pcf	152.8 pcf
3	6 Passes-Pneumatic Roller	153.5 pcf	152.8 pcf
3	4 Passes-Pneumatic Roller + 1 Pass-Vibratory Roller	151.4 pcf	153.2 pcf
3	6 Passes-Pneumatic Roller + 1 Pass-Vibratory Roller	144.8 pcf	153.4 pcf
3	6 Passes-Pneumatic Roller	151.8 pcf	154.0 pcf

HAND COMPACTION

Small areas which could not be effectively accessed or maneuvered on by the large rollers were compacted with walk-behind rollers and "pogo-stick" tampers. The same equipment was used for the following situations: to provide compaction of RCC around the perimeter of each lift where it contacted the foundation rock, immediately behind the precast upstream face and spillway wall panels, and along a 3-foot-wide zone of the downstream face so that the large rollers would not be exposed to the safety hazard of operating at the edge.

The contractor was required to have walk-behind rollers producing a dynamic force of 150 pounds per inch of drum width for double drum rollers and 300 pounds per inch of drum width for single drum rollers. Tampers were required to produce a force per blow of at least 1,900 pounds. The contractor used Mikasa Model NDR-90 dual drum walk-behind rollers having 155 pounds of dynamic force per inch of drum width and Model N7R-120N tampers with 3,510 pounds of force per impact blow.

COMPACTION METER

The compaction meter is a relatively new device which can indicate to the roller operator the relative density of the material directly below the roller drum as it is operating. The contract required each roller to be equipped with a compaction meter, and intended that they be used as a tool to help determine where high and low density was being achieved. Experience at Willow Creek showed that the meter is suited to use with noncementitious deep fills of a fairly uniform moisture content, but it is not applicable to roller compacted concrete.

The compaction meter is an onboard instrument which provides a digital LED readout to the operator. A number such as "25" or "53" is displayed which increases with increasing density and compaction. The readout value can be related back to a density value for any given material. The methodology of the equipment is that it uses the response of the vibratory drum to the material being compacted, specifically the fundamental frequency and first harmonic. Quite simply, if the drum vibrates on an uncompacted, soft, and loose material the readout is low. As the material becomes compacted and tight, the value increases.

The problem with RCC is that the response includes reaction of materials below the first lift. Usually that material would be more than 12 hours old and would have hydrated into a hard mass regardless of density. Similarly, a lift surface which may have low density but is maturing through hydration will be getting hard and show a misleading high digital readout. At Willow Creek, meter readings could not be correlated with density. The readings were really indicating some composite value of the hardness of the mass below the roller, not necessarily the density.

Experience at Willow Creek also showed that each meter should be installed and calibrated by knowledgeable factory representatives. Unfortunately, assistance from suppliers of the meters was not punctual.

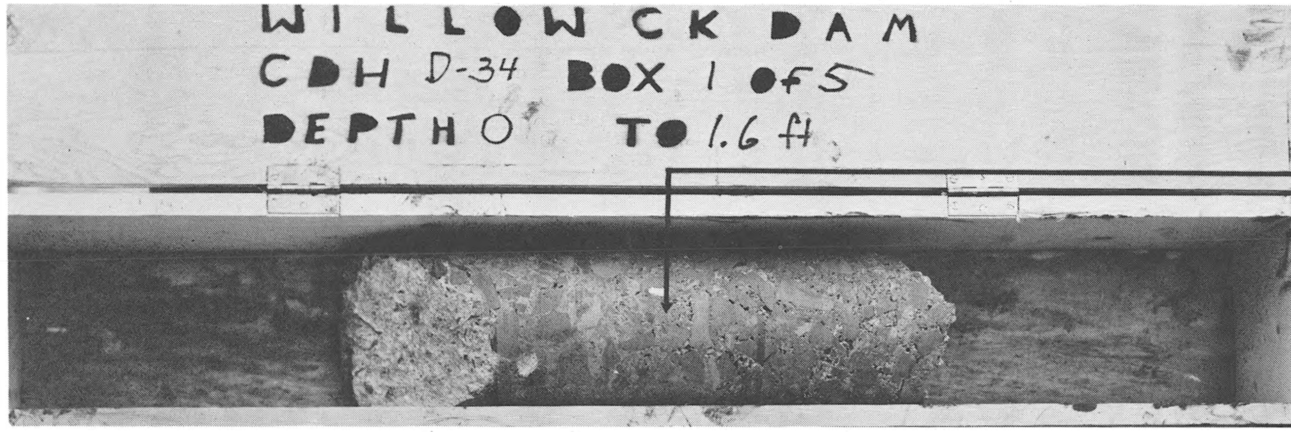
CHAPTER 8

CORES

A major coring program will be completed during 1982. This effort will carefully and systematically retrieve cores for evaluation as discussed in Chapter 24, "Future Evaluations and Testing."

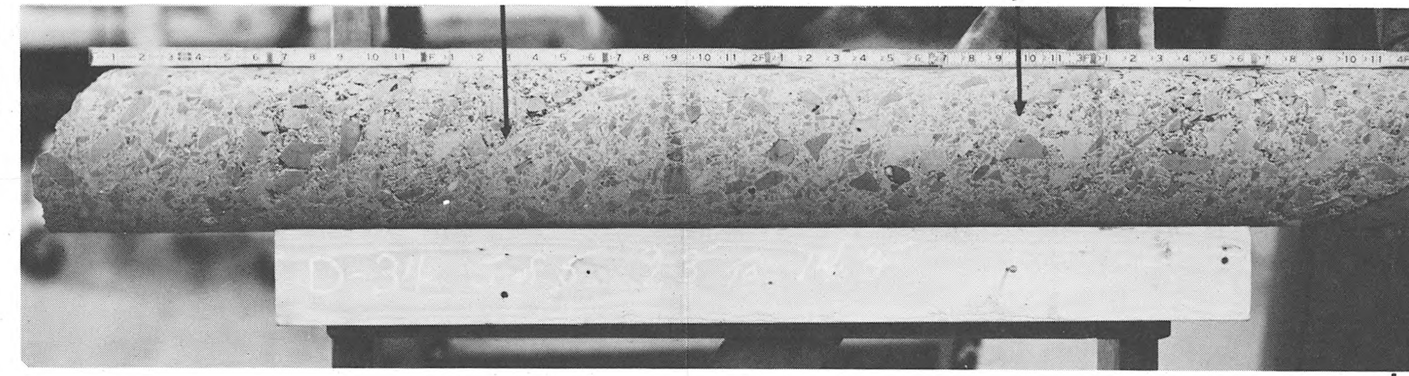
During construction of the dam, drain holes were required as a part of design in the stilling basin and spillway area. In order to get a preliminary indication of the in-place quality of concrete being achieved, some of these holes were drilled by coring with a 6-inch nominal size barrel. Most of these were short holes in the stilling basin (mix 4) but some were longer holes going from the spillway face through the lean interior mix (mix 1) to the foundation. The holes crossed lift or layer joints at different angles depending on the hole inclination.

Compressive strengths of the cores are discussed in Chapter 9, "Test Cylinders and Compressive Strength Results." Plates 8.1 through 8.5 show typical core photos including good and bad results. Some of the core, as can obviously be seen in the photos for hole E-16, was distinctly and severely damaged by drill technique and equipment. In this hole the core catcher did not retract. It tore up and broke apart the core. At other times, the drillers were observed removing the core from the barrel with a sledgehammer. Whether all instances of poor core recovery were the result of bad equipment and practice is unknown. There probably also were cases of poorly consolidated material at lift joints, and of segregation which would have resulted in poor core recovery. At any rate, the upcoming core program using 9-inch nominal size barrels will be closely inspected and provide accurate information. As evidenced in the photos, there typically are examples of excellent core recovery. Also, every concrete/foundation rock zone drilled showed excellent contact.



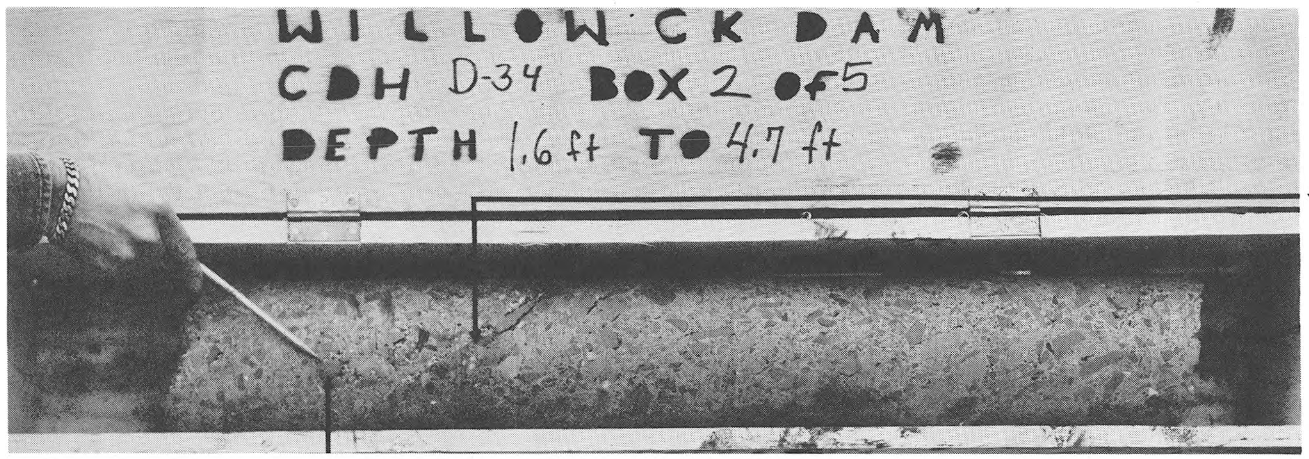
JOINT

JOINTS



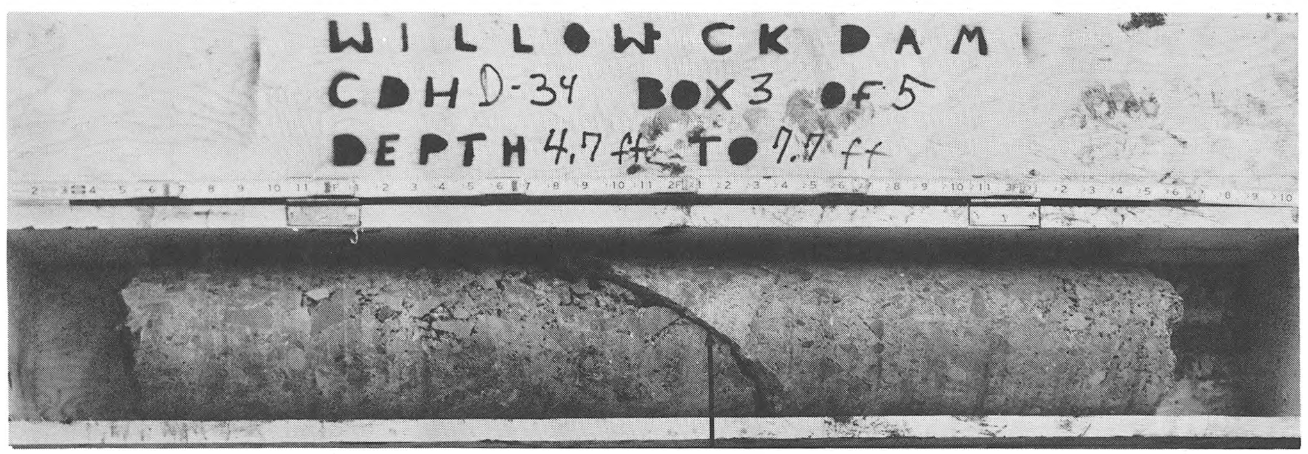
SECTION OF CORE LATER BROKEN AT JOINTS TO FIT INTO BOX.

FOUNDATION ROCK



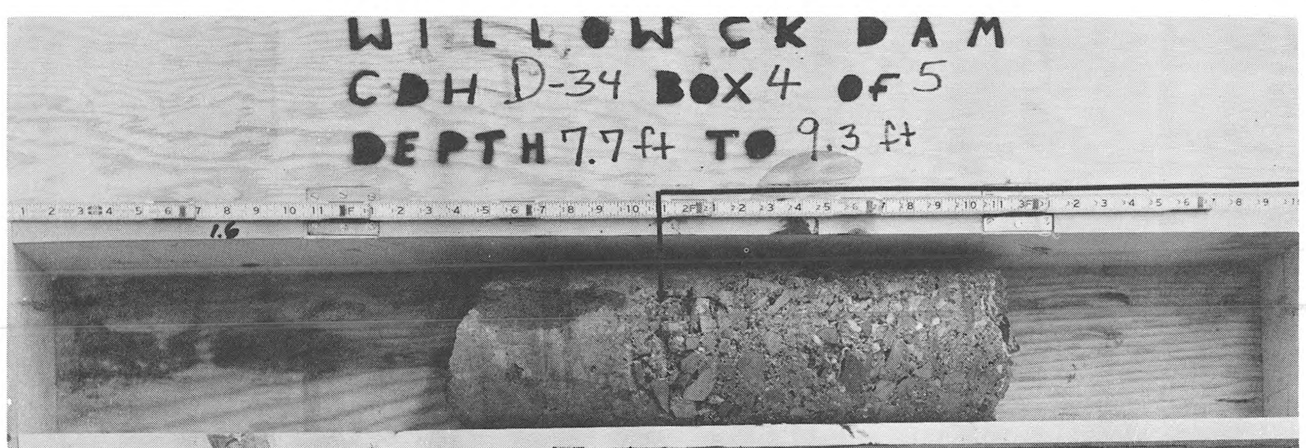
JOINT

REBAR 2 INCHES ABOVE JOINT.
NO BEDDING MIX.



HOLE D-34 DRILLED AT AN ANGLE IN THE STILLING BASIN. DRILL EQUIPMENT WAS OPERATING PROPERLY. ZERO CORE LOSS. ALL BREAKS IN THE CORE WERE DELIBERATELY FORCED DURING DRILLING AND HANDLING TO OBTAIN PIECES THAT ARE OF A SMALLER SIZE FOR STORAGE/TESTING.

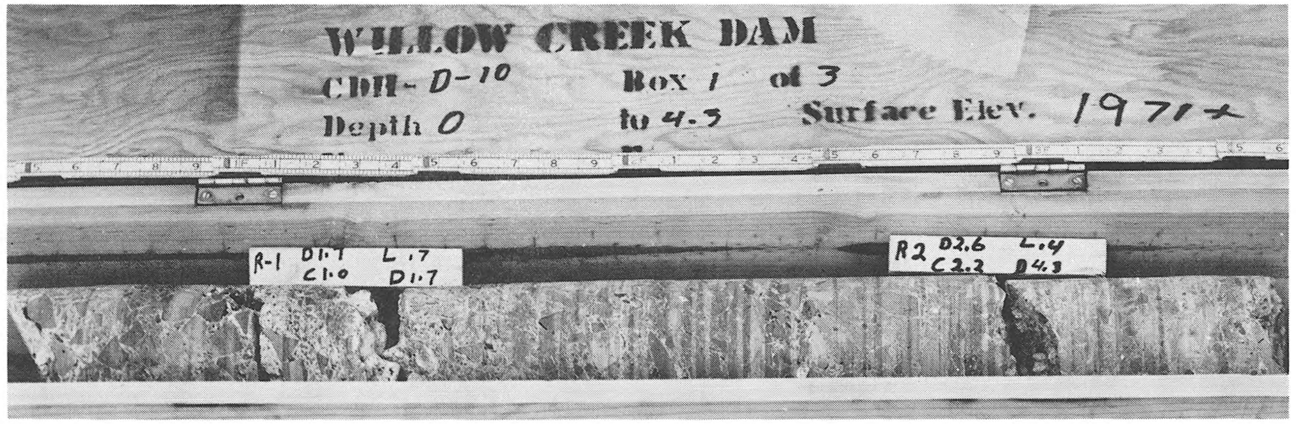
JOINT SEPARATED DURING HANDLING.

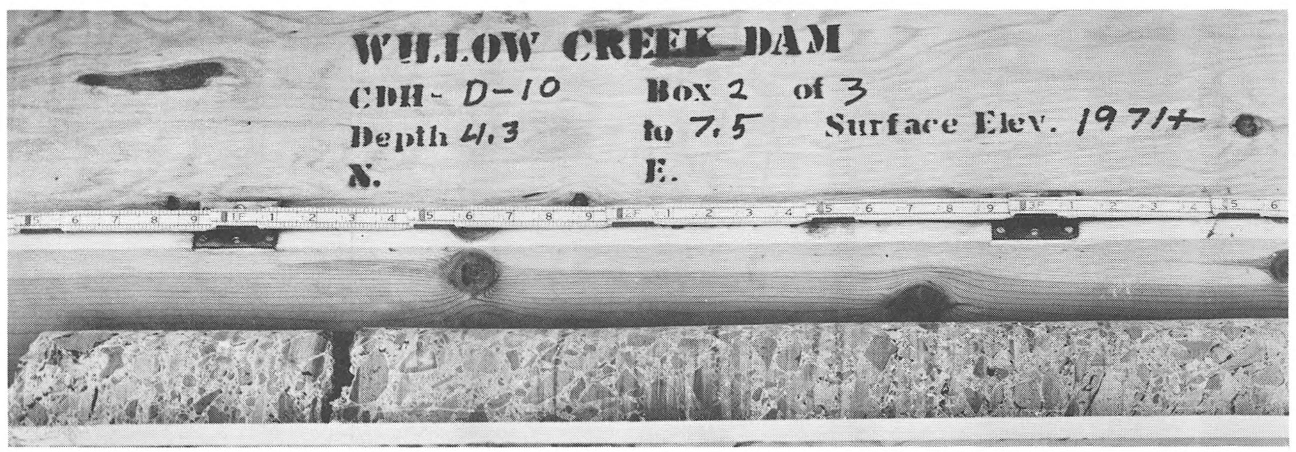


JOINT

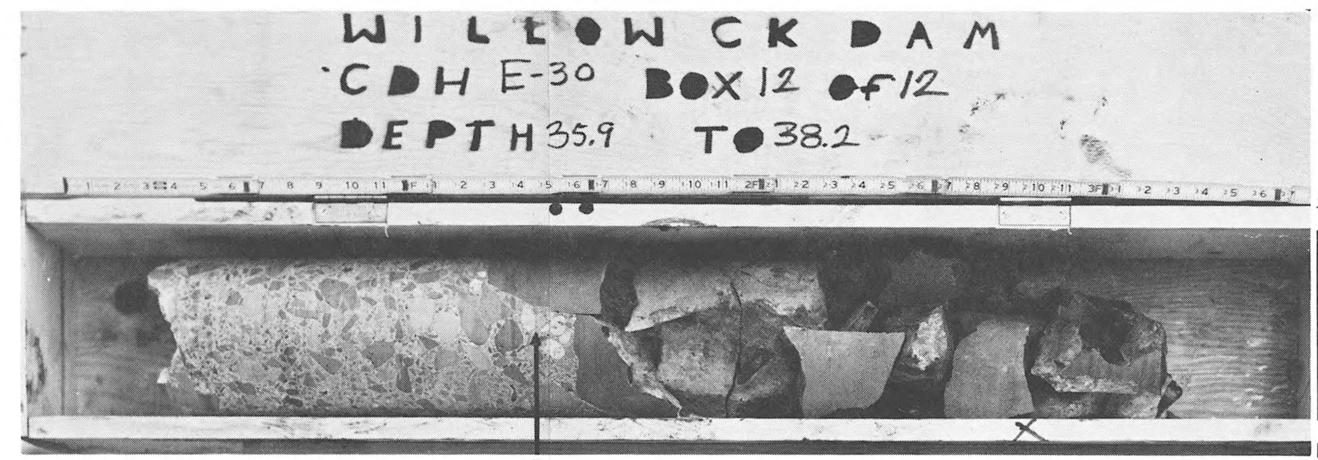
RCC CORES I

PLATE 8.1

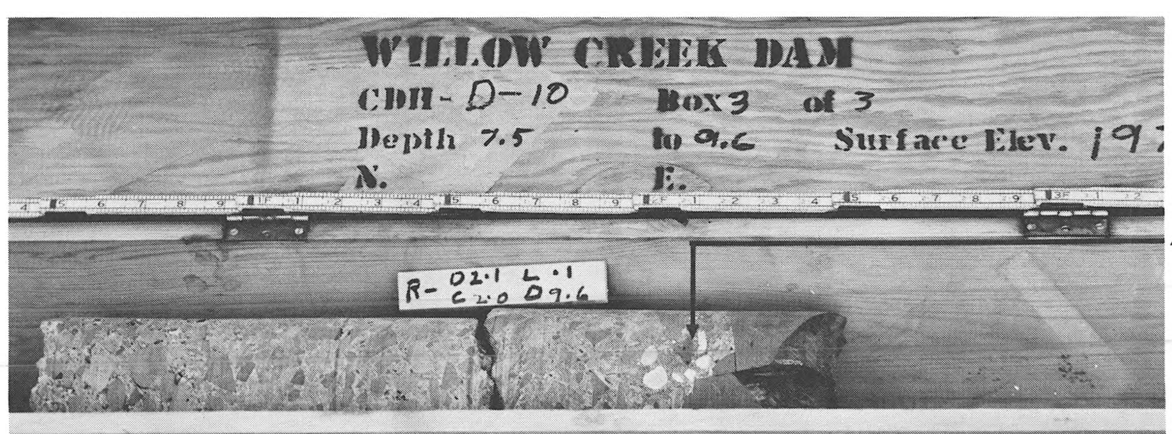




BOTTOM OF HOLE E-30

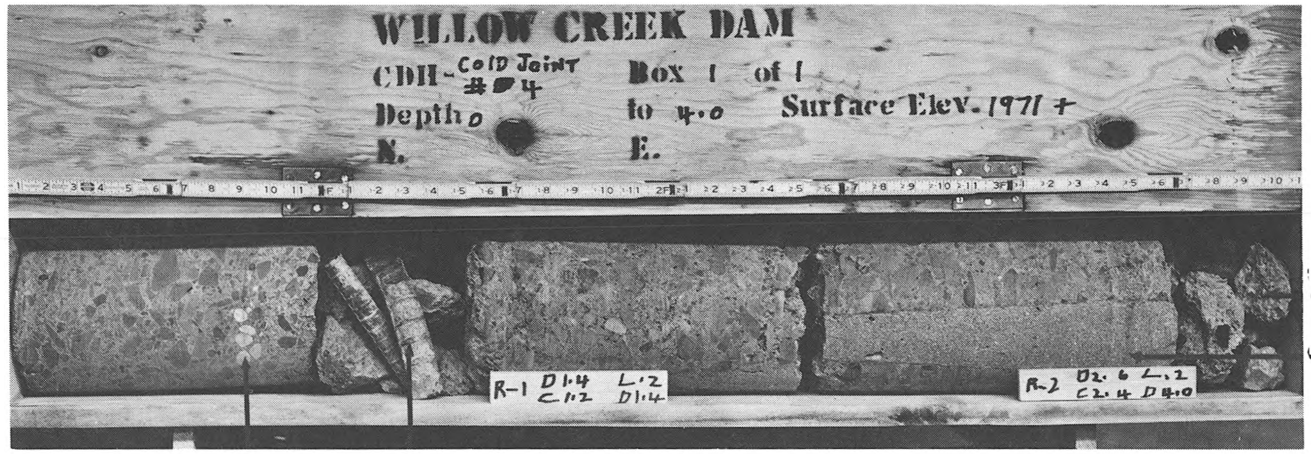


CONVENTIONAL CONCRETE BEDDING BETWEEN FOUNDATION ROCK AND THE FIRST LAYER OF RCC.



RCC CORES II

PLATE 8.2

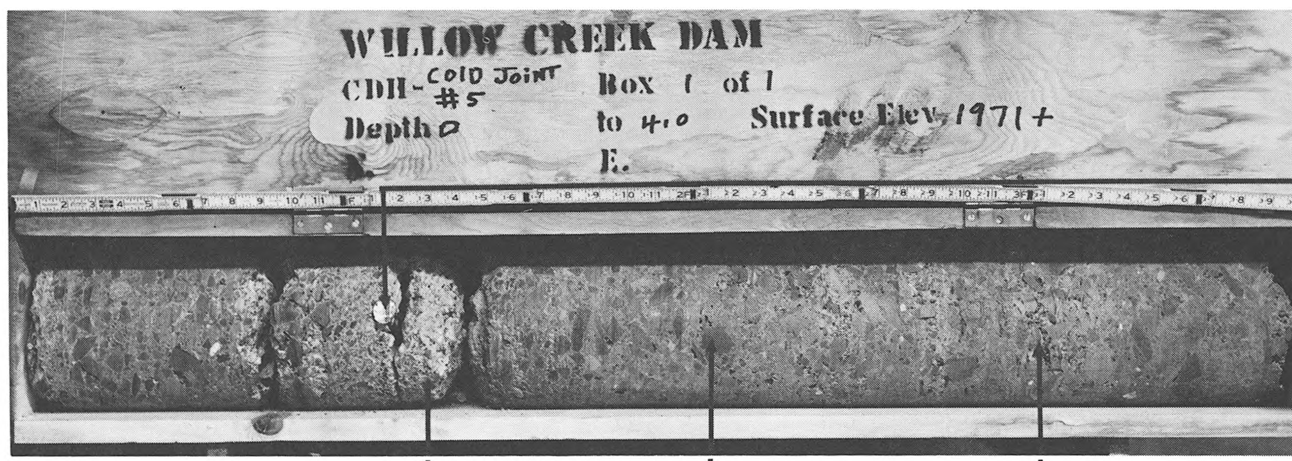


RCC BEDDING

GROUT IN A VERTICAL STILLING BASIN ANCHOR BAR HOLE.

SEGMENTS OF HORIZONTAL REBAR AND VERTICAL ANCHOR BAR AT THE BEND.

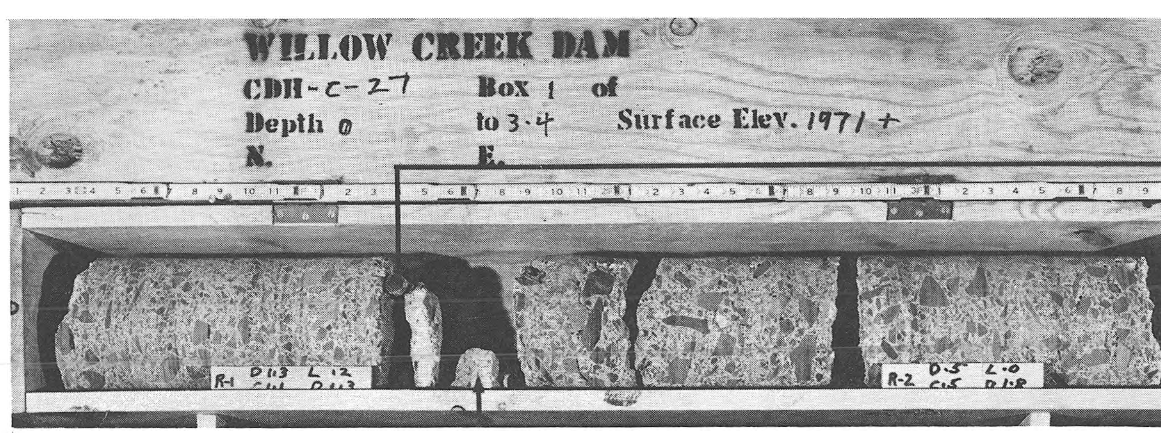
THIN LAYER OF CONVENTIONAL BEDDING AT AN UNPLANNED COLD JOINT.



HORIZONTAL REINFORCING STEEL

JOINTS WITH NO BEDDING.

RCC BEDDING



HORIZONTAL REINFORCING STEEL

RCC BEDDING

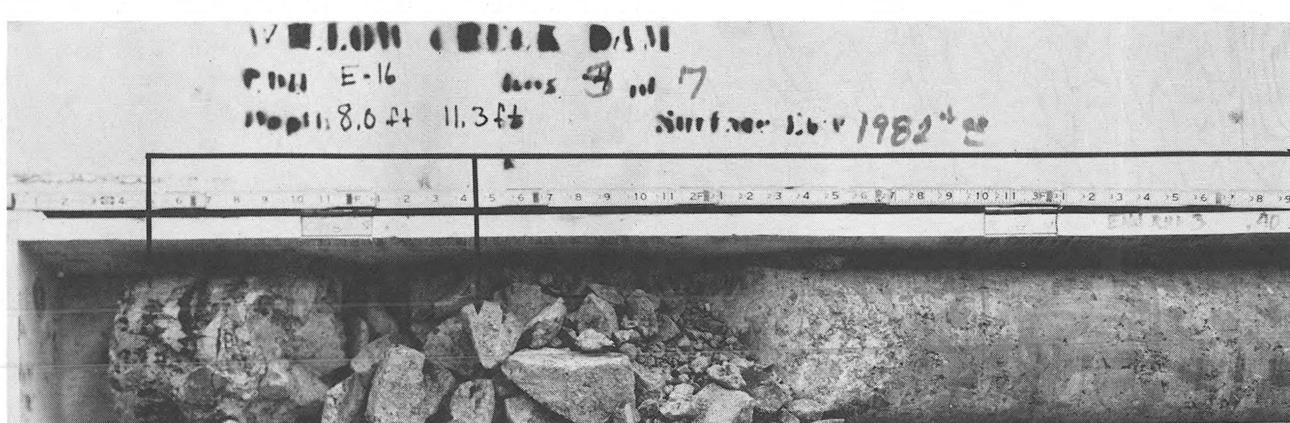
RCC CORES III

PLATE 8.3

OBVIOUS CIRCUMFERENTIAL SCORE MARKS FROM MALFUNCTIONING DRILL EQUIPMENT/OPERATIONS.

MORE SCORING AND DRILL EQUIPMENT DAMAGE IS EVIDENT.

CORE E-16 WAS DRILLED WHEN THE EQUIPMENT WAS NOT FUNCTIONING PROPERLY AND INSPECTION DID NOT REQUIRE CORRECTION OF THE PROBLEM. THE CORE CATCHER DID NOT RETRACT AND DEBRIS CHURNED AROUND WITHIN THE INNER CORE BARREL. ALSO, SOME CORE WAS REMOVED BY HAMMERING IT OUT OF THE BARREL AND WITH A PRY BAR.



SEGMENT REMOVED BY HAMMER. NOTE SCORING OF UPPER CORE HAD BOUND-UP WITHIN THE BARREL.

RCC CORES IV

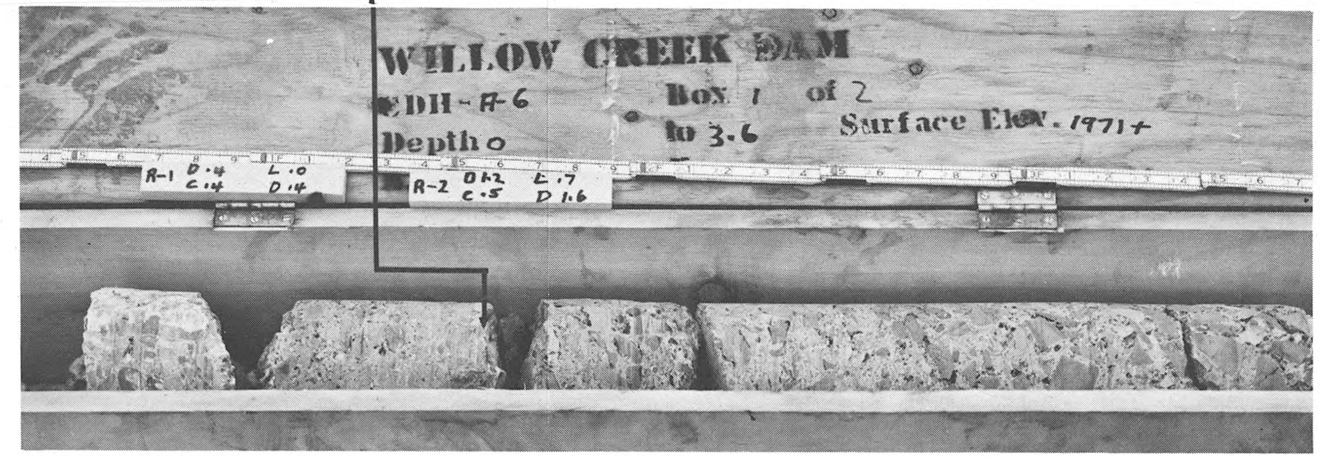
PLATE 8.4

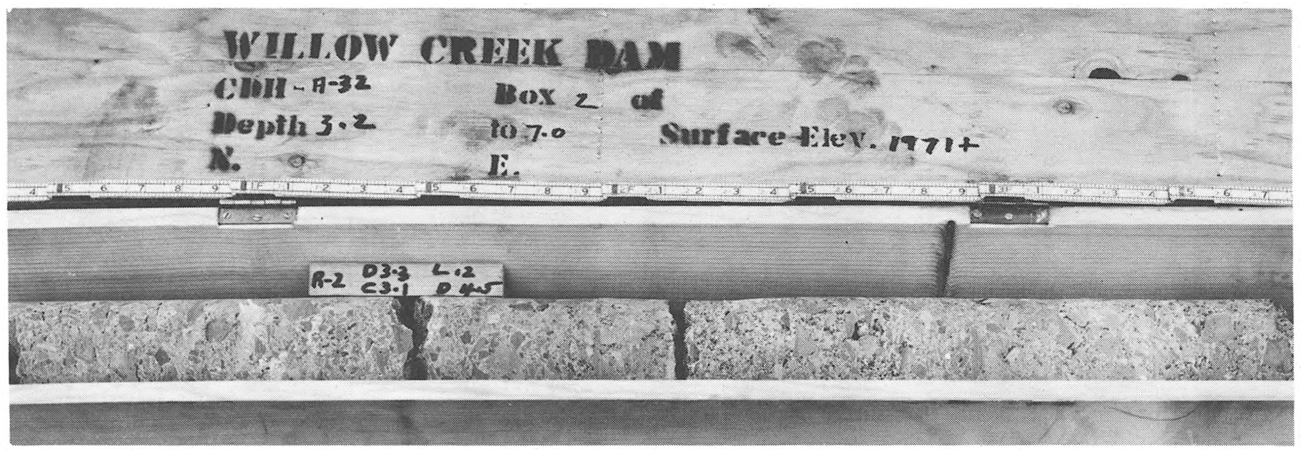
CORE A-32

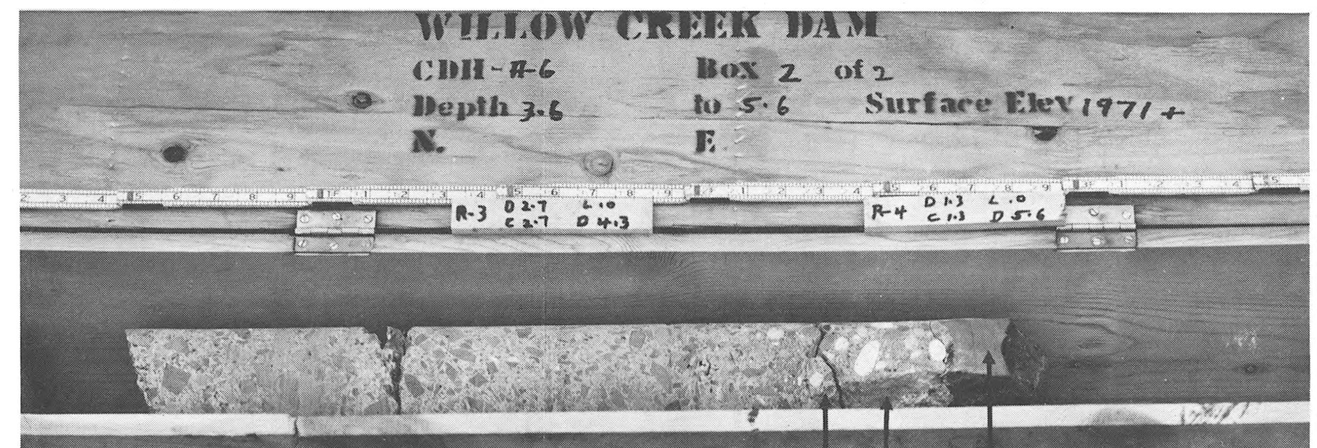
CORE A-6

HORIZONTAL REBAR 2 INCHES ABOVE JOINT.
NO BEDDING MIX USED IN THIS LOCATION.

DRILLERS FAILED TO RETRIEVE 0.7 FEET OF CORE MATERIAL.



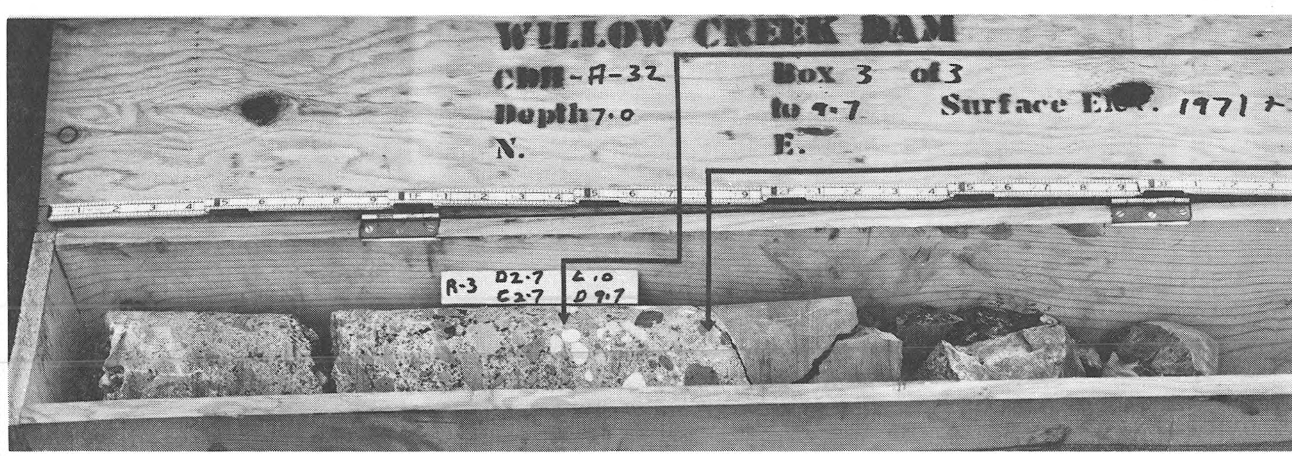




RCC BONDED TO DENTAL CONCRETE BY A THIN LAYER OF CONVENTIONAL CONCRETE BEDDING.

DENTAL CONCRETE

FOUNDATION ROCK



RCC CORES V

PLATE 8.5

CHAPTER 9

TEST CYLINDERS AND COMPRESSIVE STRENGTH RESULTS

METHODS OF MAKING CYLINDERS

Two sizes and two methods of making test cylinders were used. The majority of cylinders were the standard 6- x 12-inch size made from material sieved over a 2-inch screen. Companion 9- x 18-inch cylinders were made with the full mix for every sixth set of 6- x 12-inch cylinders for each mix design. Plate 9.1 shows compaction of test cylinders.

Rigid molds were used for all RCC mixes. A very large number of the heavy rigid molds would have been necessary but a contractor value engineering proposal was adopted which used plastic liners inside split rigid molds for the 6- x 12-inch cylinders. After compaction, the rigid split mold was opened (by removing the retaining ring and separating the mold longitudinally into two halves) and the liner with compacted mix was removed. The rigid molds were then reassembled and reused with new liners. A savings of about $5,000 was realized with the use of the reusable molds.

Cylinders were made by compaction with a pneumatic pole tamper and also by vibration on a modified vebee table. The pole tamper was used for both 6- x 12-inch and 9- x 18-inch cylinders. The vebee was used for 6- x 12-inch cylinders only since it cannot be adapted to the larger size.

Of these techniques, compaction by tamping in 6- x 12-inch cylinders was the most practical method and gave results that, at this point, appear to best represent material compacted in the dam. However, none of the procedures thoroughly consolidated the cylinders. In all cases, voids were typically found around the perimeter of the cylinder and a lift line between the three layers that went into the mold were prominent. Fully compacted cylinders of RCC without voids at the perimeter could be achieved only when the mix was too wet, i.e., wetter than would be of practical use in construction and that would support the weight of a vibratory roller.

The problem of compaction was complicated by the fact that by the time the mix was obtained, brought to the laboratory, screened, placed in the molds, and compacted in three lifts, it hydrated and dried somewhat. All reasonable efforts were made to minimize hydration and drying.

Future work should also pay particular attention to this but it cannot be eliminated. The mix was obtained from the dam by using a loader to scoop up a sample immediately after being dumped. The reason for taking the sample from the dam instead of the batch plant is discussed in Chapter 5, "Roller-Compacted Concrete Production and Plant Capacity." Approximately 1/2-cubic yard was dumped into a pickup truck bed and brought directly to the laboratory. It was covered with wet burlap and all work was done inside the covered laboratory. The length of time from when a mix was batched until all cylinders from it were made usually was about 1 hour for the 3-inch aggregate mixes and slightly less for the 3/4-inch and 1-1/2-inch aggregate mix. Occasionally it would take well over an hour to make the cylinders and a few sets were finished after about 2 hours. This delay is certainly undesirable if conventional concrete is used but it is even more important for RCC because just a slight loss of moisture from optimum causes a great loss of compactibility.

The compactor was a pneumatic pole tamper designed for compaction around fenceposts and telephone poles. A standby compactor and spare seals are necessary laboratory equipment. The foot of the compactor fit easily within the 6-inch mold with about 1/4-inch clearance. The mold was filled in three layers, each layer being compacted separately. The exact number of blows per layer and the different techniques of the different technicians doing the work was found not to be critical to making the cylinders. Compaction instructions do not need to be any more complicated than: (1) work as fast as possible, minimizing the amount of drying and hydration, and (2) compact each layer until the material begins to rebound up around the compactor foot. In the field, compaction reached nearly 100 percent and simply did not result in less than about 0.2-percent to 1.2-percent voids regardless of additional compactive effort. The laboratory pole compactor achieved similar compaction (except for the void space around the perimeter of the molds) at which time material would rebound out from the mold and additional compaction had no significant effect.

The modified vebee apparatus is only suited to mixes that contain more water, paste, and/or mortar than would be used in practical field mixes. At the moisture content and gradation typically used at Willow Creek, a well-compacted cylinder could not be obtained with the vebee equipment. The procedure consisted of vibrating the mix into the cylinder mold on the vebee table while simultaneously pushing the mix down with a rigid 20-pound surcharge weight the diameter of the mold. The actual surcharge effort was significantly higher because the operators pushed down with a kneading action on the handle of the weight during consolidation.

Ideally, compaction would be by the pole tamper while the rigid cylinders are securely anchored to a large vibrating table. This would simulate the action of a vibratory roller as used in the field. The procedure would be expensive and probably would not give significantly different results than from pole compaction without vibration, but it should be investigated on a future project.

FREQUENCY OF TESTING

A basic set of guidelines was established for the frequency of making RCC cylinders. Because the project was the first of its type, and because records complete enough to allow various evaluation studies were needed, the frequency of testing was higher than ordinarily would have been necessary. On a normal production project where significant post-construction studies are not anticipated, the frequency of testing could be decreased after stable production is established.

At Willow Creek, the following general guidelines for testing frequency were followed with supplemental tests when changes in ash source, admixtures, etc., were tried. During initial production, a set of 6- x 12-inch cylinders was made for every 2,000 cubic yards or three shifts of placement (whichever occurred last) for each mix used. Each "set" of cylinders included two samples for each age to be tested. After the first 16,000 cubic yards of each mix were placed, the frequency of testing was reduced to one set of each mix for every 12 shifts of production. Every sixth set of cylinders for each mix included a companion set of 9- x 18-inch cylinders with two cylinders of each size to be tested at ages of 3, 7, 14, 28, 90, 180, and 365 days. When only 6- x 12-inch cylinders were made and the companion set was not required, only two cylinders were made for testing at each age of 7 and 28 days.

COMPRESSIVE STRENGTH RESULTS

A computer program was established to keep track of compressive cylinder test results. As data became available it was routinely inputted to the computer, and the summary of test results was automatically updated. Data for later age strengths are still being received and the summary will continue to be updated. The final update of this concrete report scheduled for publication in October 1983 will include all data to be obtained for the project. As of February 1983, approximately 2,500 cylinder strengths had been recorded. Along with strengths, the unit weights, vebee time (when applicable), temperature of the mix, cement content as determined by CQM, and water content as determined by CQM were also recorded for each set of cylinders.

The program allows for listing of all data of each mix by date made, but its main purpose was to provide the summary sheets shown in Exhibit 9.1. This summary shows average strengths, average unit weights, average cement and water contents, and the number of tests for each mix at each age and for each cylinder size. It also separates cylinders by the method of compaction and shows averages when all cylinders of all sizes and methods of compaction are combined for each mix and age. In addition the summary shows if trends developed, such as increasing or decreasing strengths with time, by comparing results of the last 10 and 25 sets of tests to all test results.

Plates 9.2 through 9.13 show the graphical relationship between age and strength for each mix and cylinder size when compaction was by tamping. A number of important observations are evident:

(1) For all mixes and ages, the 9- x 18-inch cylinders gave significantly less strength than the 6- x 12-inch cylinders.

(2) There was very little strength benefit from the fly ash (compare the 175+80 to the 175+00 mixes).

(3) For all mixes and each cylinder size, the average test strength followed a very predictable pattern of strengths versus age. The points defined a very clear graphical line.

(4) Predicted strengths based on initial laboratory mix designs compare well with cylinder strengths achieved during construction.

(5) For all mixes and each cylinder size, the rate of strength gain with time was considerably higher than normally would be expected with conventional concrete.

(6) Mixes made with Class C fly ash had similar strengths to mixes made with Class F ash until an age of about 2 to 3 months, at which time it consistently showed a tremendously increased strength. This is discussed further in Chapter 2, "Cement and Fly Ash."

(7) Water-reducing admixtures had no effect on strength. This is discussed further in Chapter 12, "Admixtures."

The fact that the rolled concrete mixes produced such high strengths for the relatively low cement factors has raised questions about whether this was due to the aggregate, cement, fly ash, or the fact that rolled concrete is simply more efficient. To find out, aggregate, cement, and fly ash from the job were sent to the Division laboratory and used to make a quality conventional concrete mix. The aggregate was processed to clean it, wash it, and improve the gradation so that it met ideal requirements for conventional mass concrete. Water-reducing and air-entraining admixtures were included at optimum recommended dosages, and the mix was batched to a low slump but workable mix - idealized conditions for quality conventional mass concrete. The results are shown graphically on Plate 9.14. The rolled concrete mix consistently gave substantially higher strengths than the conventional mix at the same cement and ash content. Also shown in the graph is the interesting fact that higher RCC strength was achieved by increasing the amount of silt (nonplastic natural fines) in the aggregate.

As discussed in Chapter 24, "Future Evaluations and Concrete Testing," a major drilling program to obtain large diameter in-place cores and compare their strengths to the strengths predicted by laboratory cylinders will be conducted in the summer of 1983. Limited data on 6-inch cores from the 315+135 mix used in the stilling basin has been obtained. When compared to strengths of tamped 6- x 12-inch cylinders made from the mix that went into the placement, the cores had average strengths significantly higher. This data is very promising but should be used with caution until additional data is obtained.

	Strength (psi)	Unit Weight (pcf)	Age (days)
Cores (average of 25)	3,948	153.0	75*
Cylinders	2,193	151.0	28
Cylinders	2,640	148.3	90

*Cores were obtained at an age ranging from about 6 weeks to 3 months. The cores were stored in a dry environment with varying temperatures down to near freezing until testing. The estimated average effective cure for these cores at 72^{o} F is 75 days.

Higher strengths for the in-place material were expected and did occur. The mix was placed and compacted much faster and more effectively in the field than could be accomplished in the laboratory and the compactive effort was much greater in the field. Also, as discussed earlier, cylinders cannot be effectively filled with compacted RCC mix. This resulted in voids and rock pockets at the perimeter of the cylinders and an effective cross sectional area less than 28.27 square inches which corresponds to the full area of a 6-inch cylinder. The full theoretical area was used in the computation of compressive strengths for the cylinders. On the other hand, the cores were solid RCC throughout their interior section. Regardless of the method of fabrication, it appears safe to say that in-place compressive strengths of RCC will be greater than predicted by laboratory prepared samples of the same mix. Another influencing factor is the elevated temperature of mass RCC (because of heat of hydration) which should accelerate initial strength gains.

Table 9.1 compares the average strengths of 6- x 12-inch cylinders made by tamping and by the modified vebee. For all mixes at all ages there was a very significant decrease in strength when the vebee method was used. As recommended elsewhere in this report as well as here, the vebee method is not recommended for future projects. As an overall weighted average, the 3-inch maximum size aggregate mixes (made with the 2-inch minus fraction) gave 40 percent less strengths than the tamped cylinders. The 1-1/2-inch maximum size aggregate mix gave better but still not good results with an 11 percent difference.

The consistently lower strength of the 9- x 18-inch cylinders as compared to the 6- x 12-inch cylinders when both were made by tamping was similarly analyzed. The data are summarized in Table 9.2. For all mixes at all ages there was a significant decrease in strength for the 9- x 18-inch cylinders. The 3-inch maximum aggregate size mixes gave an overall average strength in the 9- x 18-inch molds that was 24 percent less than for the same mixes in 6- x 12-inch molds. The mix with 1-1/2-inch aggregate gave strengths that averaged 10 percent less in the larger molds.

The explanation for the lower strength of the larger cylinder size as well as for the vebee manufactured test specimens is that they could not be consolidated as well as the tamped 6- x 12-inch test specimens. This was very evident in the appearance of the cylinders. The cores which typically gave the highest strength also visually had the least voids. Density data for the cylinders are given in Table 10.1 and are discussed in detail in Chapter 10, "Density and Void Space." It was noted that project cylinders with lower strengths not only visually had more voids but, in fact, also had lower measured density.

Additional laboratory tests were then run to establish the relationship between density and strength. Graphical results are shown on Plate 9.15. Within a wide range of possible densities, an increase of each pcf resulted in an increase of 100 psi at 28 days. The results can broadly be interpreted to show a definite need to obtain good and consistent compaction in order to develop good and consistent strengths. However, within the easily attainable typical density range of say 151 to 155 pcf, strength variability would be a very acceptable 10 percent. This indicates that from a compressive strength standpoint, compaction and density are not critical items requiring overattention during construction. Also indicated is that the considerable extra effort that would be required to go from say 154 pcf to 155 pcf would result in only a marginal strength gain of about 1 percent. When considering the fact that the RCC mixes had much more compressive strength than required for design, extra compaction was of little benefit. In fact, adequate strength was probably achieved after only one or two passes of the roller. It should be noted that although it was not needed for compressive strength, additional compaction may have been valuable to improving joint integrity and shear strength.

Because of the new methods of manufacturing test specimens, lower strengths were anticipated for the earlier cylinders while technicians became familiar with the equipment and developed efficient methods of obtaining and handling the sample material. There was a definite improvement during the first week or so of cylinder manufacturing, both from a visual standpoint and from the test results. After each technician had made several sets of cylinders he was competent, proficient, and consistent.

TABLE 9.1

COMPARISON OF STRENGTH FOR
VEBEE VERSUS TAMPED CYLINDERS

TABLE 9.1

Mix No. 1

Age	Avg. Strength 6x12 Vebee (psi)	Avg. Strength 6x12 Tamped (psi)	Difference (percent)
3	226	419	46
7	423	580	27
14	489	792	38
28	677	1,172	42
90	915	1,689	46
180	690	2,295	70
365	--	--	--

Mix No. 2

Age	Avg. Strength 6x12 Vebee (psi)	Avg. Strength 6x12 Tamped (psi)	Difference (percent)
3	0	656	--
7	560	997	44
14	727	1,381	47
28	850	1,839	54
90	1,320	2,668	51
180	--	3,872	--
365	--	--	--

TABLE 9.1 (continued)

Mix No. 3

Age	Avg. Strength 6x12 Vebee (psi)	Avg. Strength 6x12 Tamped (psi)	Difference (percent)
3	632	789	20
7	826	1,147	28
14	902	1,564	42
28	1,648	2,073	21
90	2,090	3,020	31
180	2,177	2,987	27
365	--	--	--

Mix No. 4

Age	Avg. Strength 6x12 Vebee (psi)	Avg. Strength 6x12 Tamped (psi)	Difference (percent)
3	1,347	1,384	3
7	2,137	2,033	5
14	2,440	2,636	7
28	2,833	3,423	17
90	4,050	4,511	10
180	2,923	4,522	35
365	--	--	--

TABLE 9.2

COMPARISON OF STRENGTH FOR
6- x 12-INCH VERSUS 9- x 18-INCH CYLINDERS

TABLE 9.2

Mix No. 1

Age	Avg. Strength 6x12 Tamped (psi)	Avg. Strength 9x18 Tamped (psi)	Difference (percent)
3	419	383	8.6
7	580	501	13.7
14	792	669	15.5
28	1,172	781	33.4
90	1,689	1,185	29.8
180	2,295	1,712	25.4
365	--	--	--
		Average	21.1

Mix No. 2

Age	Avg. Strength 6x12 Tamped (psi)	Avg. Strength 9x18 Tamped (psi)	Difference (percent)
3	656	566	13.7
7	997	730	26.8
14	1,381	987	28.5
28	1,839	1,317	28.4
90	2,669	2,031	23.9
180	--	--	--
365	--	--	--
		Average	24.3

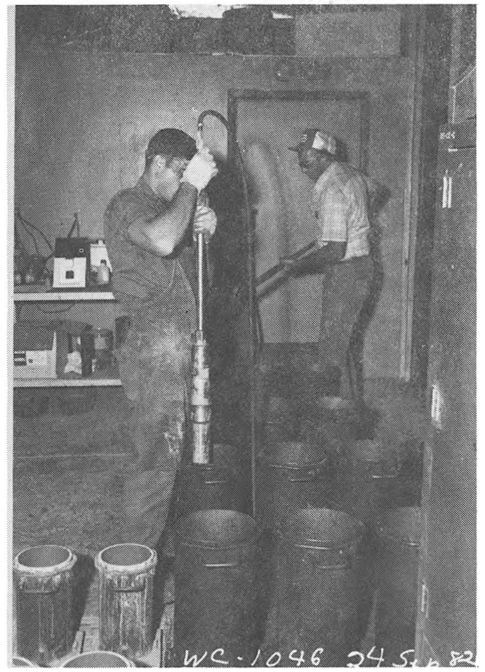
TABLE 9.2 (continued)

Mix No. 3

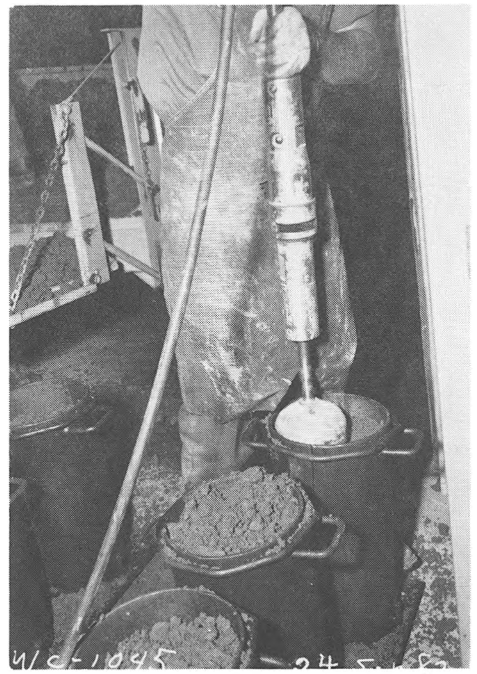
Age	Avg. Strength 6x12 Tamped (psi)	Avg. Strength 9x18 Tamped (psi)	Difference (percent)
3	789	554	29.8
7	1,147	869	24.2
14	1,564	1,130	27.8
28	2,073	1,525	26.4
90	3,020	2,195	27.3
180	--	--	--
365	--	--	--
		Average	27.1

Mix No. 4

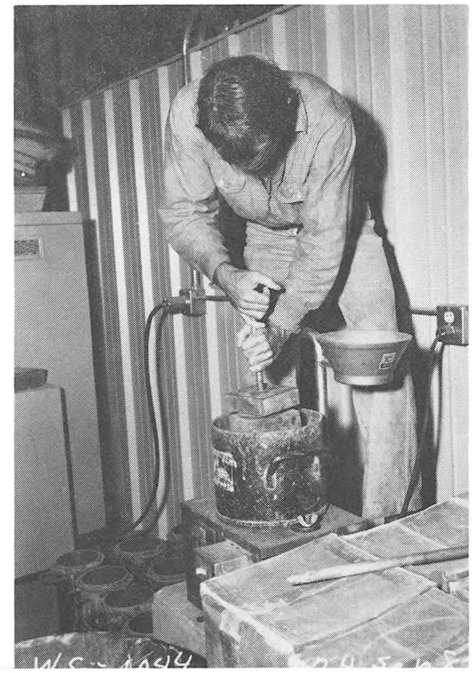
Age	Avg. Strength 6x12 Tamped (psi)	Avg. Strength 9x18 Tamped (psi)	Difference (percent)
3	1,384	1,359	1.8
7	2,033	1,793	11.8
14	2,636	2,246	14.8
28	3,423	2,889	15.6
90	4,511	4,185	7.2
180	--	--	--
365	--	--	--
		Average	10.2



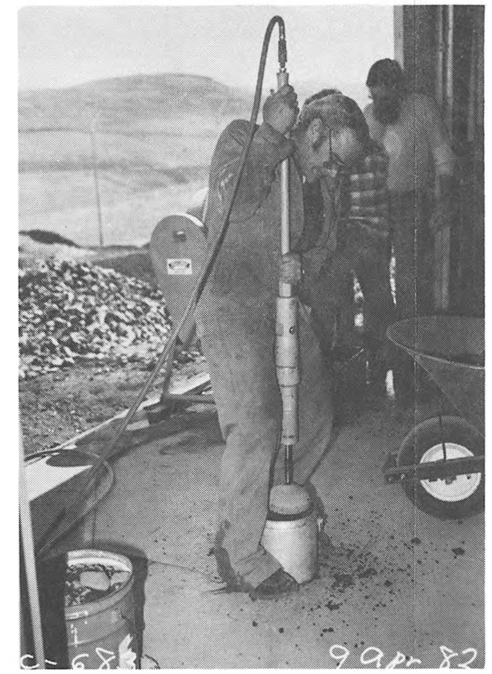
COMPACTION OF 9 x 18 AND 6 x 12 CYLINDERS WITH THE TAMPER.



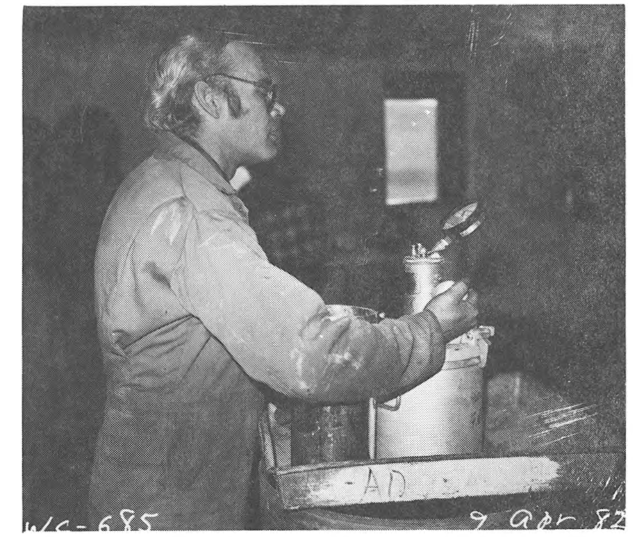
COMPACTION OF 9 x 18 CYLINDERS BY TAMPING.



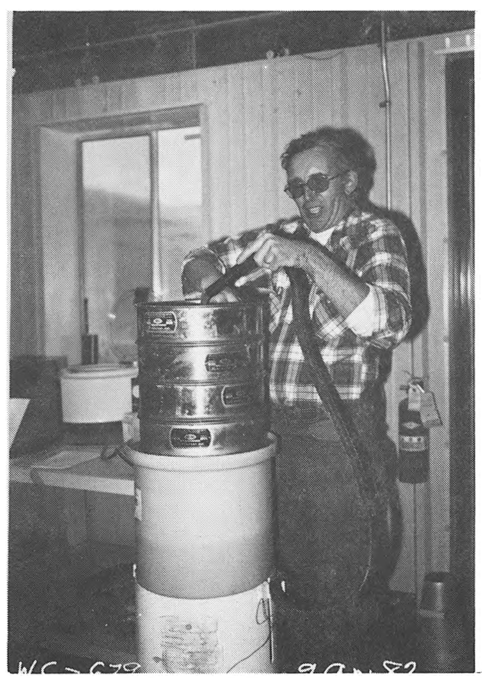
MODIFIED VEBE.



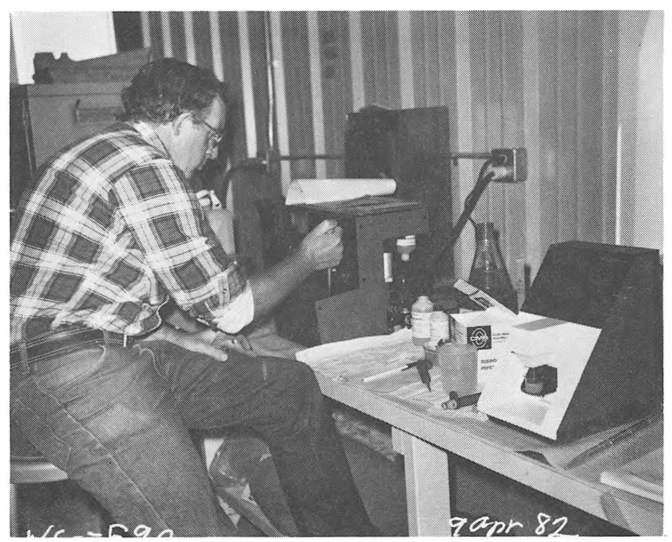
COMPACTING RCC IN THE AIR POT.



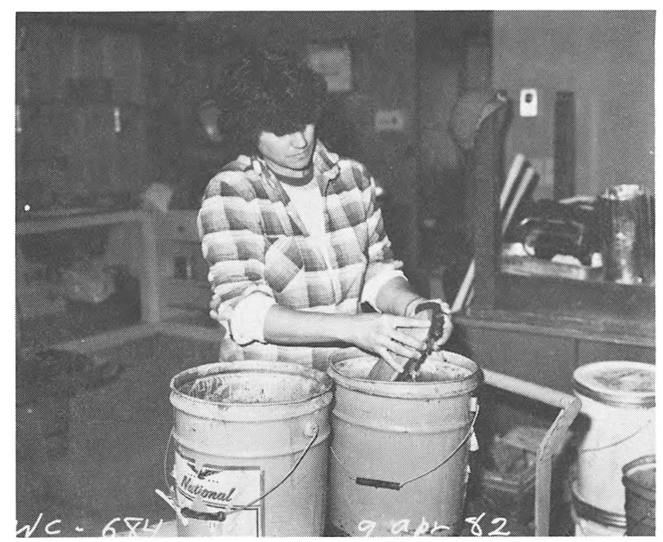
PRESSURE TEST FOR AIR CONTENT.



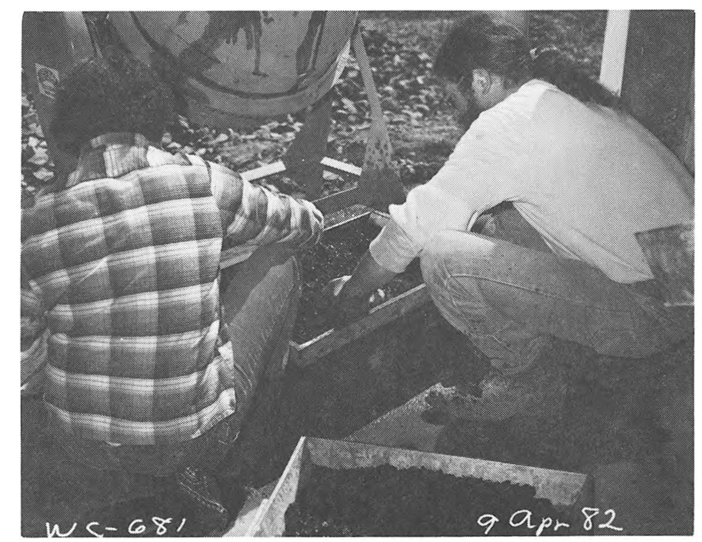
WASHING AN RCC SAMPLE FOR CQM TESTS.



CQM TESTING WITH THE CALCIUM AND CHLORIDE METERS.

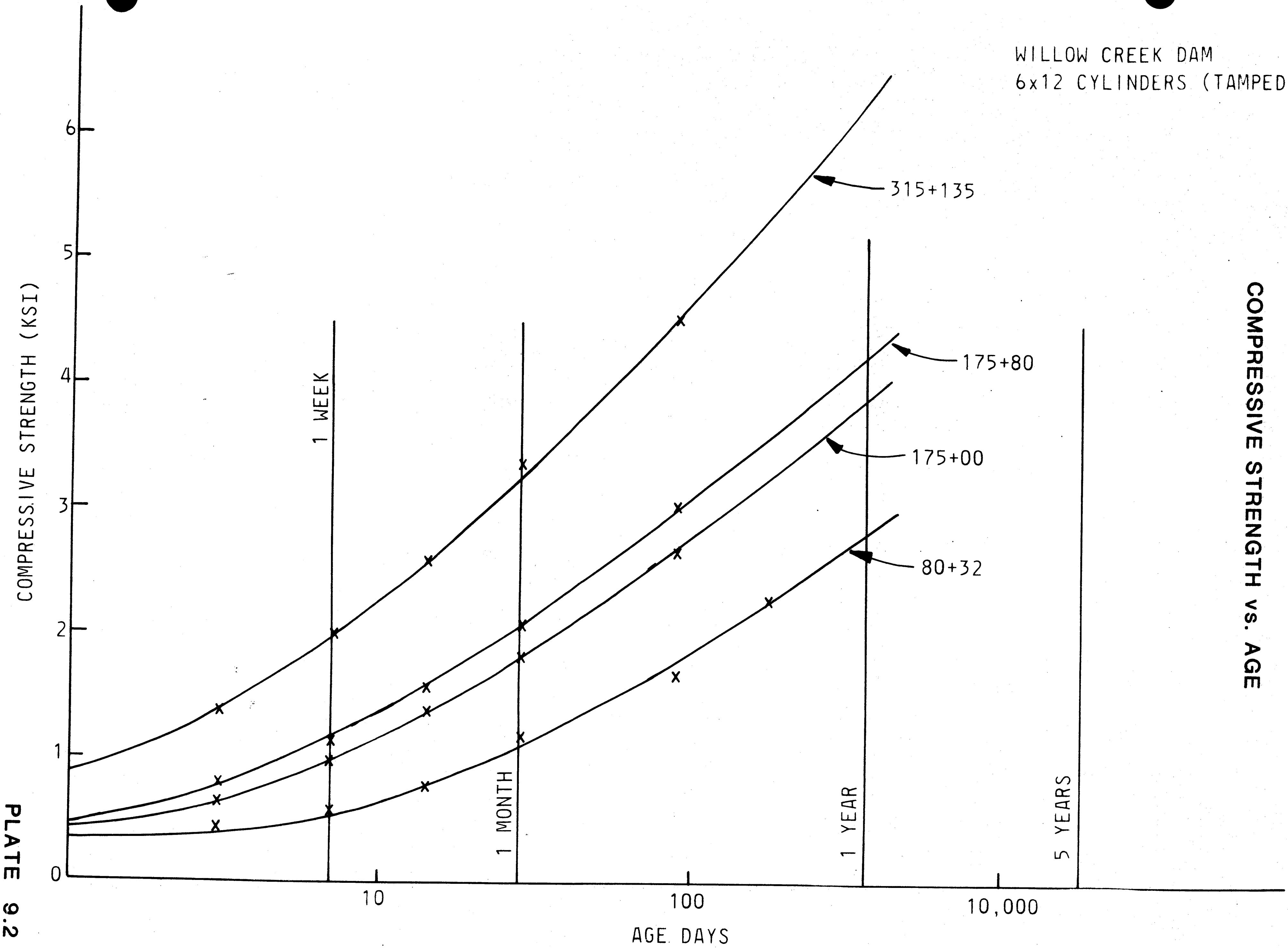


WASHING COARSE AGGREGATE FOR MIXER PROFICIENCY TESTS.



SIEVING AGGREGATE FOR MIXER PROFICIENCY TESTS.

FIELD LAB TESTING



COMPRESSIVE STRENGTH vs. AGE

PLATE 9.2

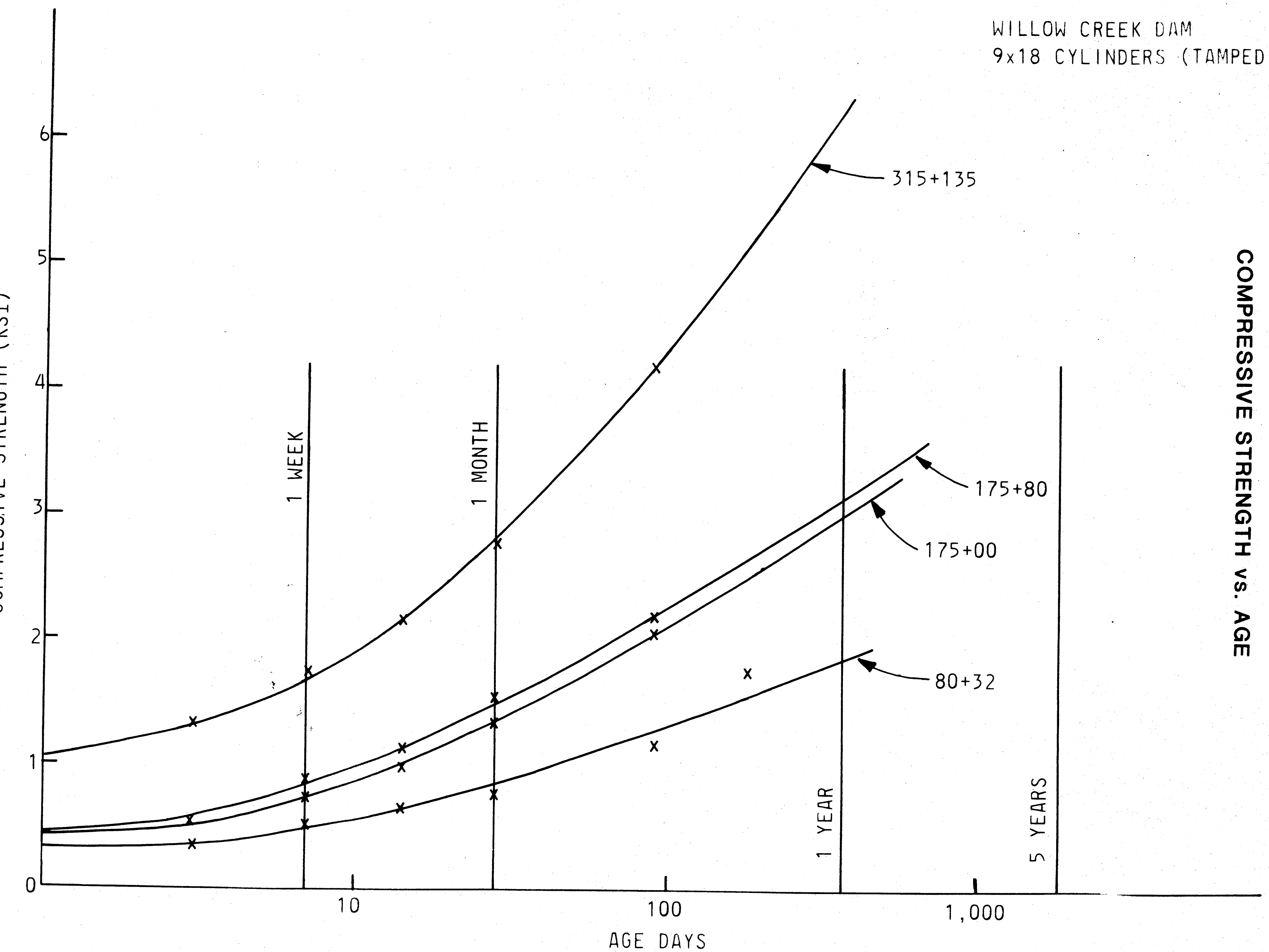


PLATE 9.3

COMPRESSIVE STRENGTH vs. AGE

COMPRESSIVE STRENGTH vs. AGE

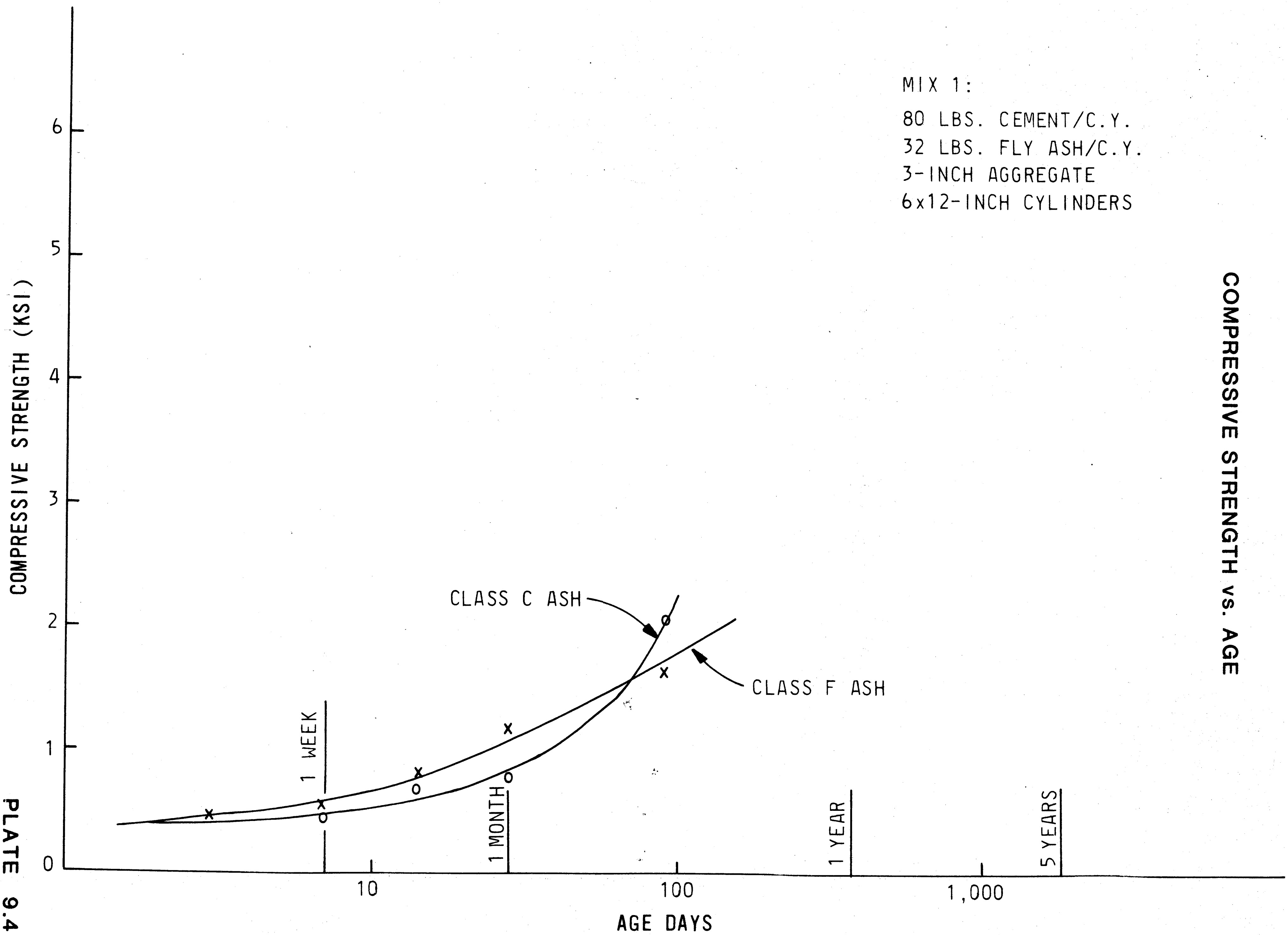


PLATE 9.4

COMPRESSIVE STRENGTH vs. AGE

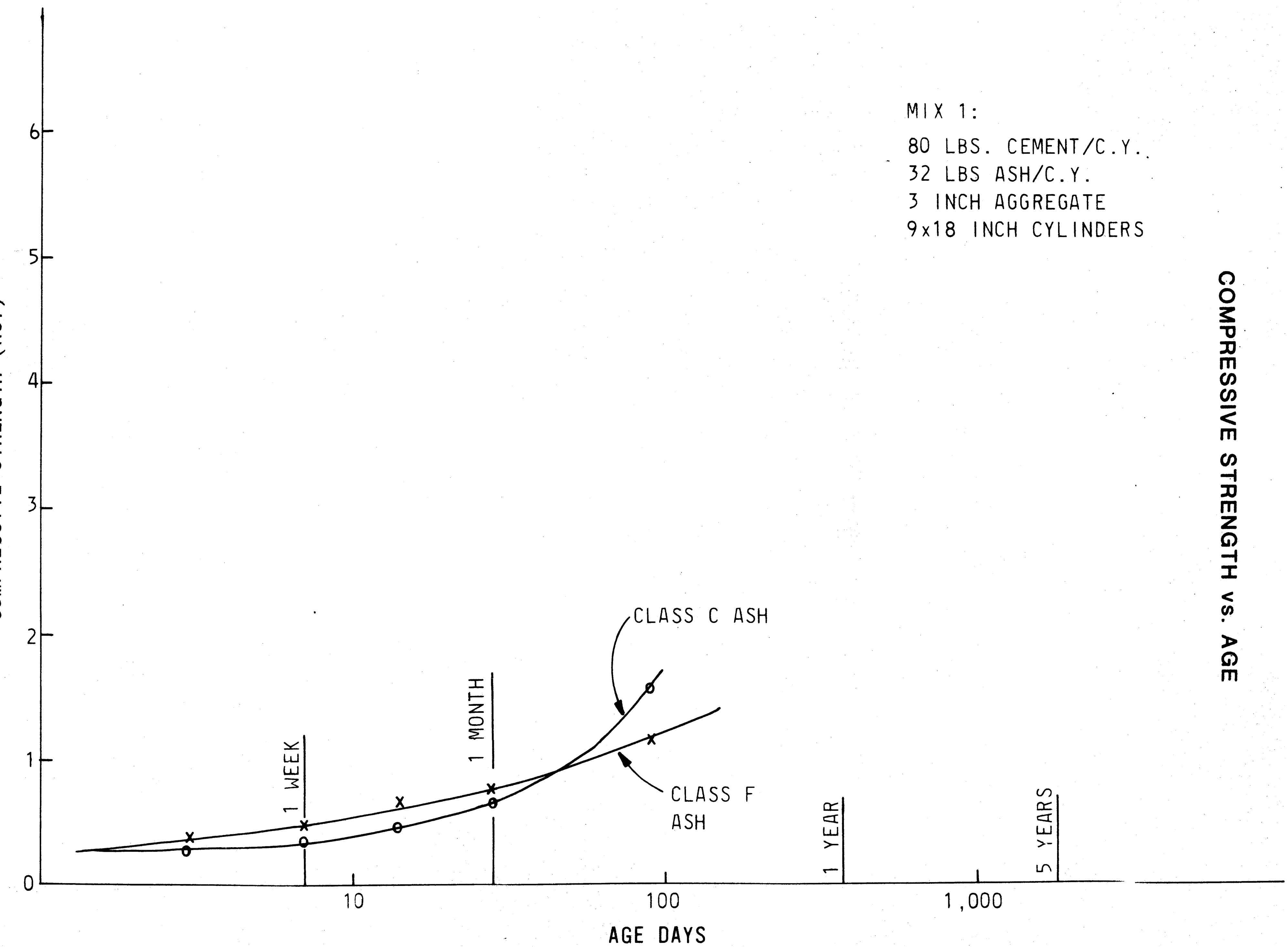
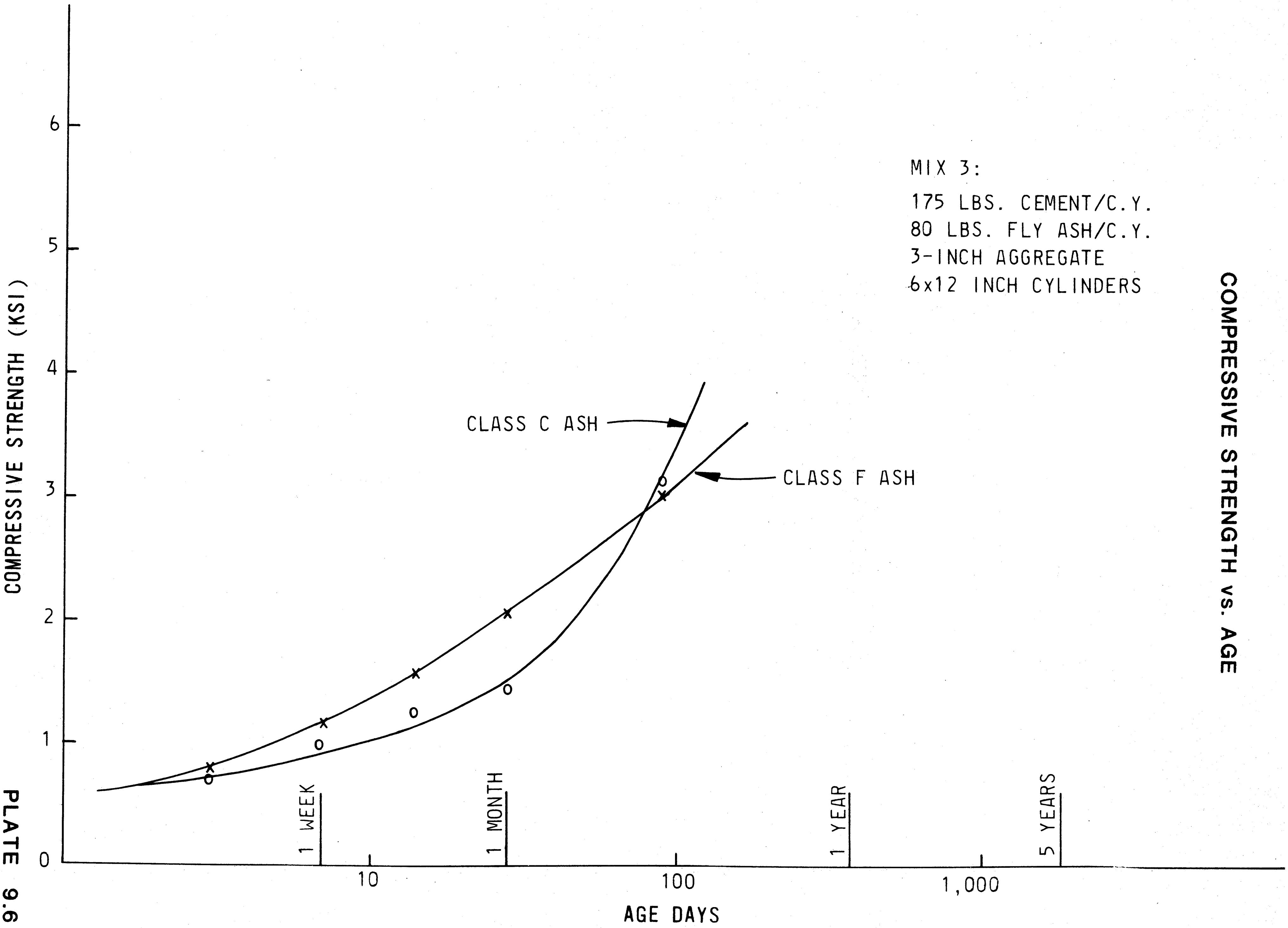
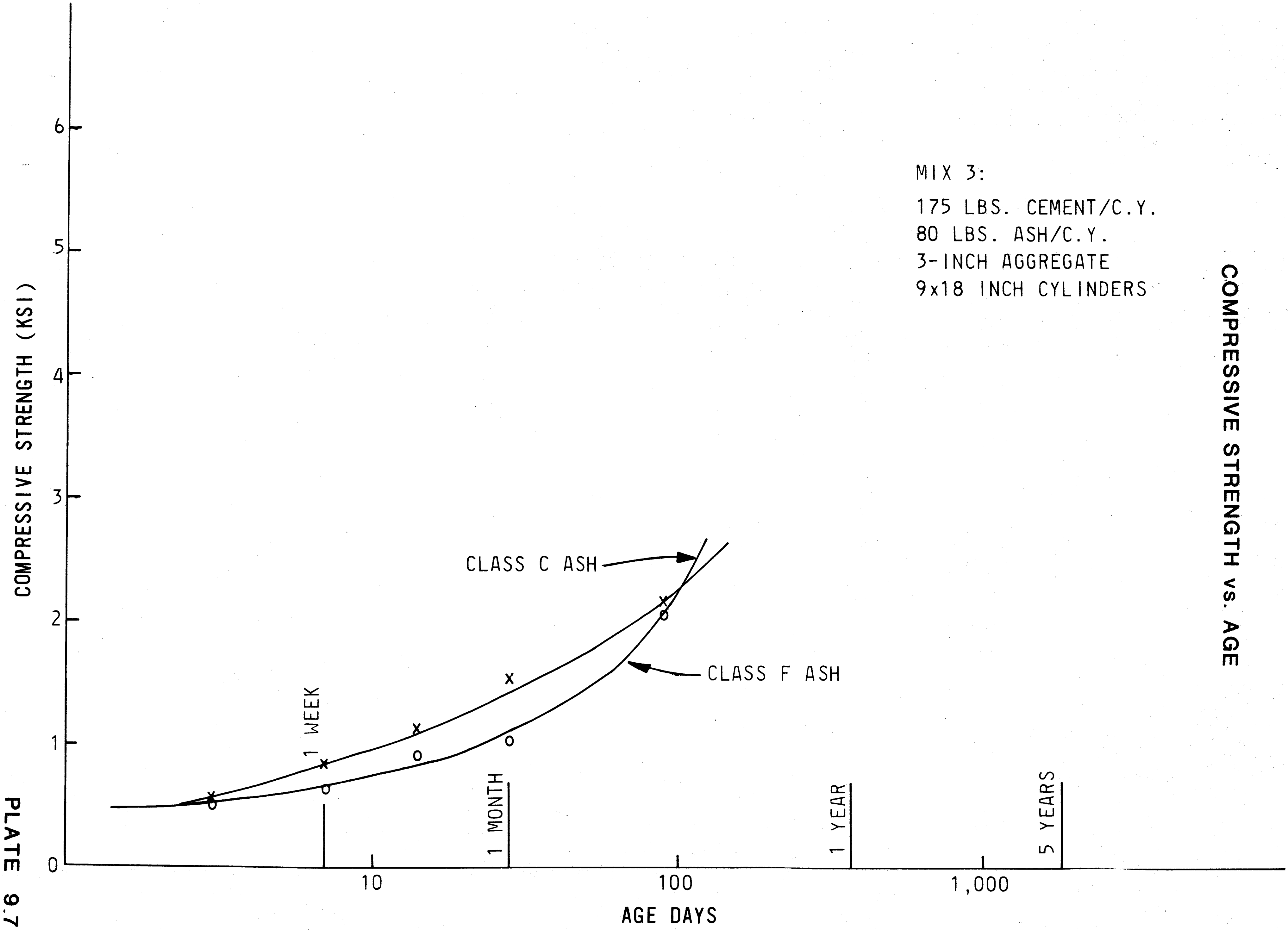


PLATE 9.5



COMPRESSIVE STRENGTH vs. AGE

PLATE 9.6



COMPRESSIVE STRENGTH vs. AGE

PLATE 9.7

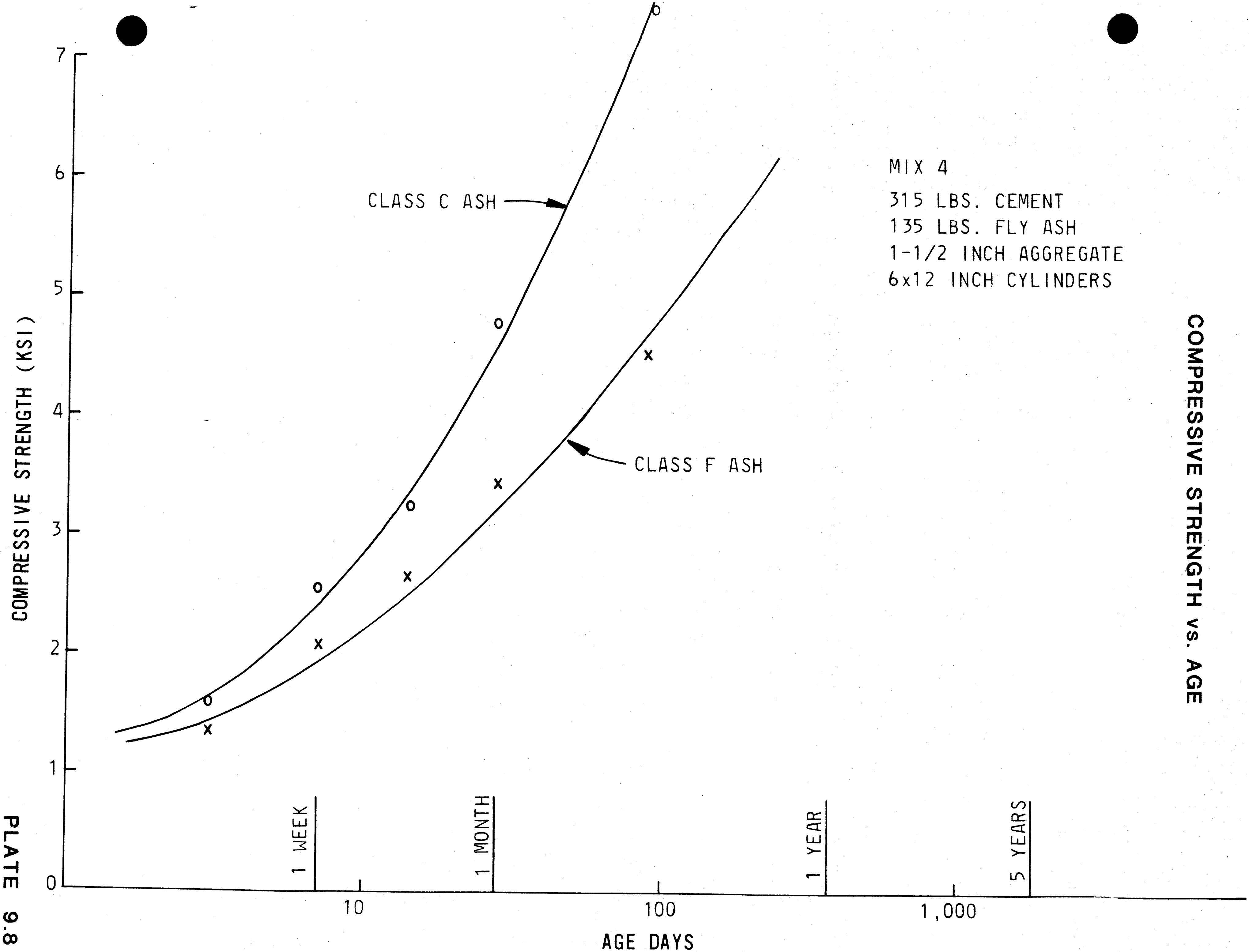


PLATE 9.8

COMPRESSIVE STRENGTH vs. AGE

COMPRESSIVE STRENGTH vs. AGE

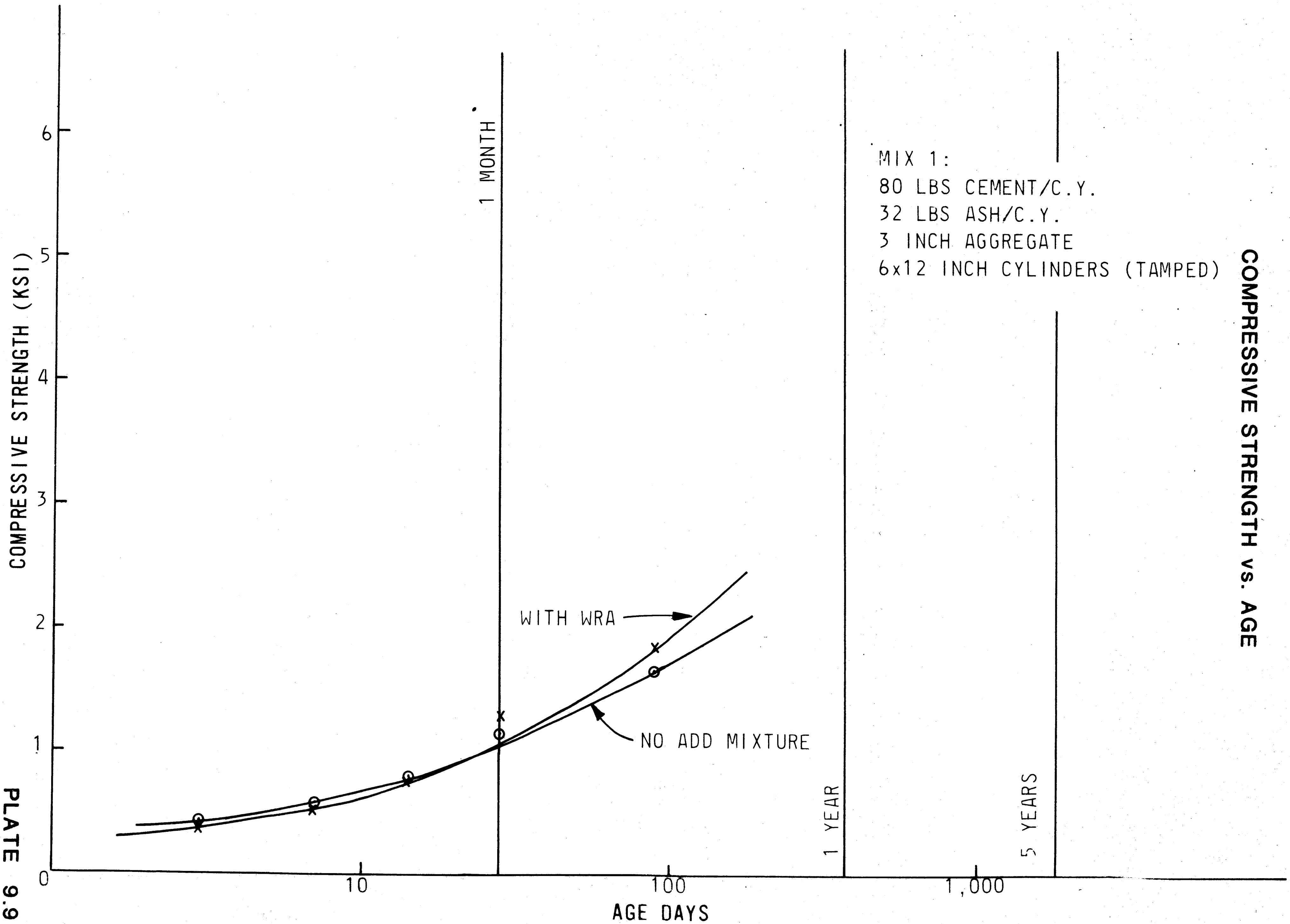
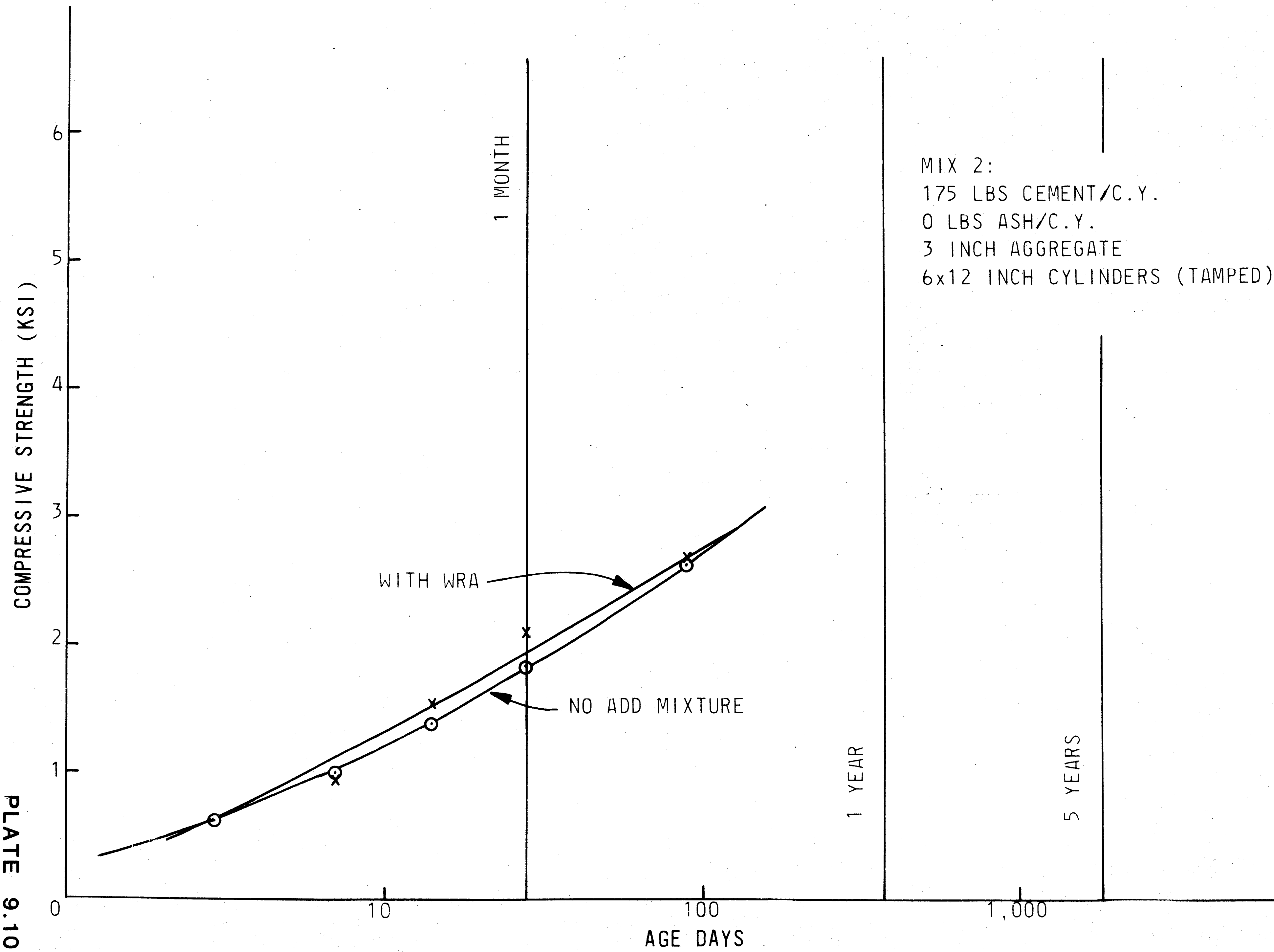
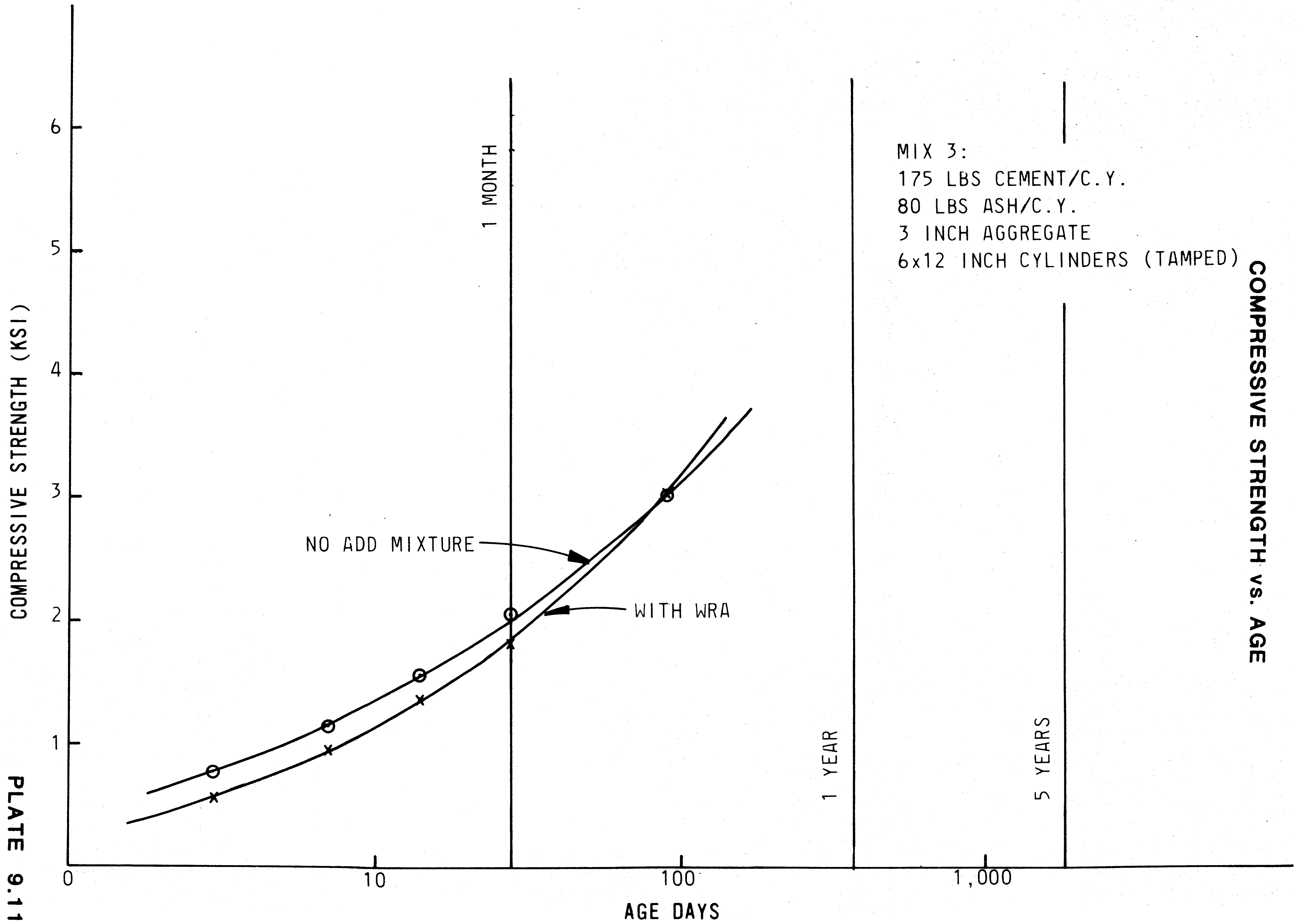


PLATE 9.9

PLATE 9.10



COMPRESSIVE STRENGTH vs. AGE



COMPRESSIVE STRENGTH vs. AGE

PLATE 9.11

COMPRESSIVE STRENGTH vs. AGE

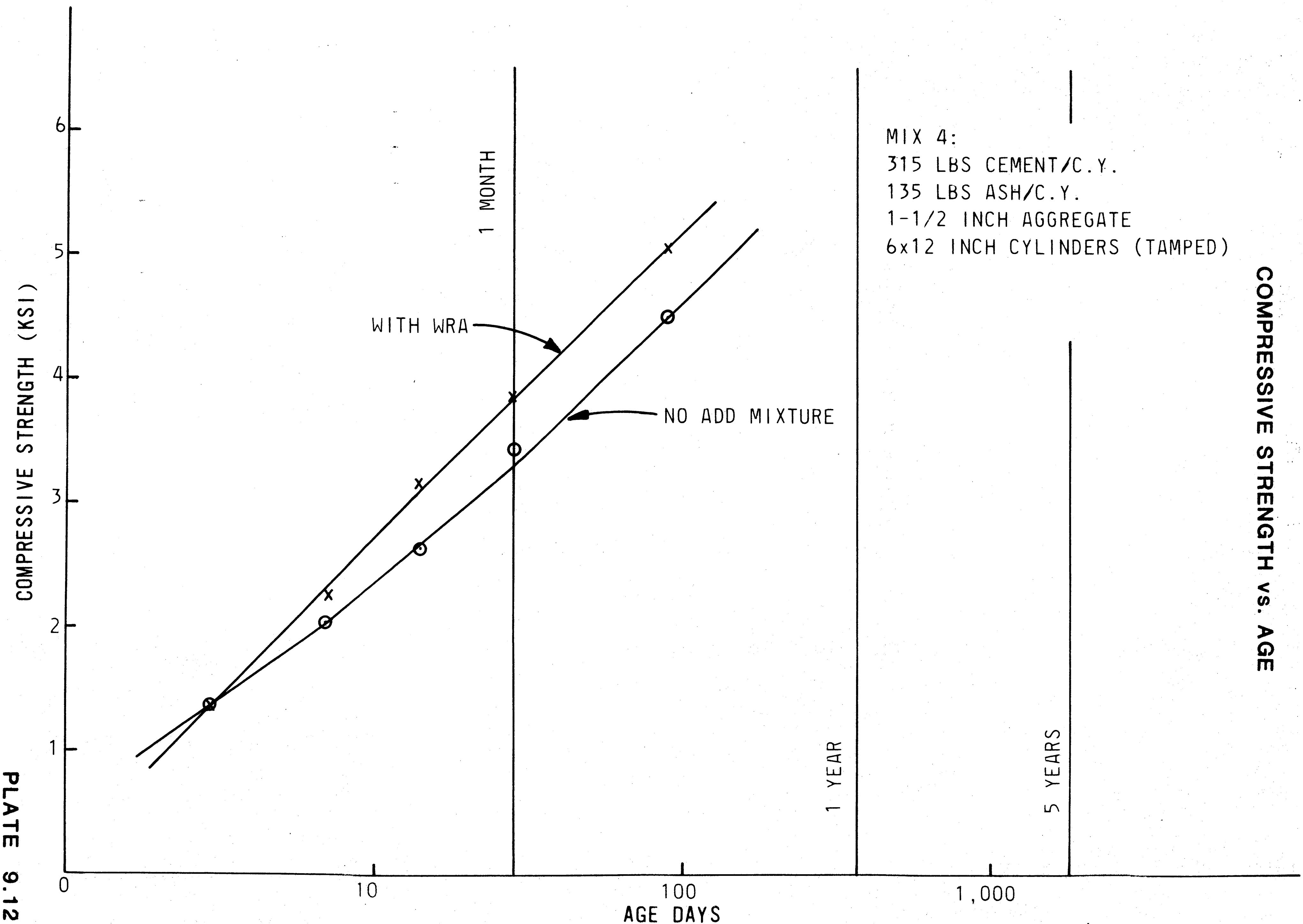


PLATE 9.12

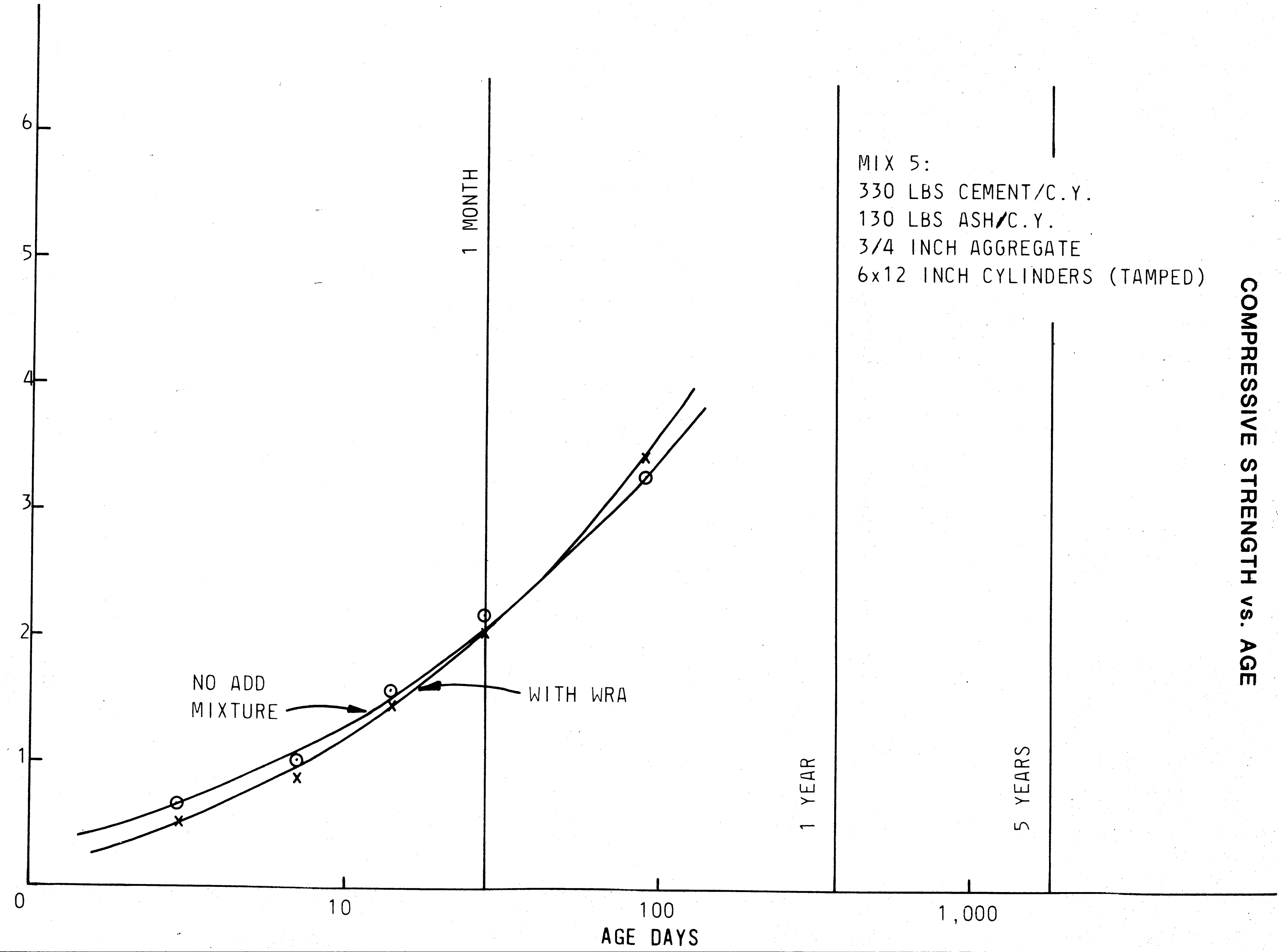


PLATE 9.13

COMPRESSIVE STRENGTH vs. AGE

COMPRESSIVE STRENGTHS - CONVENTIONAL vs. ROLLED CONCRETE

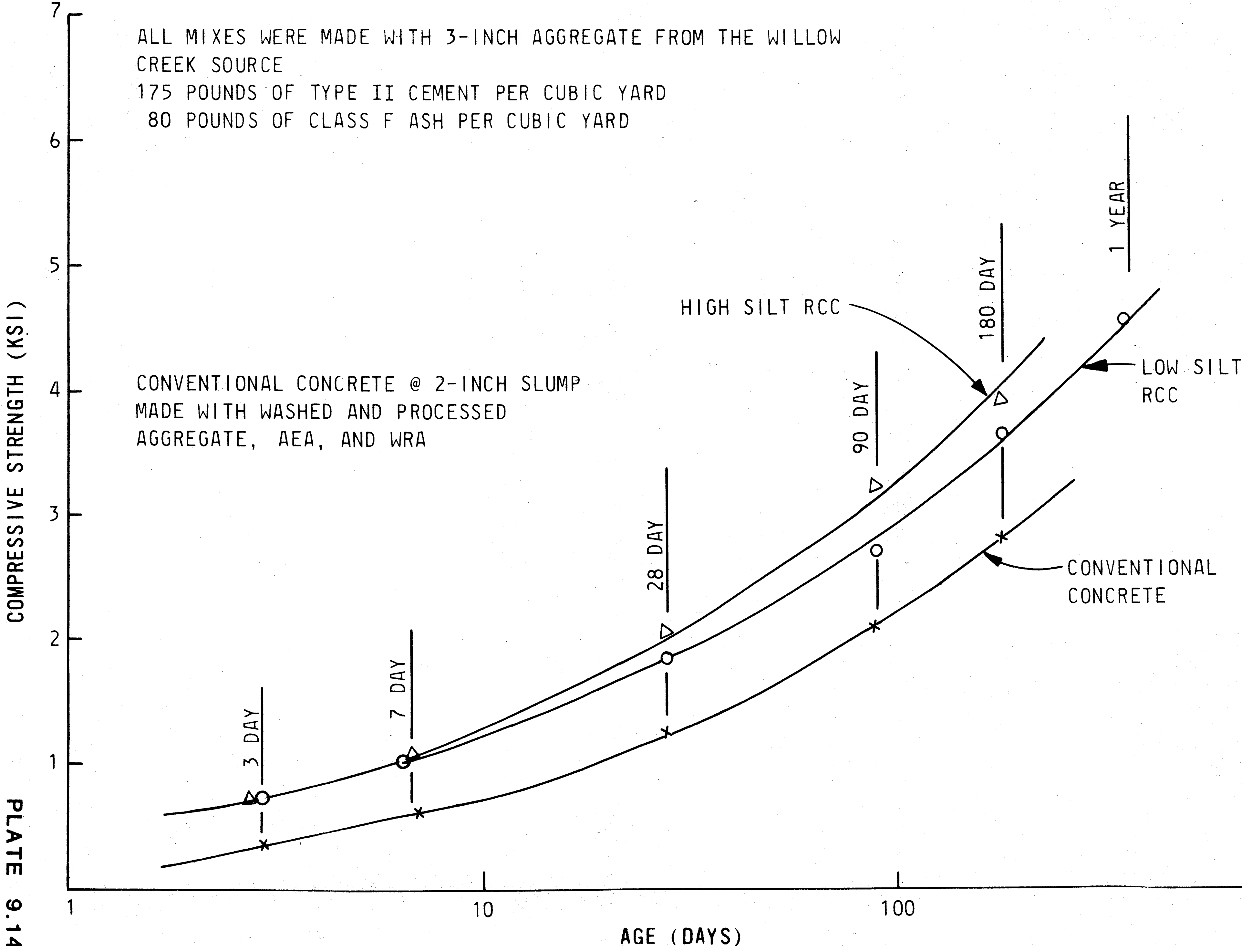
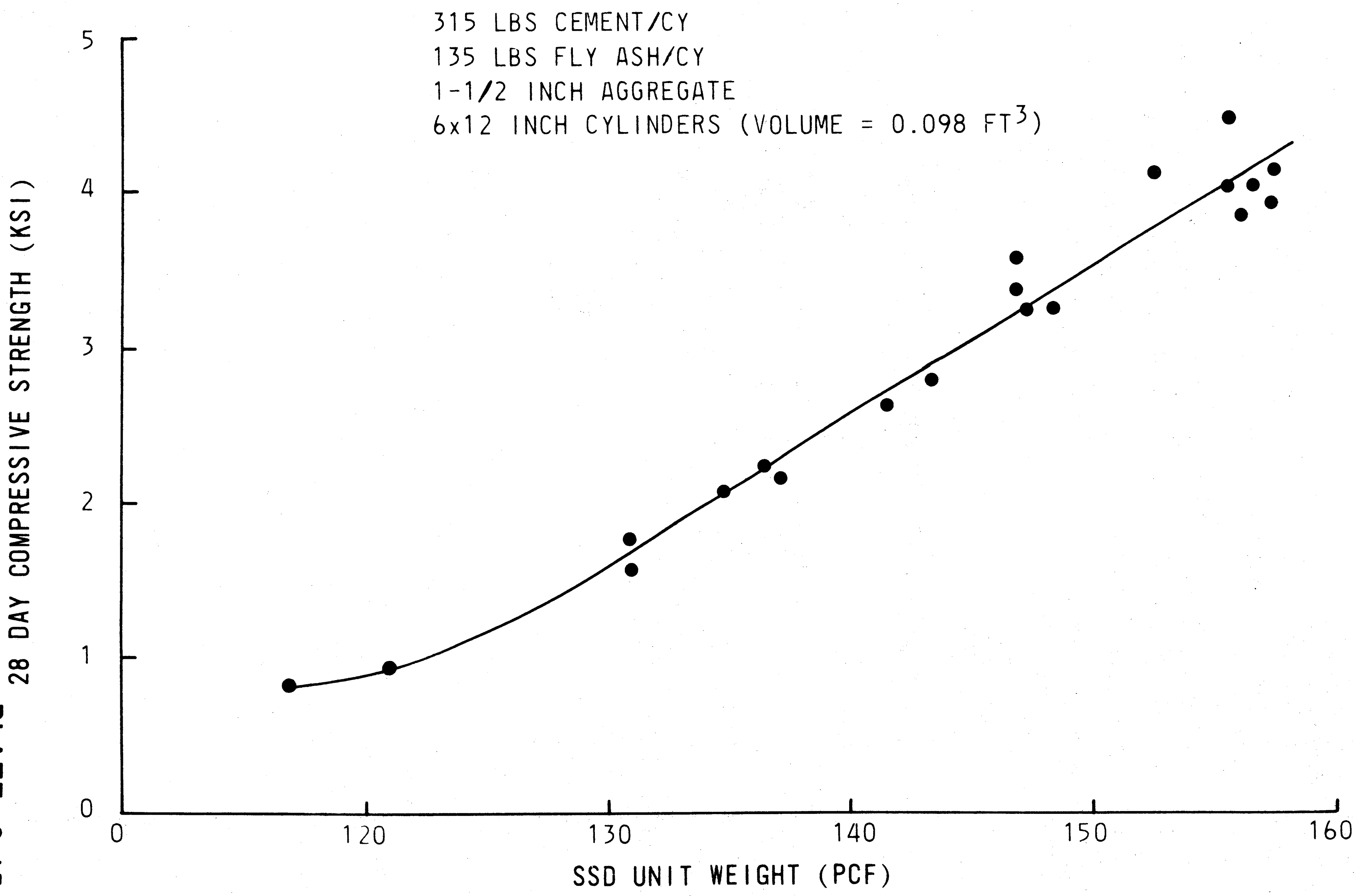


PLATE 9.14



COMPRESSIVE STRENGTH VS. DENSITY

PLATE 9.15

EXHIBIT 9.1

COMPRESSIVE CYLINDER DATA SUMMARIES

The data is listed according to mix design and, within each mix, also by the age of test. Data shown here is current through February 1983. The October 1983 update will include the data for all cylinders and all breaks through 1-year age.

PROJECT: WILLOW CREEK DAM
CONTRACT: DACW68-82-C-0018
MIX: MIX 1: 80+32
DAY 3
MSA=3.0

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	11	343.	143.	41.67	9	85.	213.	11	151.4
6X12 TAMPED	48	419.	108.	25.67	38	78.	214.	46	153.7
6X12 VEBE	5	226.	55.	24.36	3	74.	215.	4	143.4
ALL	64	391.	123.	31.57	50	79.	214.	61	152.6

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	3	212.	123.	58.07	3	93.	202.	3	144.6
6X12 TAMPED	22	425.	106.	24.89	20	81.	203.	21	152.5
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	25	399.	127.	31.72	23	83.	203.	24	151.5

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	1	70.	0.	0.00	1	58.	189.	1	146.0
6X12 TAMPED	9	433.	133.	30.82	9	70.	215.	8	153.7
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	10	397.	170.	42.93	10	69.	212.	9	152.8

PROJECT: WILLOW CREEK DAM
CONTRACT: DACW68-82-C-0018
MIX: MIX 1: 80+32
DAY 7
MSA=3.0

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	11	501.	187.	37.36	9	85.	213.	11	151.8
6X12 TAMPED	49	580.	167.	28.74	39	78.	215.	46	153.8
6X12 VEBE	6	423.	123.	29.03	5	78.	235.	6	146.0
ALL	66	552.	172.	31.14	53	79.	217.	63	152.7

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	3	338.	25.	7.29	3	93.	202.	3	146.8
6X12 TAMPED	22	606.	159.	26.28	20	81.	203.	21	152.1
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	25	574.	174.	30.25	23	83.	203.	24	151.4

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	1	350.	0.	0.00	1	58.	189.	1	150.5
6X12 TAMPED	9	603.	211.	35.00	9	70.	215.	8	152.8
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	10	578.	215.	37.13	10	69.	212.	9	152.5

PROJECT WILLOW CREEK DAM | CONTRACT DACW68-82-C-0018 | MIX MIX 1: 80+32 | DAY 14 | MSA=3.0

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	11	669.	191.	28.58	9	85.	213.	10	150.9
6X12 TAMPED	48	792.	197.	24.81	39	78.	215.	48	153.3
6X12 VEBE	7	489.	144.	29.48	5	76.	249.	7	143.9
ALL	66	740.	212.	28.73	53	79.	218.	65	151.9

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	3	708.	269.	37.96	3	93.	202.	3	143.8
6X12 TAMPED	22	820.	217.	26.52	21	80.	206.	22	151.5
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	25	806.	221.	27.38	24	81.	206.	25	150.6

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	1	740.	0.	0.00	1	58.	189.	1	144.5
6X12 TAMPED	9	836.	330.	39.44	9	70.	215.	9	151.6
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	10	827.	312.	37.80	10	69.	212.	10	150.9

PROJECT: WILLOW CREEK DAM
CONTRACT: DACW68-82-C-0018
MIX: MIX 1: 80+32
DAY 28
MSA=3.0

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	10	781.	258.	33.08	8	86.	216.	9	150.2
6X12 TAMPED	47	1172.	327.	27.88	38	78.	215.	46	153.7
6X12 VEBE	8	677.	216.	31.88	6	79.	240.	8	142.8
ALL	65	1051.	362.	34.42	52	79.	218.	63	151.8

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	3	545.	49.	9.04	3	93.	202.	3	143.6
6X12 TAMPED	22	1133.	323.	28.54	21	80.	206.	21	151.6
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	25	1063.	360.	33.90	24	81.	206.	24	150.6

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	1	505.	0.	0.00	1	58.	189.	1	148.2
6X12 TAMPED	9	1088.	479.	44.00	9	70.	215.	9	151.5
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	10	1029.	487.	47.35	10	69.	212.	10	151.2

CONCRETE COMPRESSION TESTS SHEET 5

PROJECT: WILLOW CREEK DAM
CONTRACT: DACW68-82-C-0018
MIX: MIX 1: 80+32
DAY 90
MSA=3.0

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	10	1185.	455.	38.40	8	86.	216.	5	146.9
6X12 TAMPED	45	1689.	394.	23.33	35	78.	214.	26	150.5
6X12 VEBE	8	915.	330.	36.08	5	79.	234.	1	154.4
ALL	63	1511.	489.	32.33	48	79.	216.	32	150.0

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	4	830.	148.	17.79	4	91.	208.	4	144.9
6X12 TAMPED	21	1643.	338.	20.55	19	81.	205.	21	149.9
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	25	1513.	436.	28.83	23	83.	205.	25	149.1

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	1	740.	0.	0.00	1	58.	189.	1	149.0
6X12 TAMPED	9	1514.	452.	29.83	9	75.	216.	9	148.6
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	10	1437.	491.	34.18	10	74.	214.	10	148.6

CONCRETE COMPRESSION TESTS

SHEET 6

PROJECT: WILLOW CREEK DAM

CONTRACT: DACW68-82-C-0018

MIX: MIX 1: 80+32

DAY 180

MSA=3.0

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	3	1712.	1022.	59.69	0	0.	0.	3	151.6
6X12 TAMPED	9	2295.	786.	34.27	1	77.	241.	9	154.1
6X12 VEBE	2	690.	339.	49.19	0	0.	0.	2	137.0
ALL	14	1941.	943.	48.60	1	77.	241.	14	151.1

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	3	1712.	1022.	59.69	0	0.	0.	3	151.6
6X12 TAMPED	9	2295.	786.	34.27	1	77.	241.	9	154.1
6X12 VEBE	2	690.	339.	49.19	0	0.	0.	2	137.0
ALL	14	1941.	943.	48.60	1	77.	241.	14	151.1

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	1	1300.	0.	0.00	0	0.	0.	1	151.1
6X12 TAMPED	7	2131.	739.	34.69	1	77.	241.	7	153.9
6X12 VEBE	2	690.	339.	49.19	0	0.	0.	2	137.0
ALL	10	1760.	873.	49.61	1	77.	241.	10	150.2

PROJECT	CONTRACT	MIX	DAY 365	
WILLOW CREEK DAM	DACW68-82-C-0018	MIX 1: 80+32		MSA=3.0

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	0	0.	0.	0.00	0	0.	0.	0	0.0

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	0	0.	0.	0.00	0	0.	0.	0	0.0

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	0	0.	0.	0.00	0	0.	0.	0	0.0

CONCRETE COMPRESSION TESTS SHEET 1

PROJECT	CONTRACT	MIX	DAY 3	
WILLOW CREEK DAM	DACW68-82-C-0018	MIX 2: 175+00		MSA=3.0

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	9	566.	228.	40.31	8	181.	227.	8	149.5
6X12 TAMPED	49	656.	196.	29.80	43	173.	217.	48	151.9
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	58	642.	201.	31.38	51	174.	219.	56	151.5

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	3	412.	113.	27.55	3	169.	195.	3	144.8
6X12 TAMPED	22	686.	157.	22.84	22	172.	188.	22	150.3
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	25	653.	176.	26.88	25	172.	188.	25	149.6

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	1	540.	0.	0.00	1	232.	224.	1	144.0
6X12 TAMPED	9	730.	172.	23.61	9	170.	186.	9	150.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	10	711.	173.	24.36	10	177.	190.	10	149.4

PROJECT CONTRACT MIX DAY 7
WILLOW CREEK DAM DACW68-82-C-0018 MIX 2: 175+00 MSA=3.0

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	9	730.	233.	31.96	8	181.	227.	9	150.6
6X12 TAMPED	49	997.	258.	25.88	43	173.	217.	49	152.0
6X12 VEBE	4	560.	203.	36.22	3	148.	305.	4	146.0
ALL	62	930.	283.	30.42	54	173.	224.	62	151.4

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	3	560.	209.	37.32	3	169.	195.	3	146.0
6X12 TAMPED	22	1001.	203.	20.30	22	172.	188.	22	150.4
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	25	948.	247.	26.09	25	172.	188.	25	149.9

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	1	630.	0.	0.00	1	232.	224.	1	147.1
6X12 TAMPED	9	1023.	239.	23.38	9	170.	186.	9	150.5
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	10	984.	258.	26.18	10	177.	190.	10	150.1

PROJECT	CONTRACT	MIX	DAY 14	
WILLOW CREEK DAM	DACW68-82-C-0018	MIX 2: 175+00		MSA=3.0

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	9	987.	325.	32.92	8	181.	227.	8	149.6
6X12 TAMPED	49	1381.	338.	24.47	43	173.	217.	49	152.2
6X12 VEBE	3	727.	91.	12.49	2	149.	280.	3	145.9
ALL	61	1291.	377.	29.21	53	173.	221.	60	151.5

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	3	783.	131.	16.66	3	169.	195.	3	144.9
6X12 TAMPED	22	1368.	336.	24.53	22	172.	188.	22	150.6
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	25	1298.	371.	28.58	25	172.	188.	25	149.9

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	1	740.	0.	0.00	1	232.	224.	1	143.0
6X12 TAMPED	9	1406.	288.	20.49	9	170.	186.	9	150.6
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	10	1339.	344.	25.66	10	177.	190.	10	149.8

CONCRETE COMPRESSION TESTS — SHEET 4

PROJECT: WILLOW CREEK DAM
CONTRACT: DACW68-82-C-0018
MIX: MIX 2: 175+00
DAY 28
MSA=3.0

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	9	1317.	576.	43.77	8	181.	227.	9	150.0
6X12 TAMPED	48	1839.	468.	25.44	42	173.	218.	48	151.6
6X12 VEBE	4	850.	170.	19.99	3	148.	305.	4	142.2
ALL	61	1697.	550.	32.42	53	173.	224.	61	150.8

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	4	1046.	268.	25.57	4	178.	209.	4	148.0
6X12 TAMPED	21	1685.	476.	28.26	21	172.	188.	21	149.6
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	25	1583.	505.	31.91	25	173.	191.	25	149.3

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	1	1160.	0.	0.00	1	232.	224.	1	145.9
6X12 TAMPED	9	1686.	475.	28.15	9	169.	188.	9	149.5
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	10	1633.	477.	29.23	10	175.	192.	10	149.2

PROJECT: WILLOW CREEK DAM
CONTRACT: DACW68-82-C-0018
MIX: MIX 2: 175+00
DAY 90
MSA=3.0

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	8	2031.	1013.	49.90	7	174.	227.	6	147.5
6X12 TAMPED	42	2668.	636.	23.83	36	169.	221.	31	150.2
6X12 VEBE	4	1320.	422.	31.99	3	148.	305.	0	0.0
ALL	54	2474.	786.	31.79	46	169.	228.	37	149.7

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	3	1438.	816.	56.74	3	160.	204.	3	148.6
6X12 TAMPED	22	2451.	587.	23.94	21	170.	191.	22	149.8
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	25	2330.	685.	29.41	24	169.	193.	25	149.7

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	1	850.	0.	0.00	1	160.	202.	1	145.3
6X12 TAMPED	9	2267.	551.	24.33	9	166.	198.	9	149.4
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	10	2125.	686.	32.30	10	165.	198.	10	149.0

PROJECT WILLOW CREEK DAM | CONTRACT DACW68-82-C-0018 | MIX MIX 2: 175+00 | DAY 180 | MSA=3.0

ALL SETS

	STRENGTH DATA ANALYSIS: NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	CONCRETE QUALITY MONITOR: NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	UNIT WEIGHTS: NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 TAMPED	3	3872.	384.	9.92	0	0.	0.	3	154.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	3	3872.	384.	9.92	0	0.	0.	3	154.0

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS: NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	CONCRETE QUALITY MONITOR: NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	UNIT WEIGHTS: NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 TAMPED	3	3872.	384.	9.92	0	0.	0.	3	154.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	3	3872.	384.	9.92	0	0.	0.	3	154.0

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS: NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	CONCRETE QUALITY MONITOR: NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	UNIT WEIGHTS: NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 TAMPED	3	3872.	384.	9.92	0	0.	0.	3	154.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	3	3872.	384.	9.92	0	0.	0.	3	154.0

PROJECT: WILLOW CREEK DAM
CONTRACT: DACW68-82-C-0018
MIX: MIX 2: 175+00
DAY 365
MSA=3.0

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	0	0.	0.	0.00	0	0.	0.	0	0.0

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	0	0.	0.	0.00	0	0.	0.	0	0.0

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	0	0.	0.	0.00	0	0.	0.	0	0.0

PROJECT: WILLOW CREEK DAM | CONTRACT: DACW68-82-C-0018 | MIX: MIX 3: 175+80 | DAY 3 | MSA=3.0

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	10	554.	199.	35.97	9	184.	223.	9	148.5
6X12 TAMPED	49	789.	305.	38.67	47	179.	217.	49	153.1
6X12 VEBE	6	632.	270.	42.78	6	156.	214.	5	143.5
ALL	66	733.	300.	40.87	63	177.	218.	64	151.6

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	3	387.	93.	23.93	3	195.	215.	3	146.2
6X12 TAMPED	22	915.	356.	38.88	22	186.	215.	22	151.9
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	25	851.	377.	44.27	25	187.	215.	25	151.2

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	1	480.	0.	0.00	1	160.	185.	1	146.8
6X12 TAMPED	9	1121.	430.	38.34	9	188.	212.	9	152.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	10	1057.	453.	42.87	10	185.	210.	10	151.5

PROJECT: WILLOW CREEK DAM
CONTRACT: DACW68-82-C-0018
MIX: MIX 3: 175+80
DAY 7
MSA=3.0

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	10	869.	360.	41.44	9	184.	223.	10	150.5
6X12 TAMPED	48	1147.	436.	37.97	46	179.	218.	47	152.7
6X12 VEBE	5	826.	256.	31.01	5	152.	215.	4	143.9
ALL	64	1075.	424.	39.48	61	177.	218.	62	151.8

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	3	745.	257.	34.53	3	195.	215.	3	147.9
6X12 TAMPED	22	1307.	543.	41.56	22	186.	215.	22	152.3
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	25	1240.	546.	44.07	25	187.	215.	25	151.8

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	1	960.	0.	0.00	1	160.	185.	1	150.2
6X12 TAMPED	9	1642.	645.	39.28	9	188.	212.	9	152.7
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	10	1574.	645.	40.99	10	185.	210.	10	152.5

PROJECT: WILLOW CREEK DAM
CONTRACT: DACW68-82-C-0018
MIX: MIX 3: 175+80
DAY 14
MSA=3.0

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	10	1130.	435.	38.46	9	184.	223.	10	150.3
6X12 TAMPED	49	1564.	533.	34.07	47	178.	216.	49	152.8
6X12 VEBE	6	902.	80.	8.86	6	156.	214.	6	143.4
ALL	66	1431.	540.	37.73	63	176.	217.	66	151.5

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	3	688.	170.	24.75	3	195.	215.	3	144.1
6X12 TAMPED	22	1727.	674.	39.05	22	185.	213.	22	151.8
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	25	1602.	720.	44.96	25	186.	213.	25	150.9

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	1	595.	0.	0.00	1	160.	185.	1	142.2
6X12 TAMPED	9	2102.	766.	36.43	9	188.	212.	9	153.4
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	10	1951.	865.	44.33	10	185.	210.	10	152.3

PROJECT: WILLOW CREEK DAM
CONTRACT: DACW68-82-C-0018
MIX: MIX 3: 175+80
DAY 28
MSA=3.0

ALL SETS

	STRENGTH DATA ANALYSIS: NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	CONCRETE QUALITY MONITOR: NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	UNIT WEIGHTS: NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	10	1525.	627.	41.10	9	184.	223.	10	151.7
6X12 TAMPED	49	2073.	686.	33.07	47	178.	216.	49	152.5
6X12 VEBE	6	1648.	1091.	66.18	6	156.	214.	5	147.4
ALL	66	1949.	735.	37.72	63	176.	217.	65	152.0

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS: NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	CONCRETE QUALITY MONITOR: NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	UNIT WEIGHTS: NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	3	877.	306.	34.89	3	195.	215.	3	146.5
6X12 TAMPED	22	2122.	871.	41.05	22	185.	213.	22	151.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	25	1972.	918.	46.53	25	186.	213.	25	150.4

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS: NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	CONCRETE QUALITY MONITOR: NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	UNIT WEIGHTS: NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	1	1195.	0.	0.00	1	160.	185.	1	149.5
6X12 TAMPED	9	2505.	1077.	43.01	9	188.	212.	9	151.4
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	10	2374.	1097.	46.21	10	185.	210.	10	151.2

CONCRETE COMPRESSION TESTS SHEET 5

PROJECT: WILLOW CREEK DAM
CONTRACT: DACW68-82-C-0018
MIX: MIX 3: 175+80
DAY: 90
MSA=3.0

ALL SETS

	STRENGTH DATA ANALYSIS: NUMBER OF CYLINDER SETS	STRENGTH DATA ANALYSIS: AVERAGE SET BREAK STRENGTH (PSI)	STRENGTH DATA ANALYSIS: STANDARD DEVIATION	STRENGTH DATA ANALYSIS: COEFF. OF VARIATION (%)	CONCRETE QUALITY MONITOR: NUMBER OF CYLINDER SETS	CONCRETE QUALITY MONITOR: AVE. SET CEMENT CONTENT (LB/CY)	CONCRETE QUALITY MONITOR: AVE. SET WATER CONTENT (LB/CY)	UNIT WEIGHTS: NUMBER OF CYLINDER SETS	UNIT WEIGHTS: AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	10	2195.	1007.	45.88	9	184.	223.	7	149.0
6X12 TAMPED	40	3020.	697.	23.08	38	177.	217.	31	151.4
6X12 VEBE	5	2090.	730.	34.92	5	163.	218.	1	140.0
ALL	56	2766.	847.	30.62	53	177.	217.	39	150.7

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS: NUMBER OF CYLINDER SETS	STRENGTH DATA ANALYSIS: AVERAGE SET BREAK STRENGTH (PSI)	STRENGTH DATA ANALYSIS: STANDARD DEVIATION	STRENGTH DATA ANALYSIS: COEFF. OF VARIATION (%)	CONCRETE QUALITY MONITOR: NUMBER OF CYLINDER SETS	CONCRETE QUALITY MONITOR: AVE. SET CEMENT CONTENT (LB/CY)	CONCRETE QUALITY MONITOR: AVE. SET WATER CONTENT (LB/CY)	UNIT WEIGHTS: NUMBER OF CYLINDER SETS	UNIT WEIGHTS: AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	5	1685.	1032.	61.26	4	197.	212.	5	147.7
6X12 TAMPED	20	2834.	794.	28.01	18	184.	210.	20	151.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	25	2604.	947.	36.36	22	186.	210.	25	150.4

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS: NUMBER OF CYLINDER SETS	STRENGTH DATA ANALYSIS: AVERAGE SET BREAK STRENGTH (PSI)	STRENGTH DATA ANALYSIS: STANDARD DEVIATION	STRENGTH DATA ANALYSIS: COEFF. OF VARIATION (%)	CONCRETE QUALITY MONITOR: NUMBER OF CYLINDER SETS	CONCRETE QUALITY MONITOR: AVE. SET CEMENT CONTENT (LB/CY)	CONCRETE QUALITY MONITOR: AVE. SET WATER CONTENT (LB/CY)	UNIT WEIGHTS: NUMBER OF CYLINDER SETS	UNIT WEIGHTS: AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	3	1083.	479.	44.23	3	195.	215.	3	147.4
6X12 TAMPED	7	2588.	1060.	40.97	7	168.	215.	7	149.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	10	2137.	1153.	53.95	10	176.	215.	10	148.5

CONCRETE COMPRESSION TESTS SHEET 6

PROJECT WILLOW CREEK DAM

CONTRACT DACW68-82-C-0018

MIX MIX 3: 175+80

DAY 180

MSA=3.0

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	1	2895.	0.	0.00	0	0.	0.	1	150.4
6X12 TAMPED	3	2987.	996.	33.36	2	149.	203.	3	155.1
6X12 VEBE	3	2177.	886.	40.72	2	149.	203.	3	145.0
ALL	7	2626.	878.	33.43	4	149.	203.	7	150.1

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	1	2895.	0.	0.00	0	0.	0.	1	150.4
6X12 TAMPED	3	2987.	996.	33.36	2	149.	203.	3	155.1
6X12 VEBE	3	2177.	886.	40.72	2	149.	203.	3	145.0
ALL	7	2626.	878.	33.43	4	149.	203.	7	150.1

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	1	2895.	0.	0.00	0	0.	0.	1	150.4
6X12 TAMPED	3	2987.	996.	33.36	2	149.	203.	3	155.1
6X12 VEBE	3	2177.	886.	40.72	2	149.	203.	3	145.0
ALL	7	2626.	878.	33.43	4	149.	203.	7	150.1

PROJECT: WILLOW CREEK DAM
CONTRACT: DACW68-82-C-0018
MIX: MIX 3: 175+80
DAY 365
MSA=3.0

ALL SETS

	STRENGTH DATA ANALYSIS: NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	CONCRETE QUALITY MONITOR: NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	UNIT WEIGHTS: NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	0	0.	0.	0.00	0	0.	0.	0	0.0

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS: NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	CONCRETE QUALITY MONITOR: NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	UNIT WEIGHTS: NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	0	0.	0.	0.00	0	0.	0.	0	0.0

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS: NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	CONCRETE QUALITY MONITOR: NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	UNIT WEIGHTS: NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	0	0.	0.	0.00	0	0.	0.	0	0.0

CONCRETE COMPRESSION TESTS

PROJECT: WILLOW CREEK DAM
CONTRACT: DACW68-82-C-0018
MIX: MIX 4: 315+135
DAY 3
MSA=1.5

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	10	1359.	398.	29.32	8	323.	252.	9	153.3
6X12 TAMPED	38	1384.	352.	25.40	35	301.	259.	36	153.8
6X12 VEBE	3	1347.	443.	32.89	2	357.	327.	3	147.7
ALL	51	1377.	358.	25.99	45	307.	261.	48	153.3

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	4	1134.	242.	21.38	4	325.	246.	4	150.6
6X12 TAMPED	21	1377.	362.	26.27	21	296.	243.	21	153.3
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	25	1338.	353.	26.39	25	301.	244.	25	152.9

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	2	1095.	389.	35.52	2	323.	231.	2	150.2
6X12 TAMPED	8	1470.	276.	18.80	8	298.	248.	8	151.8
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	10	1395.	318.	22.81	10	303.	245.	10	151.4

PROJECT: WILLOW CREEK DAM
CONTRACT: DACW68-82-C-0018
MIX: MIX 4: 315+135
DAY 7
MSA=1.5

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	10	1793.	479.	26.71	8	323.	252.	9	151.7
6X12 TAMPED	40	2033.	605.	29.77	36	301.	257.	37	154.2
6X12 VEBE	3	2137.	906.	42.42	2	357.	327.	3	148.7
ALL	53	1994.	597.	29.94	46	307.	260.	49	153.4

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	4	1608.	424.	26.36	4	325.	246.	4	150.0
6X12 TAMPED	21	1969.	625.	31.72	21	295.	242.	21	153.5
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	25	1911.	605.	31.65	25	300.	242.	25	153.0

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	2	1353.	32.	2.35	2	323.	231.	2	150.0
6X12 TAMPED	8	1782.	698.	39.18	8	297.	244.	8	152.2
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	10	1696.	642.	37.84	10	302.	241.	10	151.8

CONCRETE COMPRESSION TESTS

SHEET 3

PROJECT: WILLOW CREEK DAM

CONTRACT: DACW68-82-C-0018

MIX: MIX 4: 315+135

DAY 14

MSA=1.5

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	10	2246.	621.	27.67	8	323.	252.	10	152.5
6X12 TAMPED	41	2636.	798.	30.29	36	301.	258.	40	153.9
6X12 VEBE	4	2440.	1460.	59.84	2	357.	327.	4	147.6
ALL	55	2551.	824.	32.30	46	307.	260.	54	153.2

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	4	1989.	626.	31.50	4	325.	246.	4	149.9
6X12 TAMPED	21	2555.	951.	37.23	21	295.	242.	21	153.1
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	25	2464.	921.	37.36	25	300.	243.	25	152.6

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	2	1723.	95.	5.54	2	323.	231.	2	149.4
6X12 TAMPED	8	2270.	874.	38.52	8	297.	244.	8	152.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	10	2161.	806.	37.29	10	302.	241.	10	151.5

CONCRETE COMPRESSION TESTS

SHEET 4

PROJECT WILLOW CREEK DAM

CONTRACT DACW68-82-C-0018

MIX MIX 4: 315+135

DAY 28

MSA=1.5

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	10	2889.	894.	30.96	8	323.	252.	9	152.5
6X12 TAMPED	39	3423.	1052.	30.74	35	302.	254.	39	154.9
6X12 VEBE	4	2833.	1781.	62.89	2	357.	327.	4	146.5
ALL	53	3278.	1091.	33.29	45	308.	257.	52	153.8

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	4	2285.	549.	24.02	4	325.	247.	4	150.6
6X12 TAMPED	21	3247.	1160.	35.73	21	295.	242.	21	153.7
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	25	3093.	1135.	36.70	25	300.	243.	25	153.2

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	2	2065.	672.	32.53	2	323.	231.	2	149.4
6X12 TAMPED	8	2834.	1018.	35.90	8	297.	244.	8	152.4
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	10	2681.	980.	36.56	10	302.	241.	10	151.8

CONCRETE COMPRESSION TESTS SHEET 5

PROJECT: WILLOW CREEK DAM
CONTRACT: DACW68-82-C-0018
MIX: MIX 4: 315+135
DAY 90
MSA=1.5

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	8	4185.	1252.	29.92	6	323.	259.	3	151.0
6X12 TAMPED	40	4511.	1515.	33.59	36	303.	259.	24	152.9
6X12 VEBE	4	4050.	2937.	72.51	2	357.	327.	0	0.0
ALL	52	4425.	1582.	35.76	44	308.	262.	27	152.6

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	2	3558.	1078.	30.31	2	326.	262.	2	148.8
6X12 TAMPED	23	4161.	1434.	34.46	23	298.	242.	23	152.6
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	25	4112.	1400.	34.05	25	301.	244.	25	152.3

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 TAMPED	10	3845.	1404.	36.53	10	301.	237.	10	152.2
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	10	3845.	1404.	36.53	10	301.	237.	10	152.2

PROJECT: WILLOW CREEK DAM
CONTRACT: DACW68-82-C-0018
MIX: MIX 4: 315+135
DAY 180
MSA=1.5

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	5	4455.	1422.	31.92	3	331.	251.	5	151.5
6X12 TAMPED	7	4522.	2132.	47.14	2	321.	241.	7	151.0
6X12 VEBE	3	2923.	1964.	67.18	1	364.	275.	3	144.0
ALL	15	4180.	1871.	44.76	6	333.	251.	15	149.8

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	5	4455.	1422.	31.92	3	331.	251.	5	151.5
6X12 TAMPED	7	4522.	2132.	47.14	2	321.	241.	7	151.0
6X12 VEBE	3	2923.	1964.	67.18	1	364.	275.	3	144.0
ALL	15	4180.	1871.	44.76	6	333.	251.	15	149.8

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	3	3990.	1759.	44.09	3	331.	251.	3	151.8
6X12 TAMPED	4	4161.	1897.	45.60	2	321.	241.	4	151.6
6X12 VEBE	3	2923.	1964.	67.18	1	364.	275.	3	144.0
ALL	10	3739.	1751.	46.84	6	333.	251.	10	149.1

CONCRETE COMPRESSION TESTS   SHEET 1

PROJECT: WILLOW CREEK DAM
CONTRACT: DACW68-82-C-0018
MIX: MIX 4: 315+135
DAY 365
MSA=1.5

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	0	0.	0.	0.00	0	0.	0.	0	0.0

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	0	0.	0.	0.00	0	0.	0.	0	0.0

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	0	0.	0.	0.00	0	0.	0.	0	0.0

PROJECT: WILLOW CREEK DAM
CONTRACT: DACW68-82-C-0018
MIX: MIX 5: 330+130
DAY 3
MSA=0.8

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	4	760.	351.	46.19	2	301.	275.	4	144.1
6X12 TAMPED	14	685.	216.	31.50	12	303.	308.	13	144.9
6X12 VEBE	1	770.	0.	0.00	0	0.	0.	1	143.6
ALL	19	706.	235.	33.36	14	302.	304.	18	144.7

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	4	760.	351.	46.19	2	301.	275.	4	144.1
6X12 TAMPED	14	685.	216.	31.50	12	303.	308.	13	144.9
6X12 VEBE	1	770.	0.	0.00	0	0.	0.	1	143.6
ALL	19	706.	235.	33.36	14	302.	304.	18	144.7

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	2	538.	25.	4.60	2	301.	275.	2	141.1
6X12 TAMPED	8	618.	202.	32.61	8	291.	320.	8	143.9
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	10	602.	181.	30.10	10	293.	311.	10	143.3

PROJECT CONTRACT MIX DAY 7
WILLOW CREEK DAM DACW68-82-C-0018 MIX 5: 330+130 MSA=0.8

ALL SETS — STRENGTH DATA ANALYSIS / CONCRETE QUALITY MONITOR / UNIT WEIGHTS

	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	4	1140.	369.	32.40	2	301.	275.	3	145.0
6X12 TAMPED	14	1003.	343.	34.24	12	303.	308.	14	145.4
6X12 VEBE	1	1100.	0.	0.00	0	0.	0.	1	140.7
ALL	19	1037.	334.	32.19	14	302.	304.	18	145.1

LAST 25 OR LESS SETS — STRENGTH DATA ANALYSIS / CONCRETE QUALITY MONITOR / UNIT WEIGHTS

	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	4	1140.	369.	32.40	2	301.	275.	3	145.0
6X12 TAMPED	14	1003.	343.	34.24	12	303.	308.	14	145.4
6X12 VEBE	1	1100.	0.	0.00	0	0.	0.	1	140.7
ALL	19	1037.	334.	32.19	14	302.	304.	18	145.1

LAST 10 OR LESS SETS — STRENGTH DATA ANALYSIS / CONCRETE QUALITY MONITOR / UNIT WEIGHTS

	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	2	943.	265.	28.13	2	301.	275.	2	145.9
6X12 TAMPED	8	971.	385.	39.69	8	291.	320.	8	143.9
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	10	965.	351.	36.40	10	293.	311.	10	144.3

PROJECT: WILLOW CREEK DAM
CONTRACT: DACW68-82-C-0018
MIX: MIX 5: 330+130
DAY 14
MSA=0.8

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	4	1454.	579.	39.82	2	301.	275.	4	143.6
6X12 TAMPED	13	1586.	423.	26.70	11	300.	288.	13	146.0
6X12 VEBE	1	1660.	0.	0.00	0	0.	0.	1	143.1
ALL	18	1561.	435.	27.89	13	300.	286.	18	145.3

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	4	1454.	579.	39.82	2	301.	275.	4	143.6
6X12 TAMPED	13	1586.	423.	26.70	11	300.	288.	13	146.0
6X12 VEBE	1	1660.	0.	0.00	0	0.	0.	1	143.1
ALL	18	1561.	435.	27.89	13	300.	286.	18	145.3

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	2	1048.	357.	34.09	2	301.	275.	2	139.6
6X12 TAMPED	8	1516.	493.	32.50	8	290.	302.	8	145.1
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	10	1423.	492.	34.59	10	292.	297.	10	144.0

CONCRETE COMPRESSION TESTS

PROJECT: WILLOW CREEK DAM — CONTRACT: DACW68-82-C-0018 — MIX: MIX 5: 330+130 — DAY 28 — MSA=0.8

ALL SETS

STRENGTH DATA ANALYSIS / CONCRETE QUALITY MONITOR / UNIT WEIGHTS

	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	4	2181.	544.	24.96	2	301.	275.	4	147.2
6X12 TAMPED	14	2196.	560.	25.50	12	303.	308.	14	145.7
6X12 VEBE	1	3060.	0.	0.00	0	0.	0.	1	147.7
ALL	19	2238.	562.	25.09	14	302.	304.	19	146.1

LAST 25 OR LESS SETS

STRENGTH DATA ANALYSIS / CONCRETE QUALITY MONITOR / UNIT WEIGHTS

	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	4	2181.	544.	24.96	2	301.	275.	4	147.2
6X12 TAMPED	14	2196.	560.	25.50	12	303.	308.	14	145.7
6X12 VEBE	1	3060.	0.	0.00	0	0.	0.	1	147.7
ALL	19	2238.	562.	25.09	14	302.	304.	19	146.1

LAST 10 OR LESS SETS

STRENGTH DATA ANALYSIS / CONCRETE QUALITY MONITOR / UNIT WEIGHTS

	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	2	1855.	431.	23.25	2	301.	275.	2	146.4
6X12 TAMPED	8	1975.	592.	29.99	8	291.	320.	8	143.8
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	10	1951.	544.	27.89	10	293.	311.	10	144.3

PROJECT: WILLOW CREEK DAM
CONTRACT: DACW68-82-C-0018
MIX: MIX 5: 330+130
DAY 90
MSA=0.8

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	4	3236.	933.	28.82	2	301.	275.	2	142.3
6X12 TAMPED	13	3259.	760.	23.32	12	303.	308.	8	144.0
6X12 VEBE	1	2560.	0.	0.00	0	0.	0.	1	147.7
ALL	18	3215.	767.	23.85	14	302.	304.	11	144.0

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	4	3236.	933.	28.82	2	301.	275.	2	142.3
6X12 TAMPED	13	3259.	760.	23.32	12	303.	308.	8	144.0
6X12 VEBE	1	2560.	0.	0.00	0	0.	0.	1	147.7
ALL	18	3215.	767.	23.85	14	302.	304.	11	144.0

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	2	2608.	979.	37.56	2	301.	275.	1	138.5
6X12 TAMPED	8	2943.	779.	26.48	8	291.	320.	8	144.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	10	2876.	774.	26.91	10	293.	311.	9	143.4

CONCRETE COMPRESSION TESTS SHEET 6

PROJECT: WILLOW CREEK DAM | CONTRACT: DACW68-82-C-0018 | MIX: MIX 5: 330+130 | DAY 180 | MSA=0.8

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	2	3783.	371.	9.81	0	0.	0.	2	147.1
6X12 TAMPED	2	4698.	315.	6.70	0	0.	0.	2	146.3
6X12 VEBE	1	3290.	0.	0.00	0	0.	0.	1	140.0
ALL	5	4050.	670.	16.55	0	0.	0.	5	145.3

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	2	3783.	371.	9.81	0	0.	0.	2	147.1
6X12 TAMPED	2	4698.	315.	6.70	0	0.	0.	2	146.3
6X12 VEBE	1	3290.	0.	0.00	0	0.	0.	1	140.0
ALL	5	4050.	670.	16.55	0	0.	0.	5	145.3

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	2	3783.	371.	9.81	0	0.	0.	2	147.1
6X12 TAMPED	2	4698.	315.	6.70	0	0.	0.	2	146.3
6X12 VEBE	1	3290.	0.	0.00	0	0.	0.	1	140.0
ALL	5	4050.	670.	16.55	0	0.	0.	5	145.3

CONCRETE COMPRESSION TESTS

SHEET 1

PROJECT: WILLOW CREEK DAM

CONTRACT: DACW68-82-C-0018

MIX: MIX 5: 330+130

DAY 365

MSA=0.8

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	0	0.	0.	0.00	0	0.	0.	0	0.0

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	0	0.	0.	0.00	0	0.	0.	0	0.0

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	0	0.	0.	0.00	0	0.	0.	0	0.0

CONCRETE COMPRESSION TESTS SHEET ?

PROJECT CONTRACT MIX C DAY 7
WILLOW CREEK DAM DACW68-82-C-0018 TOP MIX 175+93 MSA=1.5

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	1	920.	0.	0.00	1	165.	234.	1	149.4
6X12 TAMPED	2	1155.	92.	7.96	2	206.	233.	2	150.3
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	3	1077.	150.	13.97	3	192.	233.	3	150.0

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	1	920.	0.	0.00	1	165.	234.	1	149.4
6X12 TAMPED	2	1155.	92.	7.96	2	206.	233.	2	150.3
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	3	1077.	150.	13.97	3	192.	233.	3	150.0

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	1	920.	0.	0.00	1	165.	234.	1	149.4
6X12 TAMPED	2	1155.	92.	7.96	2	206.	233.	2	150.3
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	3	1077.	150.	13.97	3	192.	233.	3	150.0

PROJECT: WILLOW CREEK DAM
CONTRACT: DACW68-82-C-0018
MIX: TOP MIX 175+93
DAY 14
MSA=1.5

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	1	1060.	0.	0.00	1	165.	234.	1	150.5
6X12 TAMPED	2	1315.	191.	14.52	2	206.	233.	2	150.9
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	3	1230.	200.	16.24	3	192.	233.	3	150.8

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	1	1060.	0.	0.00	1	165.	234.	1	150.5
6X12 TAMPED	2	1315.	191.	14.52	2	206.	233.	2	150.9
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	3	1230.	200.	16.24	3	192.	233.	3	150.8

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	1	1060.	0.	0.00	1	165.	234.	1	150.5
6X12 TAMPED	2	1315.	191.	14.52	2	206.	233.	2	150.9
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	3	1230.	200.	16.24	3	192.	233.	3	150.8

CONCRETE COMPRESSION TESTS

SHEET 4

PROJECT WILLOW CREEK DAM

CONTRACT DACW68-82-C-0018

MIX TOP MIX 175+93

DAY 28

MSA=1.5

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	1	1400.	0.	0.00	1	165.	234.	1	149.8
6X12 TAMPED	2	1895.	141.	7.46	2	206.	233.	2	151.9
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	3	1730.	303.	17.50	3	192.	233.	3	151.2

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	1	1400.	0.	0.00	1	165.	234.	1	149.8
6X12 TAMPED	2	1895.	141.	7.46	2	206.	233.	2	151.9
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	3	1730.	303.	17.50	3	192.	233.	3	151.2

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	1	1400.	0.	0.00	1	165.	234.	1	149.8
6X12 TAMPED	2	1895.	141.	7.46	2	206.	233.	2	151.9
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	3	1730.	303.	17.50	3	192.	233.	3	151.2

CONCRETE COMPRESSION TESTS SHEET 5

PROJECT: WILLOW CREEK DAM
CONTRACT: DACW68-82-C-0018
MIX: TOP MIX 175+93
DAY 90
MSA=1.5

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	0	0.	0.	0.00	0	0.	0.	0	0.0

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	0	0.	0.	0.00	0	0.	0.	0	0.0

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	0	0.	0.	0.00	0	0.	0.	0	0.0

CONCRETE COMPRESSION TESTS

PROJECT: WILLOW CREEK DAM
CONTRACT: DACW68-82-C-0018
MIX: TOP MIX 175+93
DAY 180
MSA=1.5

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	0	0.	0.	0.00	0	0.	0.	0	0.0

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	0	0.	0.	0.00	0	0.	0.	0	0.0

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	0	0.	0.	0.00	0	0.	0.	0	0.0

CONCRETE COMPRESSION TESTS

SHEET 1

PROJECT: WILLOW CREEK DAM

CONTRACT: DACW68-82-C-0018

MIX: TOP MIX 175+93

DAY 365

MSA=1.5

ALL SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	0	0.	0.	0.00	0	0.	0.	0	0.0

LAST 25 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	0	0.	0.	0.00	0	0.	0.	0	0.0

LAST 10 OR LESS SETS

	STRENGTH DATA ANALYSIS				CONCRETE QUALITY MONITOR			UNIT WEIGHTS	
	NUMBER OF CYLINDER SETS	AVERAGE SET BREAK STRENGTH (PSI)	STANDARD DEVIATION	COEFF. OF VARIATION (%)	NUMBER OF CYLINDER SETS	AVE. SET CEMENT CONTENT (LB/CY)	AVE. SET WATER CONTENT (LB/CY)	NUMBER OF CYLINDER SETS	AVERAGE SET UNIT WEIGHT (LB/CY)
9X18 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 TAMPED	0	0.	0.	0.00	0	0.	0.	0	0.0
6X12 VEBE	0	0.	0.	0.00	0	0.	0.	0	0.0
ALL	0	0.	0.	0.00	0	0.	0.	0	0.0

CHAPTER 10

DENSITY AND VOID SPACE

Throughout construction, minor but frequent adjustments were made in individual aggregate batch quantities to maintain the desired overall aggregate gradations. Because of differing specific gravities in the aggregates, the theoretical unit weights also varied. Exhibit 4.1 shows typical mix proportions and associated theoretical unit weights. Overall, theoretical weights generally were about 152 pcf to 155 pcf. Based on nuclear gage readings, in-place densities typically were in the range of 95 to 102 percent of theoretical densities with occasional values as low as 85 percent and as high as 105 percent. The effect of density on strength is discussed in Chapter 9, "Test Cylinders and Compressive Strength Results."

A major effort was made to accurately determine the unit weight of the various mixes and their void or air contents. This was more difficult than originally thought and resulted in a variety of answers depending on the method and equipment used to run the test and on the mix design tested.

Excavation of compacted RCC so that a sand cone or water balloon density could be run was nearly impossible and certainly impractical. The RCC simply compacted too tightly and interlocked too well to permit a relatively neat excavation without loosening adjacent materials. Neither of these test procedures could be effectively and efficiently run.

The nuclear density gage had been evaluated earlier in RCC mixes while studying Zintel Canyon Dam as an RCC structure. In the direct transmission mode, with the probe at the full depth of the RCC layer, the gage satisfactorily indicated in-place densities. At each test location during Willow Creek construction, the probe was inserted into a pilot hole driven with a hammer and pointed rod. A reading was taken and the gage was rotated 90 degrees to the next quadrant for another reading at the same probe location. This was continued until four readings (one each quadrant) were obtained for each probe location. The average of the four readings was considered to be the average density. When the lift or layer thickness was less than 12 inches (as allowed within the contract tolerances), a probe depth of 10 inches was used. Typically, the layer below would have been old enough so that the cement had hydrated and the probe could not be driven into it.

As required by contract specifications, at least once every 2 hours during placement and at not less than six locations per lift, the nuclear density was determined. This resulted in a wide range of values, typically from a low of 143 to a high of 157 pounds pcf. Inspectors were instructed not to overreact to occasional low readings. The contractor performed all of the testing and reported results each day as shown in Exhibit 10.1. The Corps' onsite engineering representative reviewed these results daily. They show the average density, number of tests, and standard deviation for each day. Also shown is the moving average density of the last 50 tests. In this manner the overall in-place density, any trends, and changes in variability could easily be spotted without studying volumes of individual pieces of test data. As an overall average throughout the job, about 10 test locations were checked each day. The standard deviation was about 7 pcf and the average density was about 154 pcf.

A general trend of increasing density and decreasing standard deviation appeared during the first 2 months of operation. The decreasing standard deviation is attributed mostly to a "learning curve" for the operators of both the placing equipment and test equipment. The increasing density is attributed partly to a "learning curve" where the placing crew became more effective, and partly to placing in larger and more open areas instead of over small areas on an irregular foundation. However, the prime reason is that less blend fines (at a very low specific gravity) were included with the aggregates as the job progressed. After the operation stabilized, a general trend was found when comparing density shown in Exhibit 10.1 with moisture shown in Exhibit 11.1. When moisture increased slightly over a period of time (from about 6 to 8 percent in the first part of August) density decreased (from about 155 to 153 pcf). Conversely, the trend reversed itself later in the month.

Contract specifications required the nuclear gage to be calibrated against the actual mixes used. The intent was to use a rigid box of known volume approximately 1/2 to 1 cubic yard in size which could be weighed, and calibrate the gage to each mix with the known density positively determined by weight-to-volume relationship of the mass. The importance of doing this was pointed out several times during construction but, in fact, it was never done. The contractor and Resident Office erroneously thought that calibration against the standard granite block furnished with the gage was accurate. After the job was completed, one of the gages which had not been subsequently readjusted was sent to the NPD laboratory along with materials from job stockpiles. Tests showed that the gage indicated the unit weight to be 2.25 percent <u>less</u> than it actually was. On a small job this may not be significant, but for a job the size of Willow Creek (435,000 cubic yards) and at an overall in-place cost to the owner of about $20, over $250,000 is associated with the discrepancy.

Results of the post-construction nuclear gage calibration tests did not agree with indications when comparing total batched quantities of RCC, determined by automated plant records, with calculated in-place volumes. After taking into account wasted loads, block-out concrete, etc., the gage should have indicated the unit weight to have been about 4.25 percent more than it actually was. Details of the quantities along with discussion about the discrepancy are given in the Disposition Forms shown as Exhibits 10.2 and 10.3. The problem has not yet been resolved nor does it appear that there is any way at this time to resolve it.

The various methods used to compact test cylinders are described in Chapter 9, "Test Cylinders and Compressive Strength Results." Both the method of compaction and the cylinder size affected the density. In the future, the pole compaction method using 6- x 12-inch cylinders is recommended. Table 10.1 shows the average density for each mix, method of compaction, and cylinder size. Also shown are the number of tests. A more detailed breakdown of the data is given in Exhibit 9.1 along with the compressive strengths for cylinders at various ages. Unless specifically noted, the unit weight (density) was determined for the cylinders by dividing the saturated surface dry weight (as removed from the cure room and allowed to drain of free surface water) by the volume of the cylinder mold. This did not account for void spaces around the perimeter of the cylinder as was typically occurring with the harsher large aggregate RCC mixes.

For practical mixes having moisture contents used during construction, the modified vebee method of compaction simply did not do an acceptable job of consolidation. This is also discussed in Chapters 9 and 11. The 9- x 18-inch cylinders generally contained 3-inch aggregate mixes and did not consolidate well. The mix with 1-1/2-inch maximum size aggregate compacted better but still not as well as in the 6- x 12-inch molds. Part of the reason for lower density in the larger cylinders is attributed to the interlocking of large aggregate, but part of the reason is also believed to be due to the size of the compaction foot. It fit neatly inside the diameter of the smaller mold but was much smaller than the diameter of the larger mold, so the mix was not as well confined during compaction. As an overall average, the vebee cylinders had 5.0 percent lower density and the 9- x 18-inch cylinders had 1.7 percent lower density than the pole compacted 6- x 12-inch cylinders. The 6- x 12-inch cylinders agreed reasonably well with the theoretical unit weights of the mixes, the nuclear gage density, and the unit weights of cores from the dam.

Table 10.1 also compares unit weights of cylinders based on the full cylinder volume to unit weights based on the volume as determined by submerging them in water. This procedure took into account void spaces around the perimeter of typical cylinders. An average difference of only 0.6 percent occurred for the 6- x 12-inch cylinders, but the 9- x 18-inch cylinders had an average difference of 3.3 percent.

TABLE 10.1

AVERAGE DENSITY OF COMPRESSIVE CYLINDERS

TABLE 10.1

AVERAGE DENSITY BASED ON FULL CYLINDER SIZES

	Average Density (pcf)					No. of Tests		
	6x12 Vebee	Diff.	6x12 Tamped	Diff.	9x18 Tamped	6x12 Vebee	6x12 Tamped	9x18 Tamped
Mix 1	146.1	4.9%	153.3	1.7%	150.7	29	221	49
Mix 2	144.6	5.8%	153.0	2.3%	149.6	11	228	40
Mix 3	146.1	4.5%	152.6	1.7%	150.1	24	228	47
Mix 4	146.9	4.8%	153.9	1.1%	152.3	17	183	45
Avg.		5.0%		1.7%				

	Average Submerged Density (pcf)				No. of Tests		
	6x12 Vebee	6x12 Tamped	Diff.	9x18 Tamped	6x12 Vebee	6x12 Tamped	9x18 Tamped
Mix 1	-	152.4	2.7%	156.5	-	20	9
Mix 2	-	153.7	0.6%	154.6	-	46	16
Mix 3	-	155.6	0.5%	154.8	-	51	16
Mix 4	-	154.6	-	-	-	11	-
Avg.							

	Average Correction Factor (%) to Submerged Value		
	6x12 Vebee	6x12 Tamped	9x18 Tamped
Mix 1	-	-0.7%	+3.7%
Mix 2	-	+0.5%	+3.2%
Mix 3	-	+1.9%	+3.0%
Mix 4	-	+0.5%	-
Avg.		+0.6%	+3.3%

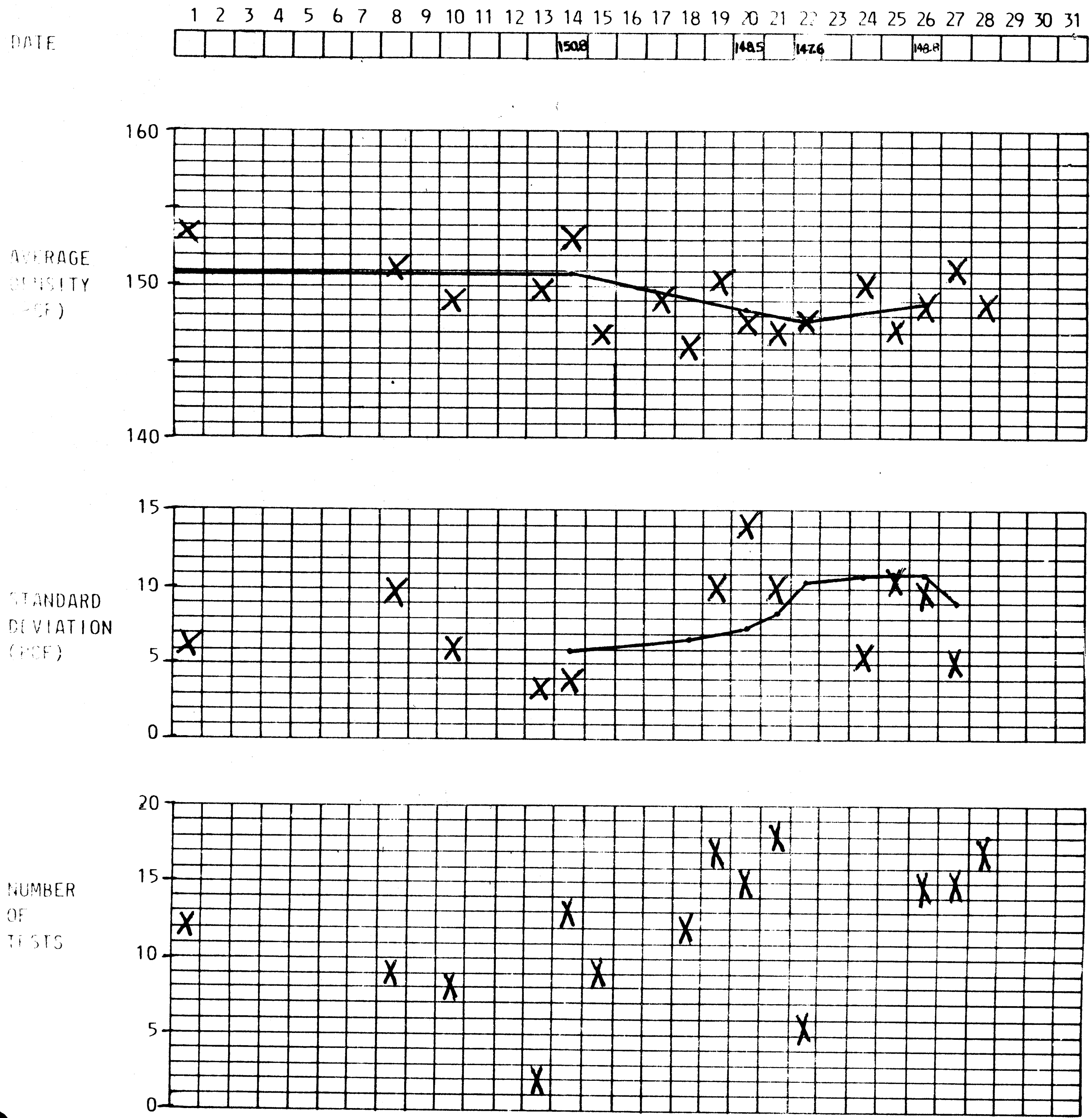
EXHIBIT 10.1

RESULTS OF IN-PLACE
NUCLEAR DENSITY TESTS

WILLOW CREEK DAM

IN-SITE DENSITY

MONTH *May* YEAR *1982*



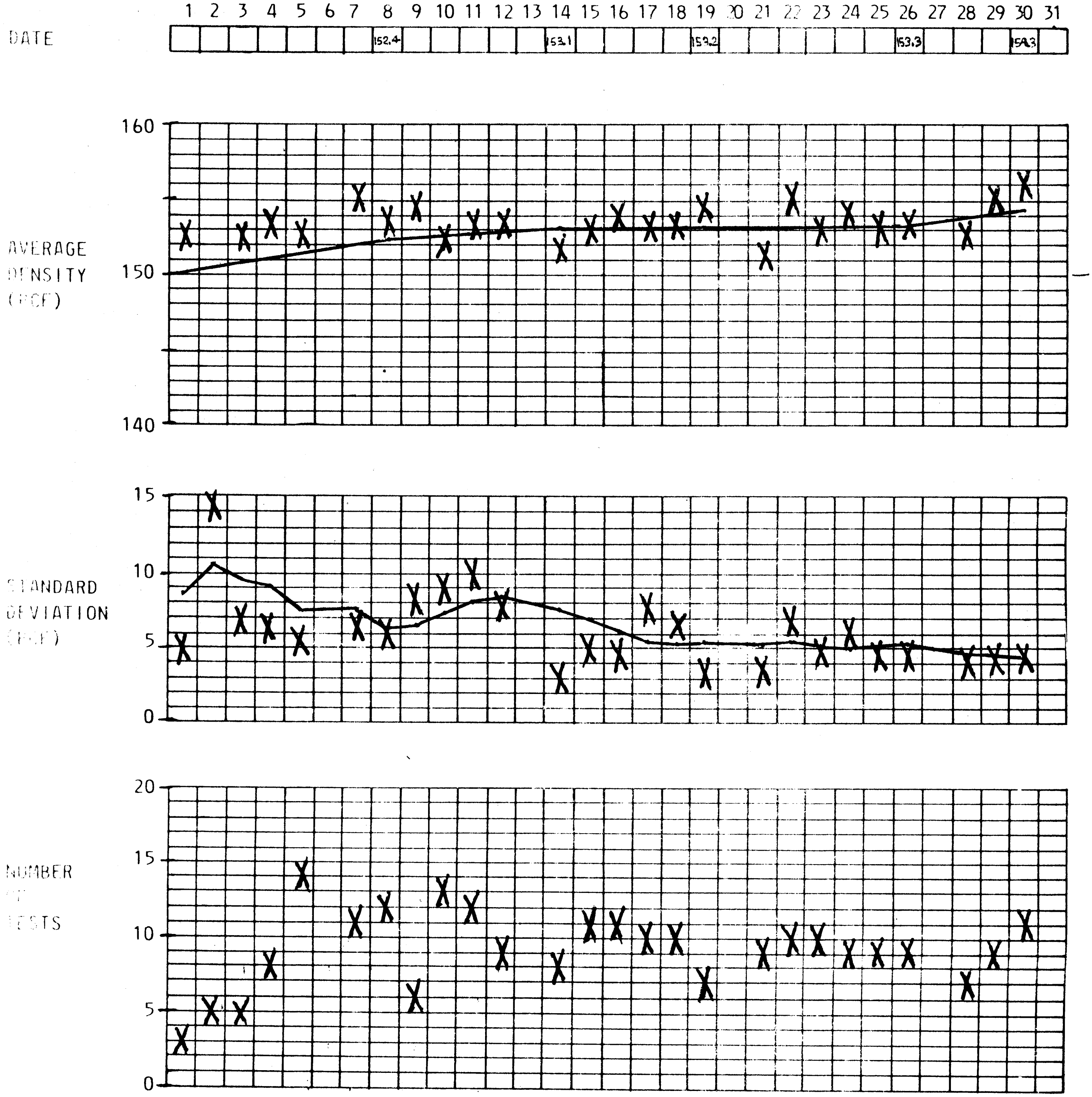
NPW Form 697 (OT)
JUL 82

EXHIBIT 10.1
Sheet 1 of 5

WILLOW CREEK DAM

IN-SITE DENSITY

MONTH *June* YEAR *1982*



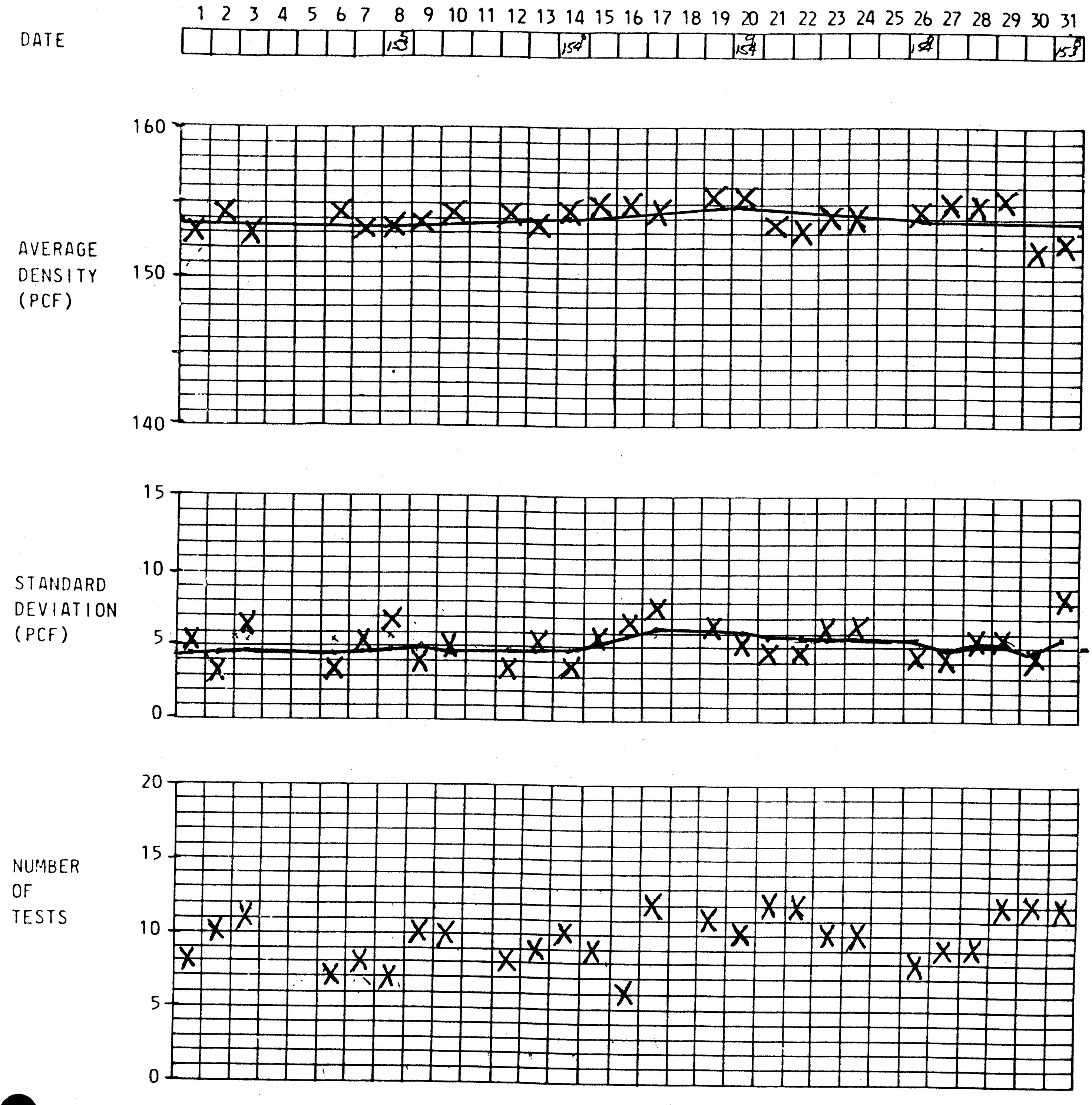
NEW Form 697 (OT)
Jul 82

EXHIBIT 10.1
Sheet 2 of 5

WILLOW CREEK DAM

IN-SITE DENSITY

MONTH July YEAR 1982



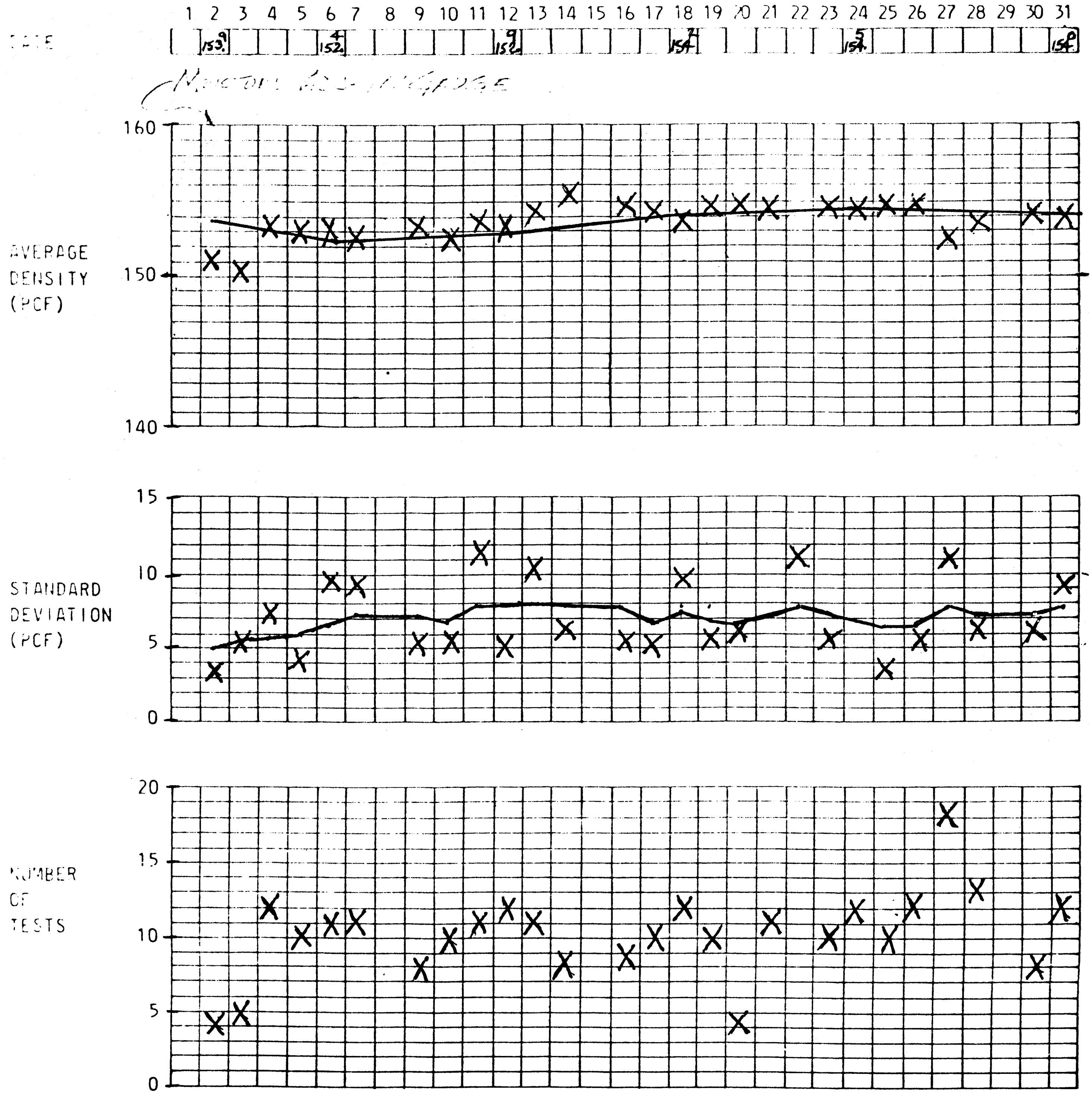
NPW Form 697 (OT)
Jul 82

EXHIBIT 10.1
Sheet 3 of 5

WILLOW CREEK DAM

IN-SITE DENSITY

MONTH August YEAR 1982



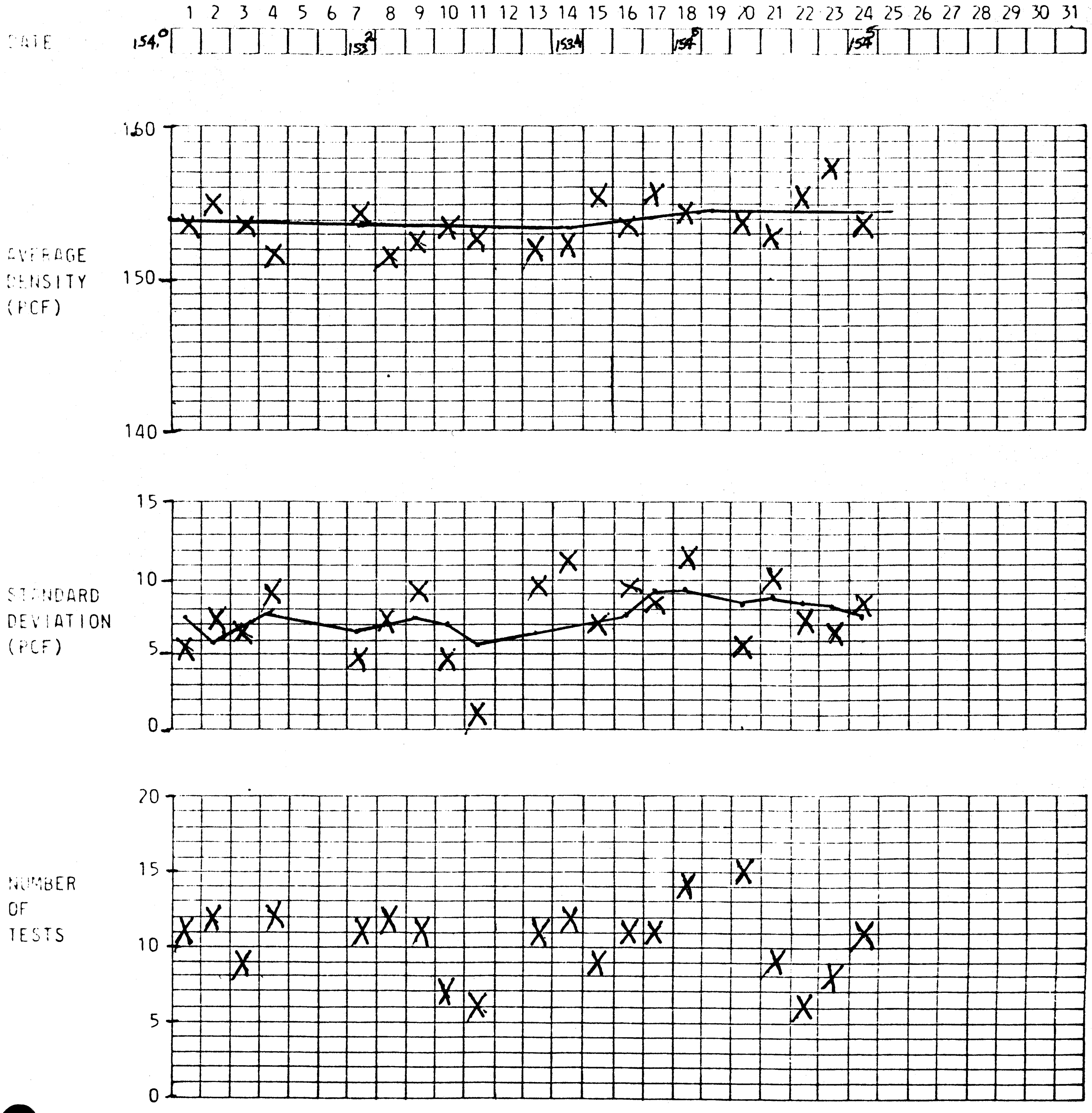
NPW Form 697 (OT)
Jul 82

EXHIBIT 10.1
Sheet 4 of 5

WILLOW CREEK DAM

IN-SITE DENSITY

MONTH *Sept.* YEAR *1982*



NPW Form 697 (OT)
Jul 82

EXHIBIT 10.1
Sheet 5 of 5

EXHIBIT 10.2

DISPOSITION FORM DATED 30 DEC 82
"RCC QUANTITIES AND UNIT WEIGHT"

DISPOSITION FORM

For use of this form, see AR 340-15; the proponent agency is TAGO.

REFERENCE OR OFFICE SYMBOL	SUBJECT
NPWEN-FM	Willow Creek Dam; RCC Quantities and Unit Weight

TO THRU Ch, Est Sec
Ch, Engr Div
Ch, Constr Div

FROM E. K. Schrader DATE 30 Dec 1982 CMT 1

TO Engr Files .

1. The purpose of this DF is to document the current status of the discrepancy between neat line calculated yardage in the dam and the quantity of rolled concrete batched by records.

2. From a payment standpoint, contract specifications are clear that payment for RCC will be the neat line quantity starting from actual rock contours with a few noted exceptions. Payment for cement is based on the designated amount that was to go into each cubic yard of each mix, multiplied by the neat line yardage of that mix. Batch records show less yardage than the neat line quantity, indicating that each yard batched contained more than one cubic yard of in-place compacted material. If this is the case, the actual weight of cement used in each cubic yard was less than the amount designated and a corresponding adjustment in cement and fly ash payment should be made. Unfortunately, there is conflicting data described below as to whether this actually occurred.

3. With the help of the REO's records for progress payments, Foundations and Materials Branch has computed the following quantity values for purposes of evaluating the discrepancy between batch records and the in-place volume of RCC.

*RCC Gross Volume for Payment Per GDP		434,915 cy
Deductions to determine actual in-place volume for the dam proper (not necessarily deducted for payment):		
Conventional concrete used at the upstream face in the top two lifts	181 cy	
Spillway and training wall precast panels	154 cy	
Spillway and training wall panel bedding	167 cy	
Outlet works control building blockout	27 cy	
Conventional bedding at upstream face and foundation	2,750 cy	
Rebar and anchor bar volume	40 cy	
Leveling pad concrete within the RCC prism	81 cy	
RCC in the endsill support	1,586 cy	
Gallery	3,056 cy	
Subtotal for deductions		8,042 cy
Actual RCC volume within the boundaries of the rock contours and perimeter neatlines for the dam		426,873 cy

DA FORM AUG 80 2496 PREVIOUS EDITIONS WILL BE USED

*Gross volume does not include dental concrete encasement for the water quality, outlet works, and diversion pipes (1455 cy); the volume of the water quality, outlet works, and diversion pipes (268 cy); the conventional concrete spillway cap (974 cy); the upstream face panels (1857 cy); and dental fill in the foundation.

From batch records, the volume of RCC placed in the dam is:

RCC gross volume batched (per REO)		415,077 cy
Deductions:		
Waste (per REO records)	1,804 cy	
Overbuild and ravel (est. @ 4½ inch)	1,958 cy	
Endsill support RCC (neat line)	1,586 cy	
Subtotal for deductions		6,348 cy
Batch record RCC volume within the boundaries of the rock contours and perimeter neat lines for the dam		408,729 cy

4. Volume computations, therefore, show that the contractor placed 18,144 cy or 4.25 percent more material than the batch records show. At an approximate average in place cost of $20/cy, a substantial value roughly on the order of $300,000 to $400,000 is associated with this problem.

5. The first reaction is that the batch counter was off or that it did not record all of the batches made. This was not the case. The contractor provided an automated plant (which was not required) that was computer controlled and provided a print out of the batch weights of all mix constituents and the batch size for each batch made. An inspector for the Corps was present in the plant whenever RCC was made. Spot checks routinely made by Engineering Division personnel in addition to the inspectors full time presence showed the printer to be working properly. Occasional checks were also made by Engineering Division to ensure that the printout values matched with display screen values, and that these matched with mechanical scale indicators. The scales were routinely checked with scale weights for verification and found to be accurate (with the exception of the water gage at the very start of the job which was then corrected).

6. Another explanation might be that the batch weights and therefore yield for the mix design was off, i.e., each cubic yard by batch weights actually made 28.14 cubic feet of concrete instead of 27.00 cubic feet. During construction the theoretical batch weights were carefully computed and checked for appropriate yield. Adjustments were properly made for specific gravities of the various aggregates as they changed slightly and as the

batch ratios of the aggregates were adjusted. Adjustments for changes in specific gravity of the fly ash were discounted because under the worst of conditions they would account for a change of only 0.1 percent in yield.

7. Another explanation might be that the compacted mix contained 4.25 percent more air or voids than assumed in the batch weight and yield calculations, i.e., about 5.2 percent to 5.7 percent total air instead of about 1.0 percent to 1.5 percent. However, the air content (which varied slightly throughout the job) was based on ongoing laboratory tests of the mix as it was being placed. The lab test might be considered suspect and not representative of the in-place material, except that its compacted unit weight compared very closely with the theoretical weight at that air content, and with the in-place nuclear density tests.

8. The next question is whether the nuclear gage was properly calibrated and giving correct values for in-place density. If the typical overall average of 154 pcf reported was actually about 148 pcf, the compacted volume would have been greater per unit weight and the discrepancy between actual and batch volumes could be explained. During construction, the issue of nuclear gauge calibration was emphatically discussed by Engineering Division personnel. The Contractor had been calibrating his gauges against a standard granite block that comes with the equipment. There was question during design as to whether the block (which works well in its normal use with chemically inert soils and asphalt) would be appropriate when the compacted material was chemically active concrete. Because of this, contract specifications called for the gauges to be calibrated against the actual RCC mix instead of the standard block. The Contractor's quality control personnel argued that this was not necessary, but finally conceded to do the calibration with freshly compacted RCC. The size of sample and procedure were discussed. Engineering Division was assured that the test would be performed. Lab personnel from the REO agreed to verify that the test was done and to obtain the test results. When results were requested by Engineering Division, they routinely were not readily available. At the end of the job, when the discrepancy between batch and computed volumes of RCC was discovered, it was revealed that, in fact, calibration of the nuclear gauge with an RCC mix was never done. Samples of job aggregate were then shipped to the Division Laboratory and a mix using typical jobsite proportions was made. One of the nuclear gauges from the job was obtained and used to determine the density of the compacted mix. The gauge did not give the correct actual unit weights. The theoretical yield and unit weight based on batch proportions, and the theoretical low air content were found to be correct. The gauge did accurately determine moisture content in the fresh mix. This might explain the difference between batch and calculated volumes in the dam except that the error with the gauge was in the wrong direction, i.e., it indicated the unit weight to be 2.25 percent less than it actually was, whereas to explain the discrepancy, it should have been 4.25 percent more. It should be noted that these tests were run at a probe depth of 12 inches, but did not include a joint surface.

9. The question becomes one of identifying the average unit weight of a large mass of RCC in the dam. The suggestion was made to weigh the tension test blocks which were recovered for that purpose during construction and are being stored at the project. This was not done because the results would be suspect for several reasons: First, the samples were deliberately obtained close to the unconfined downstream face and probably do not have the same compaction as material at the dam interior which was self confined and was rolled with the larger compactors. Secondly, the blocks do not include whatever void space may have occurred at the lift joint. Third, the determination would require weighing in water which could permit void space to be filled with water whereas it would not be filled with water under construction conditions.

10. Four 6-inch diameter core holes are now being drilled from the spillway face at an angle that will bring the holes through both the spillway mix and the lean interior mix until foundation rock is encountered. Project personnel have been asked to closely inspect this work and be certain that all particles of material from within the split core barrel are retrieved. Each box of core will be weighed in a damp condition immediately after recovery. By knowing the total weight recovered, the constant core diameter, and by accurately determining the length of hole to rock, an accurate overall average in-place unit weight can be calculated. This in turn will allow determination of the average yield for the concrete batch proportions used during construction, and identify the correction factor to be used in determining the actual average amount of cement and fly ash in a cubic yard of in-place material.

11. It is worth noting that the Contractor's cement supplier's records show that he supplied much more cement than batch records indicate was used. This reportedly amounts to 2,800 tons of material. Approximately 1,900 tons can be related to overbuild, spillage and encroachment of richer mixes into the leaner mixes. The remaining 900 tons is roughly the amount that would be necessary to make up the difference in concrete volumes between batch records and computed volumes.

ERNEST K. SCHRADER
Civil Engineer

CF:
RE, Willow Creek
NPDEN-GS&M
Proj Mgr, Weller

EXHIBIT 10.3

DISPOSITION FORM DATED 7 JUN 83
"RCC QUANTITIES AND UNIT WEIGHT"

DISPOSITION FORM

For use of this form, see AR 340 15, the proponent agency is TAGO.

REFERENCE OR OFFICE SYMBOL	SUBJECT
NPWEN-FM	RCC Quantities and Unit Weight, Willow Creek Dam

TO THRU Ch, Ests Sec
Ch, Engr Div
Ch, Constr Div

FROM E. K. Schrader

DATE 7 June 1983

CMT 1

TO Engr Div Files

1. Reference my DF to Engineering files dated 30 December 1982, same subject as above. When quantities were calculated to obtain the values shown in the DF, it was assumed that the dam was built to dimensions as shown in the contract drawings, sheet 13 - i.e., that the 8-foot distance from the CBL was measured to the inside (downstream face) of the upstream precast face panels instead of the outside (upstream face) of them. In fact, the dam was built with this dimension to the outside face. Consequently, the quantities in paragraphs 3, 4, 6 and 7 of the DF should be changed to read as follows:

a. Para. 3 - With the help of the REO's records for progress payments, Foundations and Materials Branch has computed the following quantity values for purposes of evaluating the discrepancy between batch records and the in-place volume of RCC.

RCC Gross Volume for Payment Per GDP

Deductions to determine actual in-place volume for the dam proper (not necessarily deducted for payment):

Conventional concrete used at the upstream face in the top two lifts	181 cy
Spillway and training wall precast panels	154 cy
Spillway and training wall panel bedding	167 cy
Outlet works control building blockout	27 cy
Conventional bedding at upstream face and foundation	2,750 cy
Rebar and anchor bar volume	40 cy
Leveling pad concrete within the RCC prism	81 cy
RCC in the endsill buttress	1,586 cy
Gallery	3,056 cy
Subtotal for deductions	8,042 cy

Actual RCC volume within the boundaries of the rock contours and perimeter neatlines for the dam 424,955 cy

*Gross volume does not include dental concrete encasement for the water quality, outlet works, and diversion pipes (1455 cy); the volume of the water quality, outlet works, and diversion pipes (268 cy); the conventional concrete spillway cap (974 cy); the upstream face panels (1857 cy); leveling pad concrete directly beneath the face panels, but not in the dam prism (81 cy), and dental fill in the foundation.

RCC gross volume batched (per REO)	415,077 cy
Deductions:	
Waste (per REO records)	1,804 cy
Overbuild and ravel (est. @ 4½ inch)	1,958 cy
Endsill support RCC (neatline)	1,586 cy
Subtotal for deductions	6,348 cy
Batch record RCC volume within the boundaries of the rock contours and perimeter neatlines for the dam	408,729 cy

b. Para. 4 - Volume computations, therefore, show that the Contractor placed 16,226 cy or 3.97 percent more material than the batch records show. At an approximate average in place cost of $20/cy, a substantial value roughly on the order of $325,000 is associated with this problem.

c. Para. 6 - Another explanation might be that the batch weights and therefore yield for the mix design was off, i.e., each cubic yard by batch weights actually made 28.07 cubic feet of concrete instead of 27.00 cubic feet. During construction the theoretical batch weights were carefully computed and checked for appropriate yield. Adjustments were properly made for specific gravities of the various aggregates as they changed slightly and as the batch ratios of the aggregates were adjusted. Adjustments for changes in specific gravity of the fly ash were discounted because under the worst of conditions they would account for a change of only 0.1 percent in yield.

d. Para. 7 - Another explanation might be that the compacted mix contained 3.97 percent more air or voids than assumed in the batch weight and yield calculation i.e., about 5.0 percent to 5.5 percent total air instead of about 1.0 percent to 1.5 percent. However, the air content (which varied slightly throughout the job) was based on on-going laboratory tests of the mix as it was being placed. The lab test might be considered suspect and not representative of the in-place material, except that its compacted unit weight compared very closely with the theoretical weight at that air content, and with the in-place nuclear density tests.

2. Previous computations showed an error of 4.25 percent instead of 3.97 percent. The correct volume discrepancy is 16,226 cy instead of 18,144 cy. In both cases the indication is that on the job the nuclear gage showed more unit weight than actually occurred, but the post construction calibration shows it read less unit weight than actually occurred.

E. K. SCHRADER
Civil Engineer

CF:
RE, Willow Creek
NPDEN-GS&M
Proj Mgr, Weller
Ch, Geol & Explor Sec
GDP

CHAPTER 11

WORKABILITY AND MOISTURE TESTS

Because RCC mixes have no slump, the slump cone is not applicable as an indicator of workability.

A vebee apparatus and modified vebee with surcharge weight was installed at the project laboratory. It turned out to be worthless as a practical or effective method of determining workability. As explained in Chapter 9, "Test Cylinders and Compression Strength Results," and in Chapter 10, "Density and Void Space," it also was not effective in making test cylinders.

Most of the reason for this is that practical RCC mixes made under production situations at appropriate moisture contents (that do not cause bleeding or pore pressure under heavy equipment loads) are just too dry to get a consistent and meaningful result from the vebee test. Part of the problem also is due to the fact that additional drying occurs by the time a sample is obtained, transported to the laboratory, sieved to remove oversize aggregate, and tested.

During construction, workability was controlled by placeability of the mix determined by the placing foreman at the time and location of placement. It was his responsibility to adjust the water content if necessary and advise or discuss it with the inspector. If no inspector was present, it was still his responsibility to make the adjustment. These adjustments were very slight, typically a few pounds of water per cubic yard, and primarily were needed to adjust for changes in the atmospheric drying conditions throughout the day. Changes in the aggregate fines also affected workability and water demand.

With little experience, personnel could soon tell by appearance when the workability needed adjustment. As a general rule, the mix had the right moisture content when it would not quite "weave" under heavy hauling traffic or the roller after four passes for compaction. If any free surface moisture bled to the surface, the mix was too wet. In its loose state, the proper appearance was when the coarse aggregate did not quite have an obvious glisten from free surface moisture. Because of the rate of continuous construction and nature of the material, an acceptance test procedure for workability during construction was not necessary nor is it recommended for future projects.

During construction of Willow Creek Dam, a nuclear moisture reading was taken every time a density check was made. As a minimum, this was one test every 2 hours but not less than six tests per layer. At each test location, the direct transmission mode was used with the probe driven to the bottom of the lift. The test value at each location was the average of four readings taken by rotating the gage 90 degrees around the probe for each reading. The testing was done for informational purposes and was not used as a basis for acceptance/rejection. This frequency of testing is not necessary in future work. Results of the tests are shown in Exhibit 11.1 as they were reported during the job. Each day the contractor would record the average moisture, number of tests, and standard deviation. He would also show the moving average of the last 50 tests so that trends could be identified. This information has been compared with the similarly reported companion tests for density shown in Exhibit 10.1. As moisture drifted higher, density drifted slightly lower.

A determination of the theoretical optimum moisture content for compaction could be made for rolled concrete, but its value is questionable and this knowledge may do more harm than good in the field. The potential problem is that an optimum moisture will be determined in a laboratory test similar to the way it is done for soils, and that field inspectors will try to obtain that value in the field. Conditions are continually changing in the field which affect the optimum moisture. The optimum laboratory value could be far from optimum for the particular mix being placed at a slightly different gradation, at a different temperature, and with a different shipment of cement. A change in the absorption, plasticity, and/or amount of fines in the aggregate can affect the optimum from say 5.9 percent to 6.8 percent or vice versa. A major problem in reporting moisture contents is in deciding how to determine them.

At Willow Creek, different values (but not consistently so) were common when comparing the CQM results for moisture to the nuclear density results, and when comparing either of those to oven-dry test results. Chapter 19, "Concrete Quality Monitor," discusses this equipment and procedure. A concern with all of the test methods is in how much water has been "used up" in the hydration process by the time of the test. Based on 135 test comparisons throughout construction, the nuclear gage results were about 20 percent higher than the moisture as determined in the laboratory using the CQM (i.e., 5.99 percent versus 4.92 percent). However, at times the nuclear gage indicated lower values than the CQM. Based on a random sample of 245 nuclear tests for moisture throughout the job, the coefficient of variation with the nuclear gage was 13 percent. The coefficient of variation for the CQM was 19 percent.

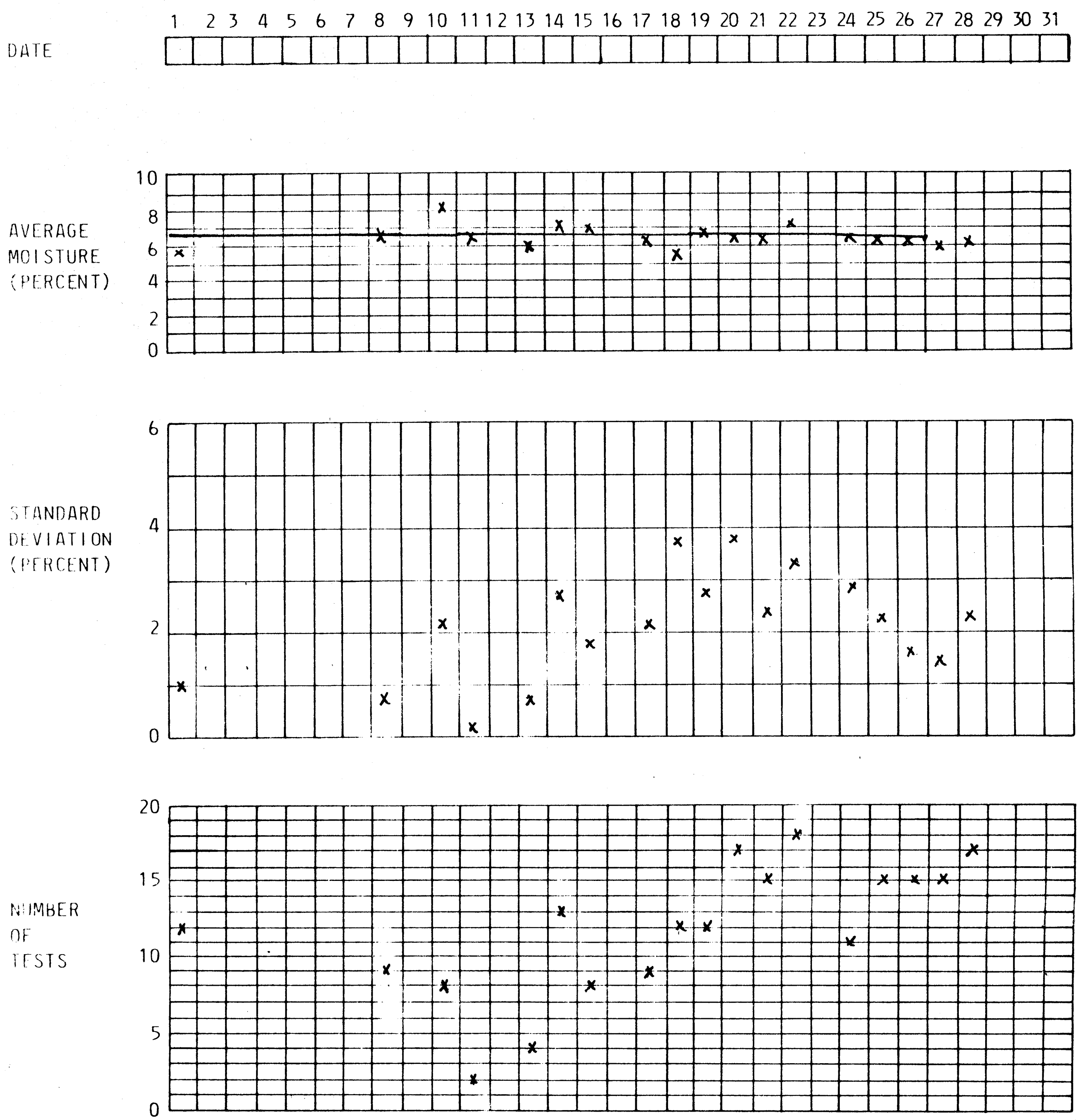
EXHIBIT 11.1

RESULTS OF IN-PLACE
NUCLEAR MOISTURE TESTS

WILLOW CREEK DAM

IN-SITE MOISTURE

MONTH MAY YEAR 1982



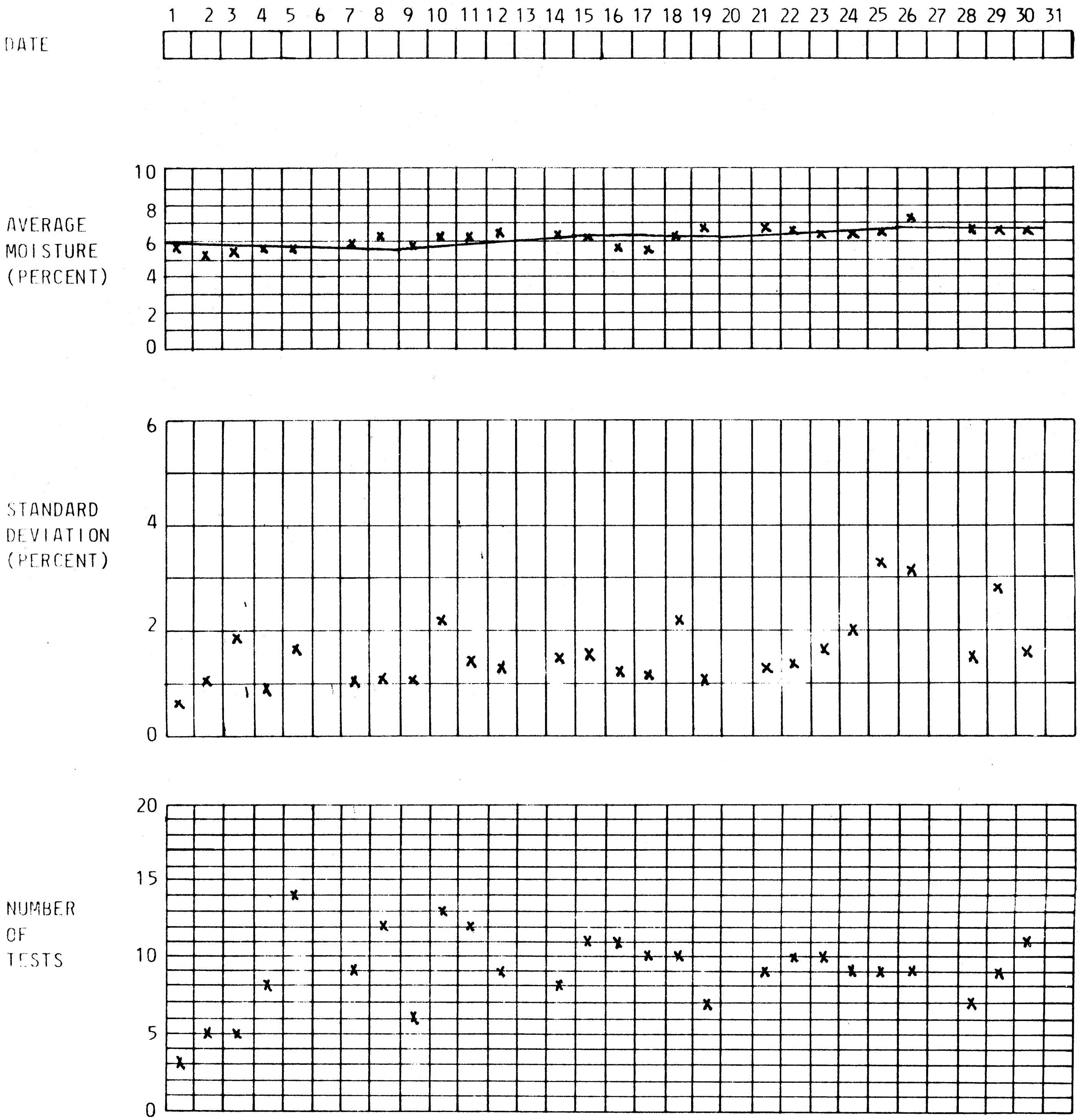
NPW Form 697-1 (OT)
Jul 82

EXHIBIT 11.1
Sheet 1 of 5

WILLOW CREEK DAM

IN-SITE MOISTURE

MONTH JUNE YEAR 1982



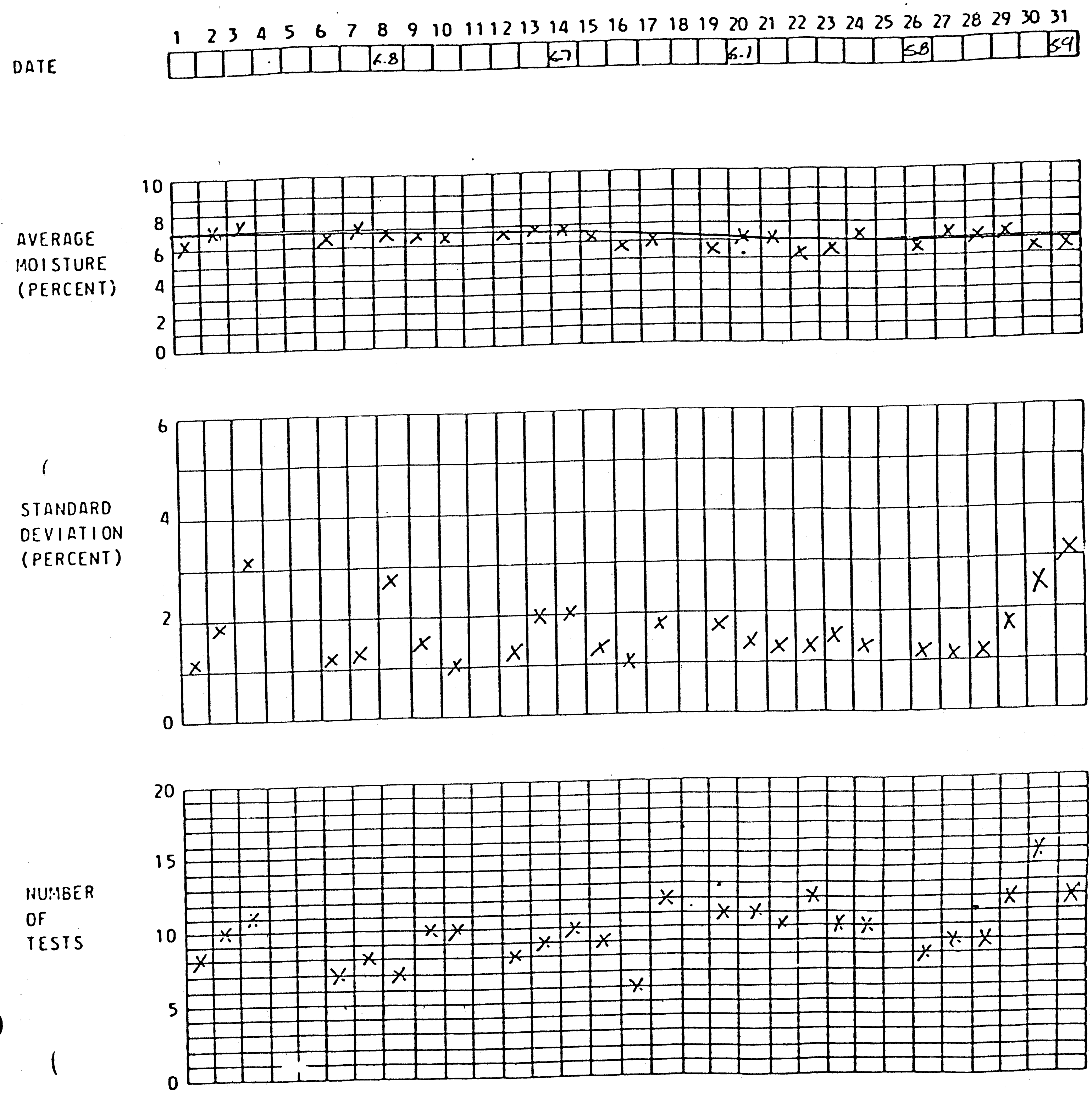
NPW Form 697-1 (OT)
Jul 82

EXHIBIT 11.1
Sheet 2 of 5

WILLOW CREEK DAM

IN-SITE MOISTURE

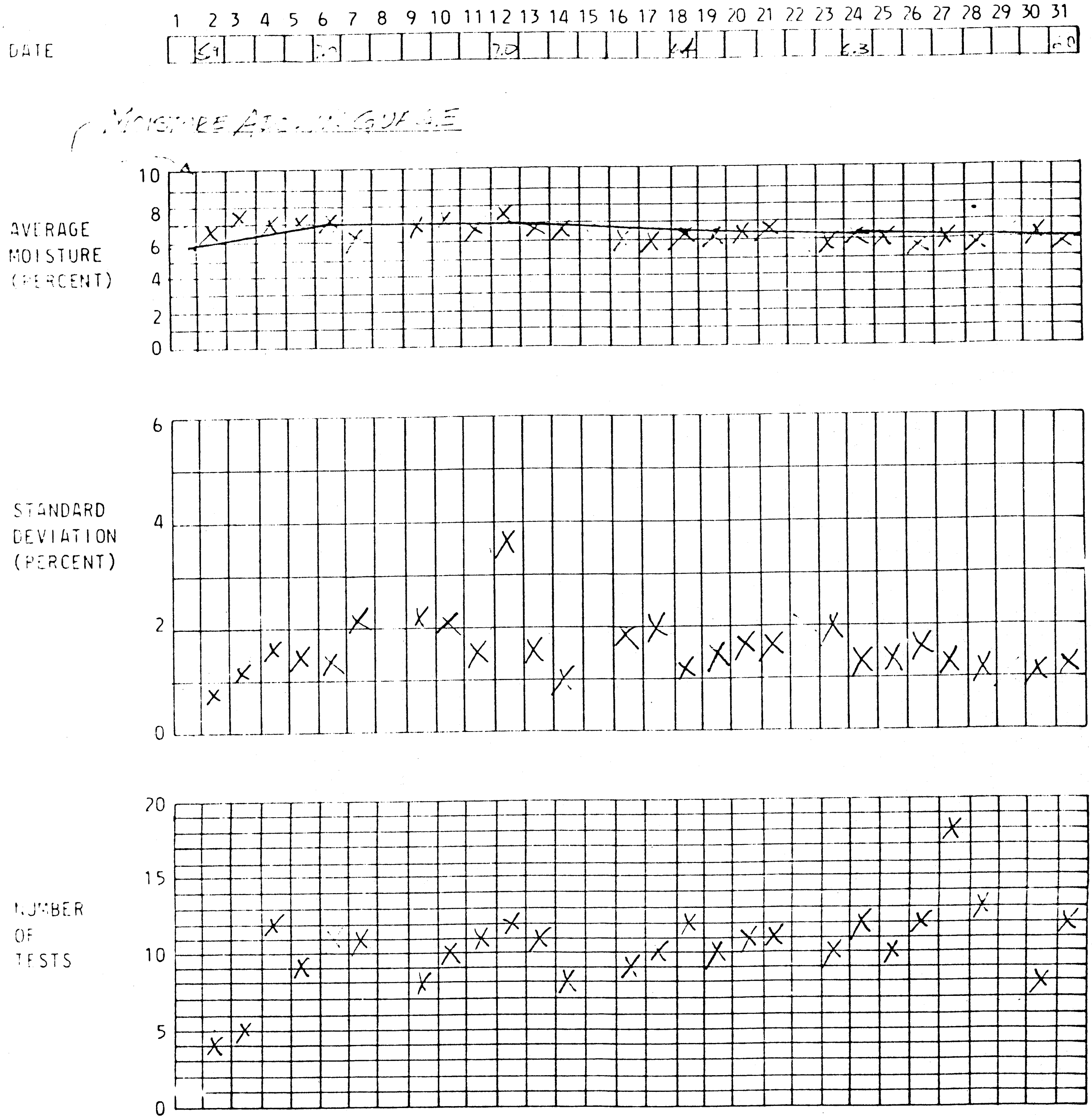
MONTH July YEAR 1982



WILLOW CREEK DAM

IN-SITE MOISTURE

MONTH August YEAR 1982



NPW Form 697-1 (OT)
Jul 82

EXHIBIT 11.1
Sheet 4 of 5

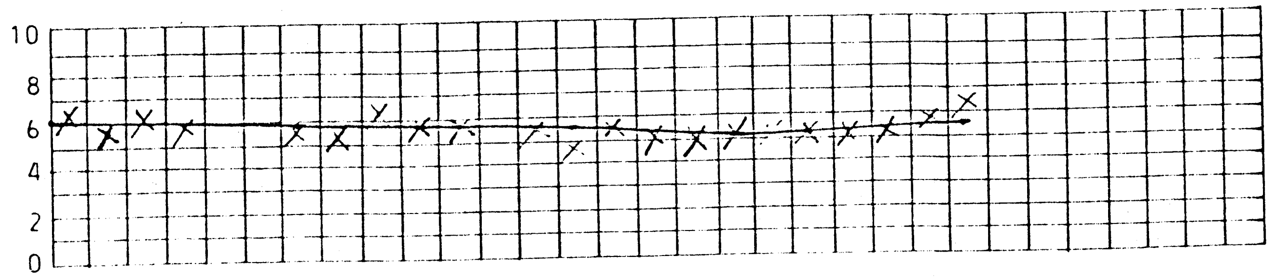
WILLOW CREEK DAM

IN-SITE MOISTURE

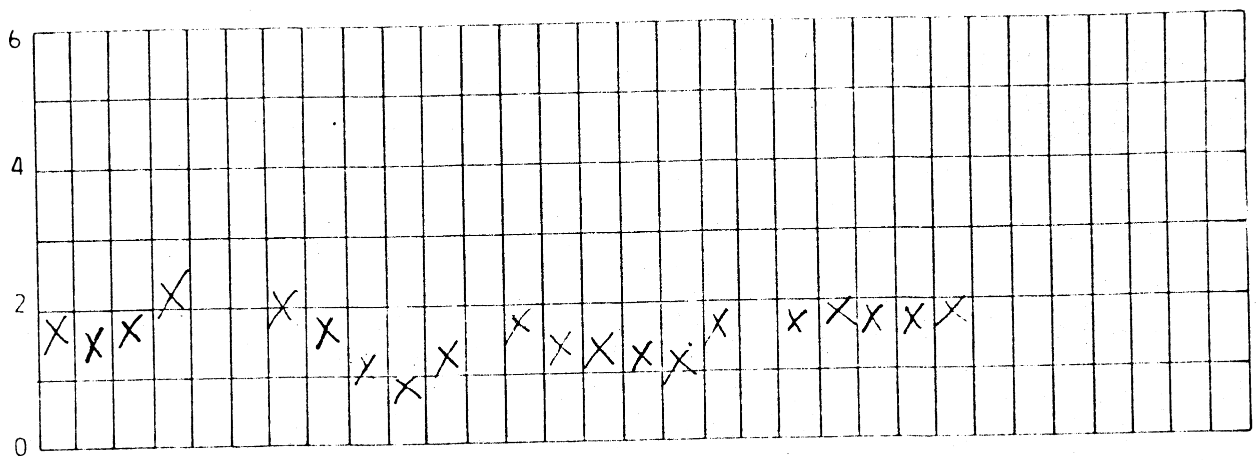
MONTH *Sept.* YEAR *1982*

DATE 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

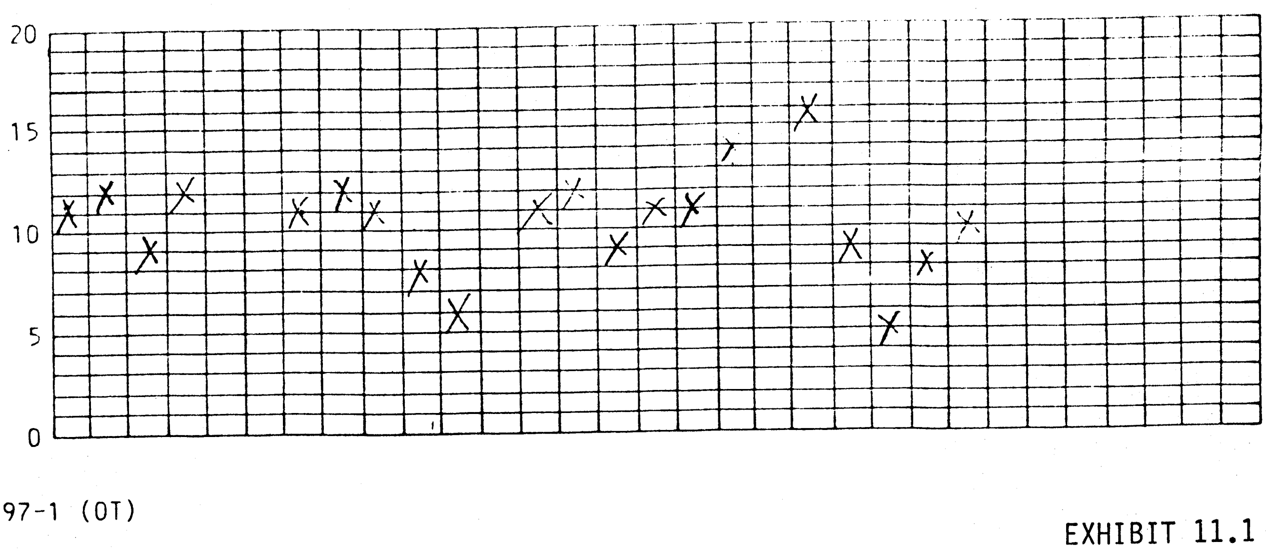
AVERAGE MOISTURE (PERCENT)



STANDARD DEVIATION (PERCENT)



NUMBER OF TESTS



NPW Form 697-1 (OT)
Jul 82

EXHIBIT 11.1
Sheet 5 of 5

CHAPTER 12

ADMIXTURES
(Freeze-Thaw and Wet-Dry Durability)

The benefit and effectiveness of admixtures for entraining air and for water reducing/retarding were evaluated in the rolled concrete. Based on laboratory studies and field experience, there was no benefit regardless of dosage or mix design. In fact, the laboratory data indicates there may be a reduction in workability with increasing admixture dosage and a slight reduction in strength. Field observations indicated no strength or workability difference at dosage rates of 0, 3, and 6 times the normal recommended dosage. There also was no noticeable effect on set time. The admixture used during construction was Master Builder's pozzolith 300 N.

Discussions with suppliers of different admixtures confirmed that they do not have nor do they currently know how to formulate admixtures that would be effective in RCC. The main reasons for this are the low cement factor and the fact that no fluid paste develops in the mix. A suggestion for future testing is to try a batching/mixing procedure that mixes the cement/fly ash in a slurry with the admixture and water and then injects it into the mixer with the dry aggregates. All of the mix water would be used to make the initial slurry.

Exhibit 12.1 at the end of this section shows results of laboratory mix evaluations with the admixtures. Dosages were tried up to about 10 times the normal recommended rate without benefit. Also shown in the exhibit are durability results for standard and nonstandard tests evaluating wet-dry and freeze-thaw tests without the benefit of admixtures. Plates 9.9 through 9.13 show the effect of water-reducing admixture on strengths when evaluated under continued production conditions. Data for these graphs is based on several days of continuous production consisting of about six shifts and 7,722 total cubic yards using all of the RCC mixes.

Laboratory tests of RCC for Willow Creek and other RCC mixes show that when using standard ASTM test procedures, RCC has poor freeze-thaw resistance. Tests at the Treat Island exposure station in a tidal zone with combined wet-dry/freeze-thaw cycles also showed poor durability. However, observations of rolled concrete fills and test slabs exposed to the local environment near Portland, Oregon, (Zintel Canyon erosion panels) show no deterioration. Wet-dry tests of the Willow Creek mix were run through 300 cycles and showed no deterioration. A modified

EXHIBIT 12.1

EFFECT OF ADMIXTURES ON RCC

freeze-thaw test more typical of what happens in the worst of local conditions was also run with moderate loss of mortar after about 100 cycles; the rate of deterioration then decreased and the test was stopped at 155 cycles. Relative dynamic modulus tests were run also and show significant reductions with freeze-thaw cycles, but it should also be remembered that these tests are on only the 1-inch-minus portions of the mix, using a relatively small sample, and under saturated conditions. It is not considered to be representative of the mass material, full mix, and exposure conditions at Willow Creek Dam.

WILLOW CREEK DAM

Summary of RCC Mixes Batched with Air-Entraining and Water-Reducing Admixtures

NPDL No.	Mix No.[1]	Admixture[2] AEA, fl oz/cwt	Admixture[2] WRA, fl oz/cwt	On Minus 1 1/2-inch Concrete: Air, %	Vebe, Seconds	Compressive Strength, psi, Age Days: 7	28	56	90	180
1866 (Control)	80+32	None	None	0.9	22	470	830	1070	1390	1860
1938	80+32	None	12	1.1	14	-	760	-	1310	-
						-	770	-	1290	-
							760		1300	
1942	80+32	None	16	0.8	14	280	730	1080	1250	1550
						280	800	1100	1250	1760
						280	760	1090	1250	1660
1940	80+32	None	20	1.3	16	-	780	-	1300	-
						-	720	-	1350	-
							750		1320	
1937	80+32	12	None	1.3	21	-	790	-	1250	-
						-	770	-	1180	-
							780		1220	
1869 (Control)	315+135	None	None	0.8	23	2520	4310	4780	5250	5710
1939	315+135	6	None	1.2	18	-	3520	-	4300	-
						-	3810	-	4690	-
							3670		4500	
1941	315+135	16	None	1.8	14	-	3350		4050	-
						-	3490		4440	-
							3420		4250	

Mixes batched using Masterbuilders LL-920-A Plasticizer & AEA and Pozzolith 300R WRA.

EXHIBIT 12.1

CHAPTER 13

MODULUS OF ELASTICITY

The modulus of elasticity at early age was determined in tension on approximate 1-cubic-foot blocks sawn from the dam. These tests are discussed further in Chapter 14, "Direct Tension Tests." Plate 14.1 shows removal of the blocks from the dam. At ages varying from 64 to 270 hours, mix 3 (175 pounds of cement plus 80 pounds of fly ash) had an average value of 0.97×10^6 psi. Mix 4 (315 pounds of cement plus 135 pounds of fly ash) had an average value of 1.15×10^6 psi. There did not appear to be a noticeable or predictable change in modulus (in tension) within this range of test ages.

The modulus of elasticity in compression was tested on many job cast cylinders at the Resident laboratory. Exhibit 13.1 shows the modulus values and stress-strain relationships for each cylinder tested. This included mixes 1, 2, 3, and 4 at ages of 3, 14, 28, and 90 days. The intent was to accurately determine how the modulus developed with time for each mix as well as to determine absolute values. Results from this testing (by ASTM method C 469) were varied. Each graph contains results of two companion cylinders made at the same time from the same mix and tested at the same time by the same personnel. In essentially all cases the stress-strain behavior of the companion cylinders agrees very well. However, there is a tremendous variability when comparing different companion cylinder sets of the same mix and age. Modulus values range all the way from about 1×10^6 to 13×10^6 with no explanation. One thought is that the large aggregate pieces are in direct contact with each other in some cases, resulting in high modulus values influenced mostly by the dense basalt pieces. In other situations a very slight increase in the amount of fines in the mix separated them just enough to allow the aggregates to "slip" under compression through a relatively soft mortar high in natural fines content. Another opinion, however, is that the batch-to-batch modulus does <u>not</u> vary as much as indicated by these tests, and that the variability is related more to the actual test procedure used.

During preliminary mix design studies, modulus of elasticity tests were run at the NPD laboratory using strain gages (two per cylinder) instead of with the ASTM C 469 rigid frame with dial gages. This procedure gave usable results with good correlation of data between test cylinders. The results of these tests along with Poisson's ratio are shown in Table 13.1. It should be pointed out that cement, ash, and aggregates for these initial mixes were very similar to, but slightly different from, those used during construction. Also, the modified vebee method of compaction was used to make the test specimens which, as discussed, is not the recommended procedure. Consequently, the associated strength data in this table is less than that which occurred during construction.

An accurate determination of the modulus of elasticity and how it developed with time in the structure was determined by a special test procedure recommended for future work. Results are shown on Plate 13.1. For this test, jobsite materials were brought to the NPD laboratory and the job mix was identically reproduced. Samples were made for testing at a variety of ages starting from the time of initial set. Cylinders were cast in 9- x 18-inch rigid steel molds using the full 3-inch aggregate mix and tamping method. Carlson strain meters were embedded in each cylinder, and strains were read to the millionth of an inch per inch. An initial mix temperature of 60 degrees F was used to duplicate conditions being experienced at that time during construction. In addition, the temperature of each cylinder during cure was kept in an environment that duplicated the internal heat rise within the dam. The test was performed only on the interior mass mix. The modulus developed linearly with time from the initial value of 0 to a value of 2.95×10^6 psi at 12 days. The rate of development in modulus then decreased. A 28-day value of 3.81×10^6 psi was ultimately achieved, which appears to be the correct sustained modulus value.

TABLE 13.1

MODULUS OF ELASTICITY OF
DESIGN MIXES

NOTE: These results are from tests on the 2-inch minus fraction of the mixes, determined in compression on 6- x 12-inch cylinders using strain gages.

TABLE 13.1

MODULUS OF ELASTICITY
AND POISSON'S RATIO

Test	Age (Days)	Mix 80+32	Mix 175+00	Mix 175+80
Modulus of Elasticity ($\times 10^6$ psi)	28	1.59	2.67	2.91
	90	1.91	2.78	3.25
	180	2.82	3.86	4.42
Poisson's Ratio	28	0.14	0.19	0.21
	90	0.17	0.18	0.21
	180	0.21	0.21	0.22

MODULUS DEVELOPMENT OF RCC

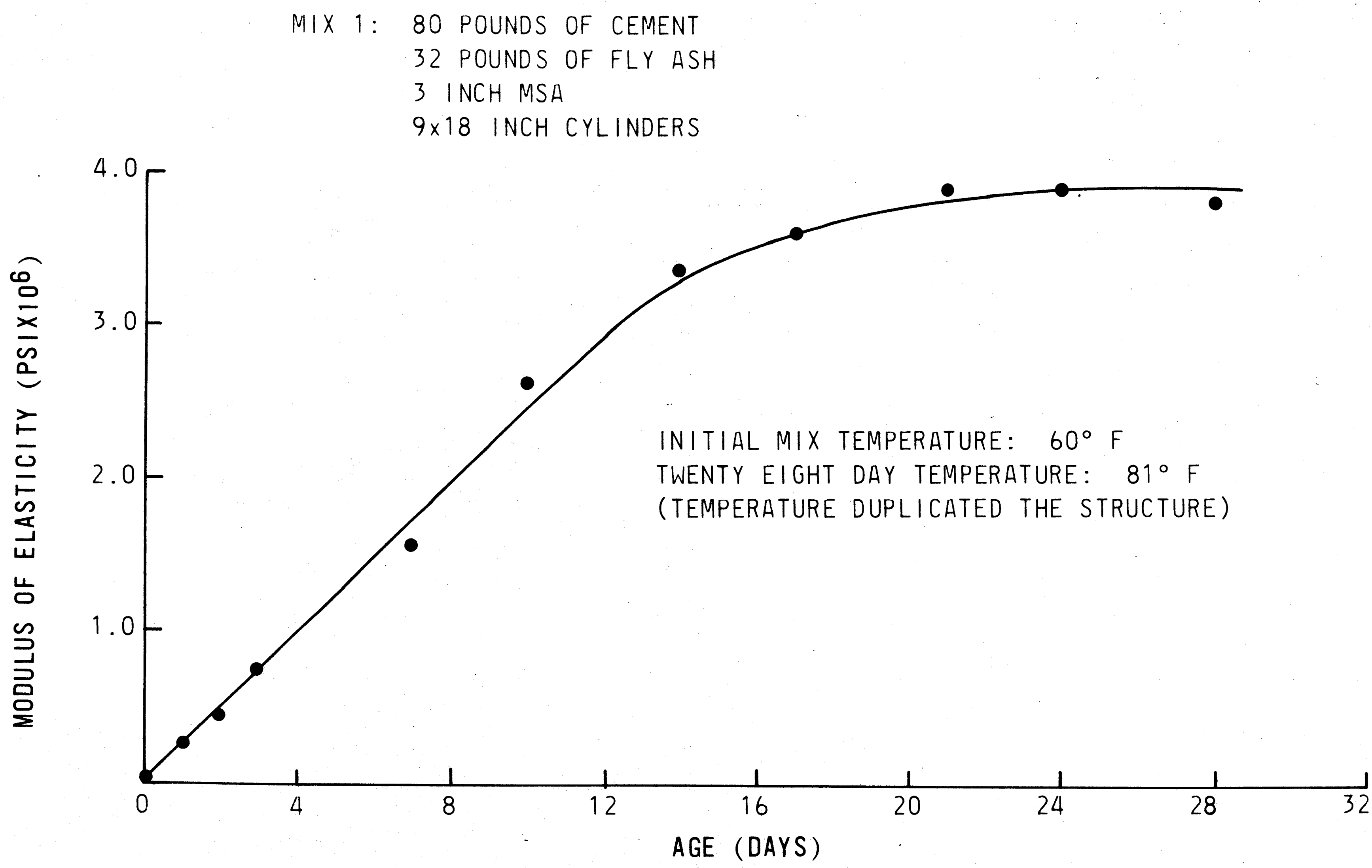


PLATE 13.1

EXHIBIT 13.1

MODULUS OF ELASTICITY
TEST RESULTS (FIELD LABORATORY)

NOTE: Each line plotted on the attached graphs was defined by approximately 25 to 75 individual points. In all cases, at least 96 percent of the points essentially plotted exactly on the line shown. There was virtually no scatter of data. The points have not been shown for the sake of clarity. Each sheet shows the result of two companion cylinders made at the same time from the same mix and tested at the same age. Many of the test results are included here because of the importance of being aware that with the ASTM C 469 method and field cylinders there was excellent agreement of data between companion cylinders, but tremendous variation between different sets of companion cylinders. (Results of an additional 50 tests are similar.)

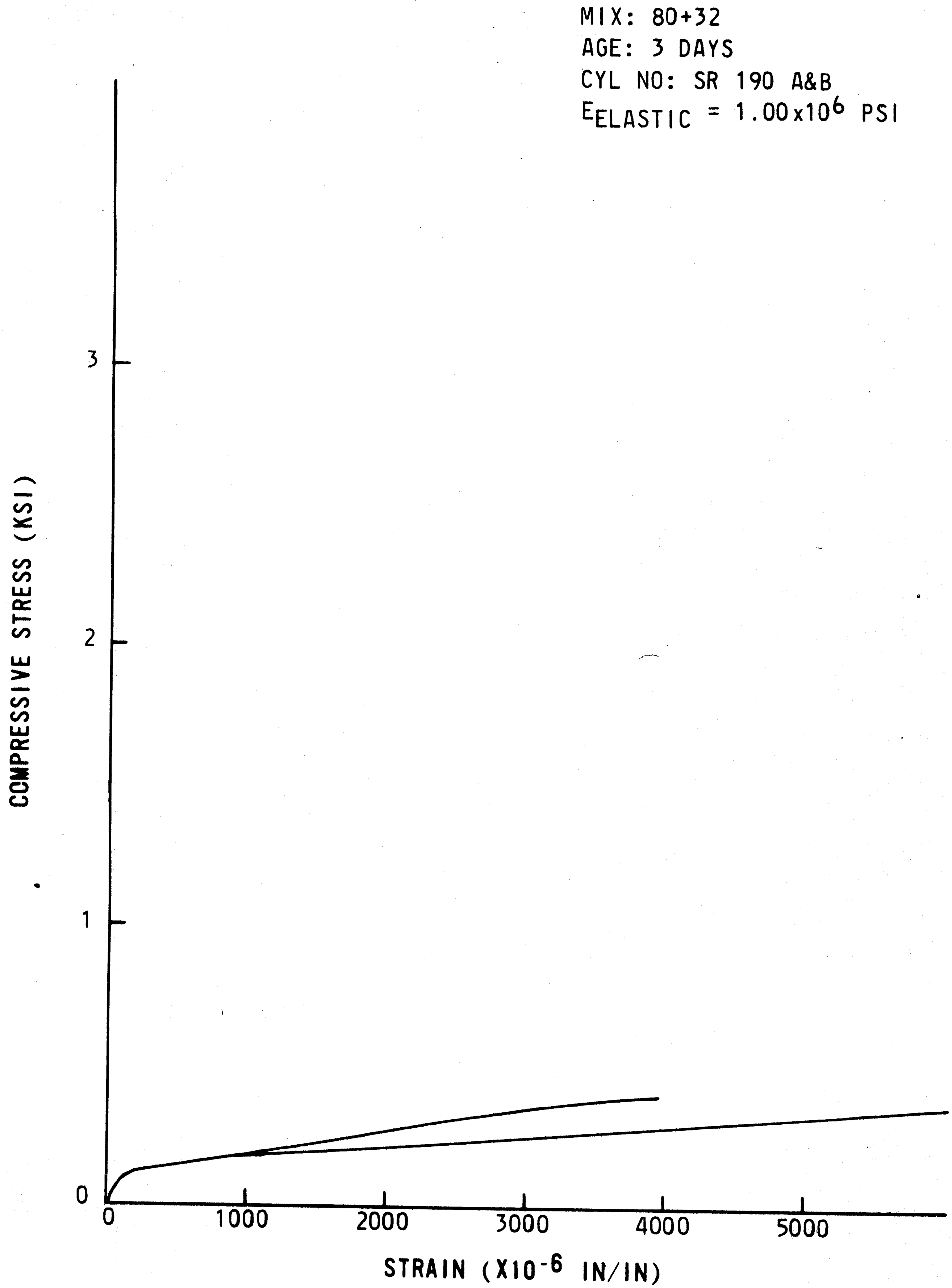
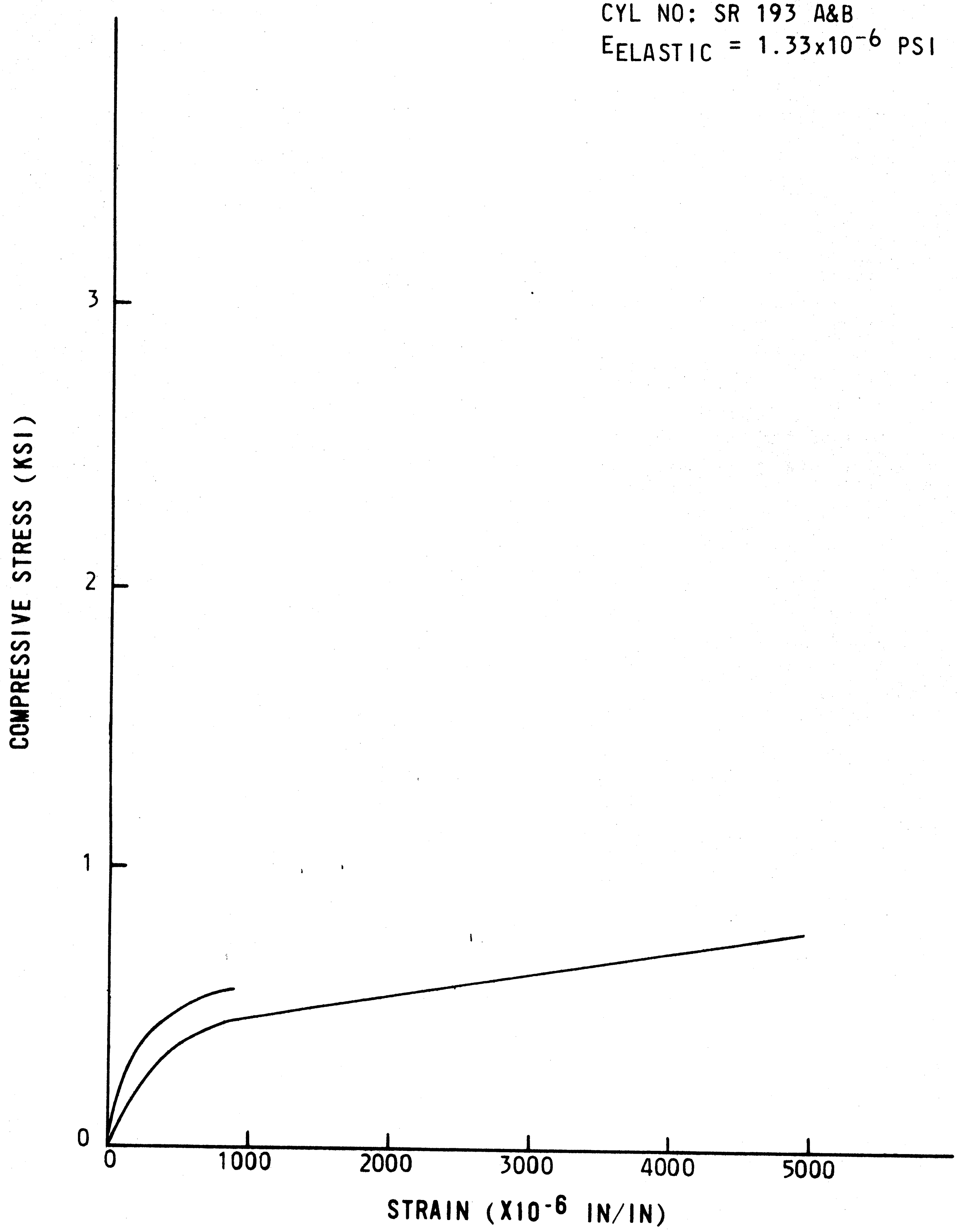
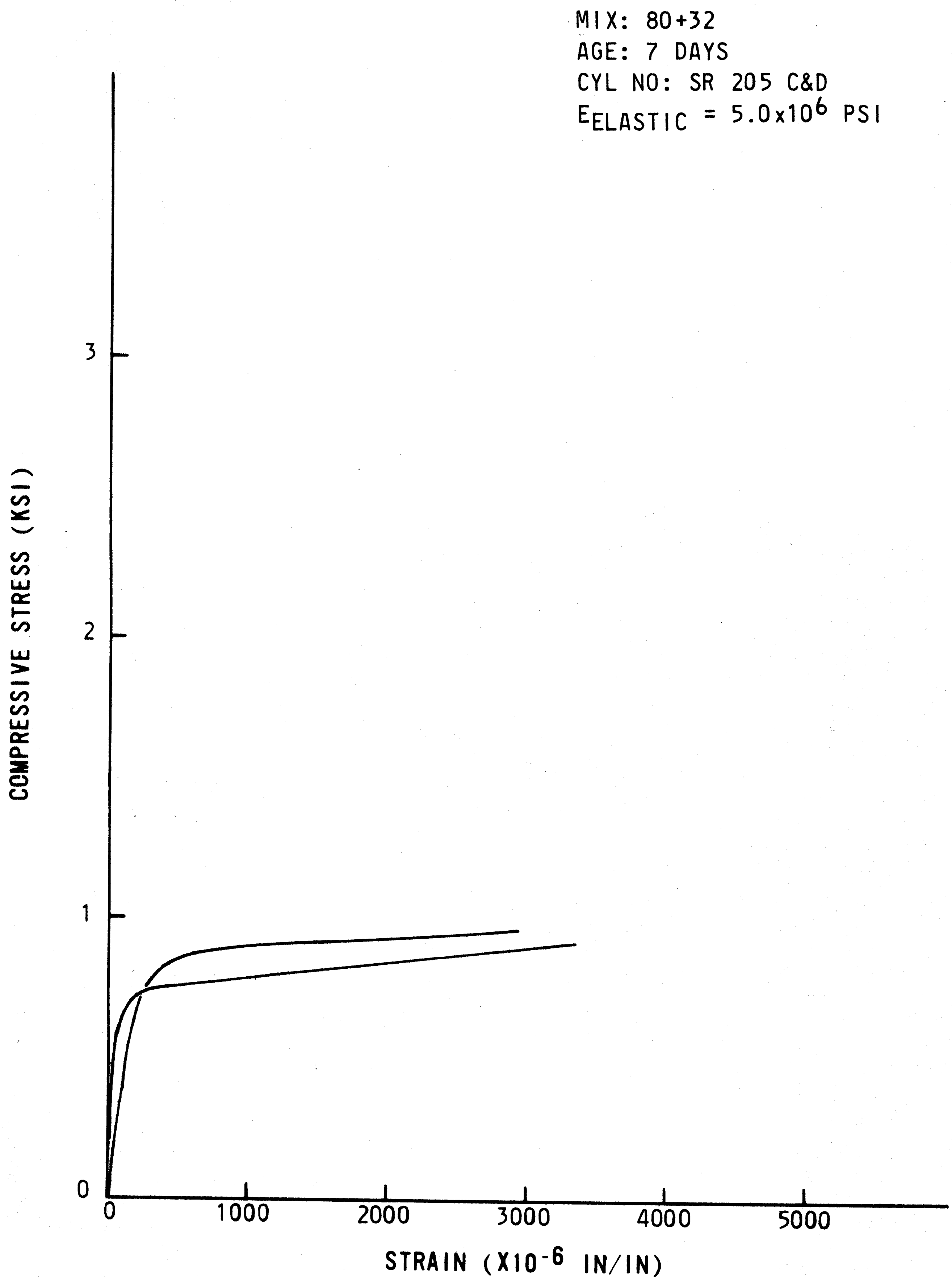
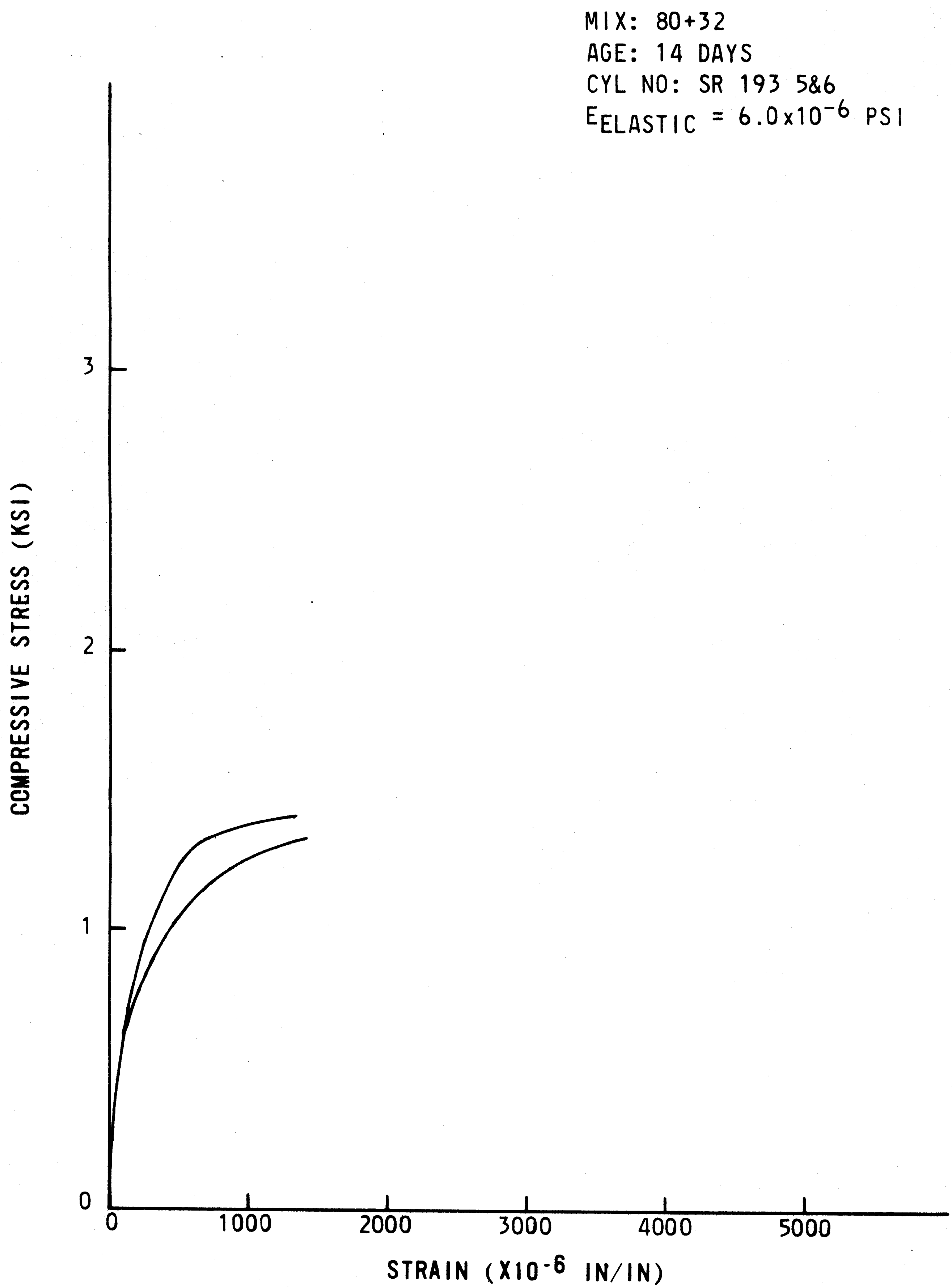


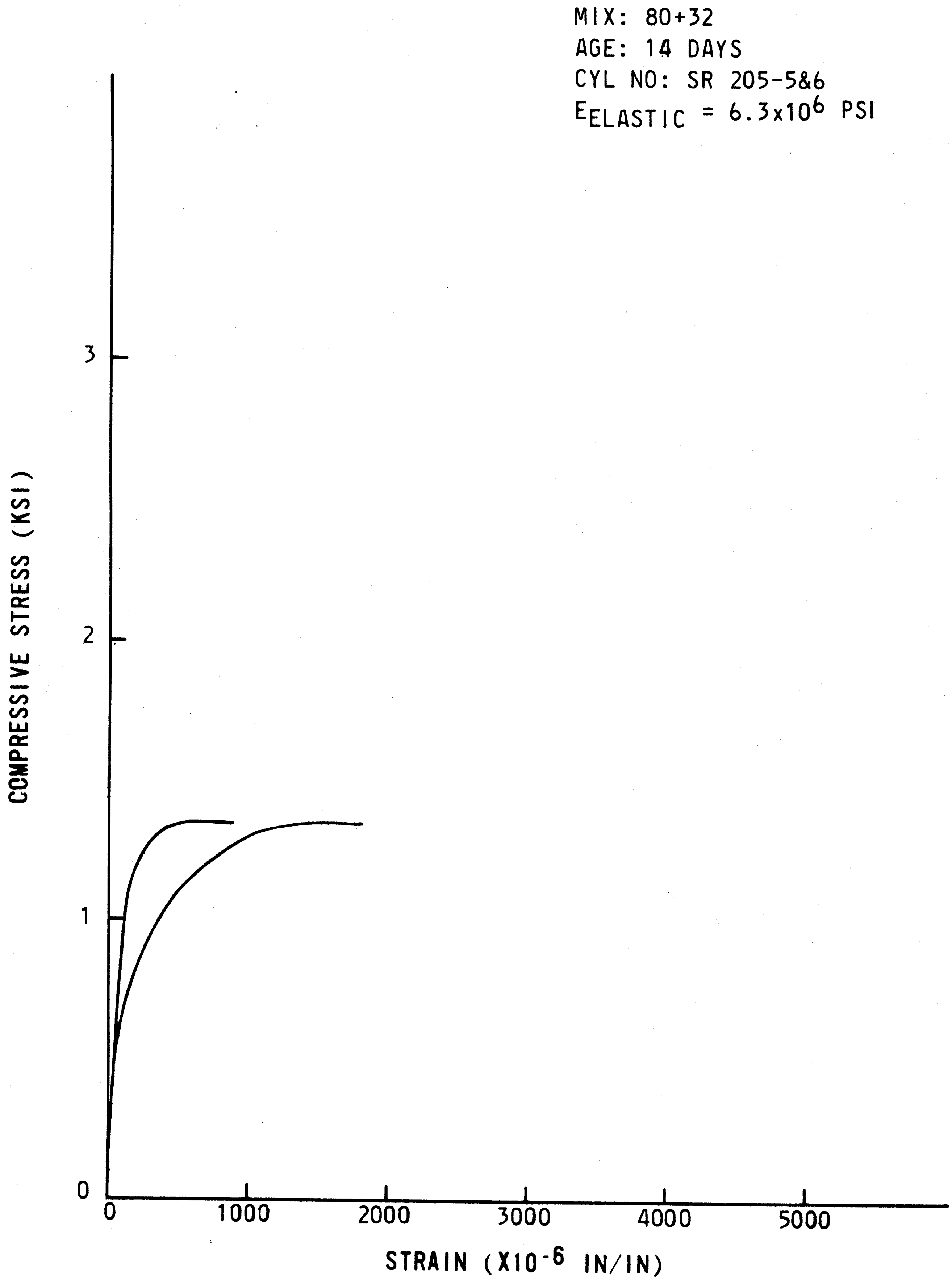
EXHIBIT 13.1
Sheet 1 of 42

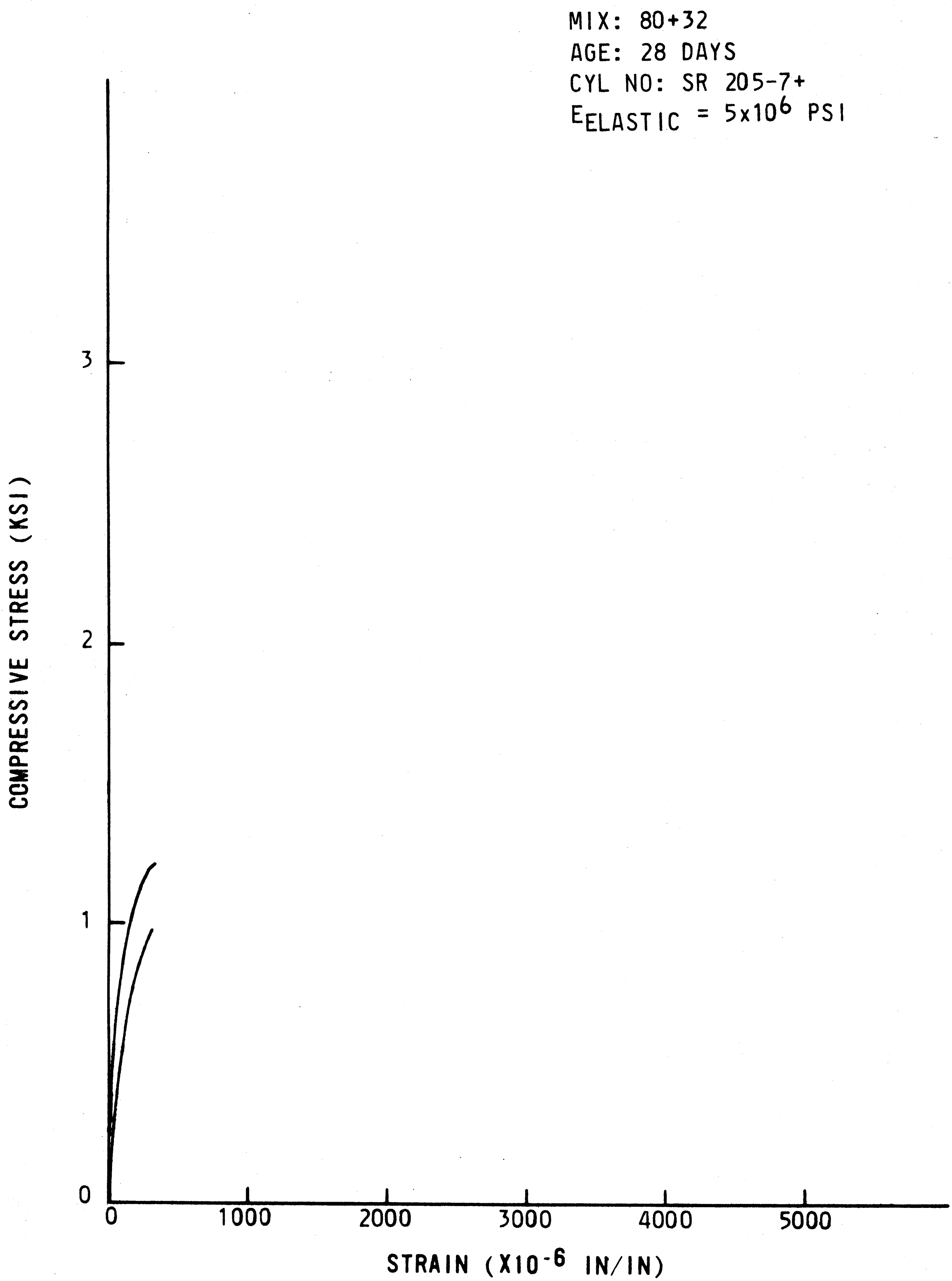
MIX: 80+32
AGE: 3 DAYS
CYL NO: SR 193 A&B
$E_{ELASTIC} = 1.33 \times 10^{-6}$ PSI



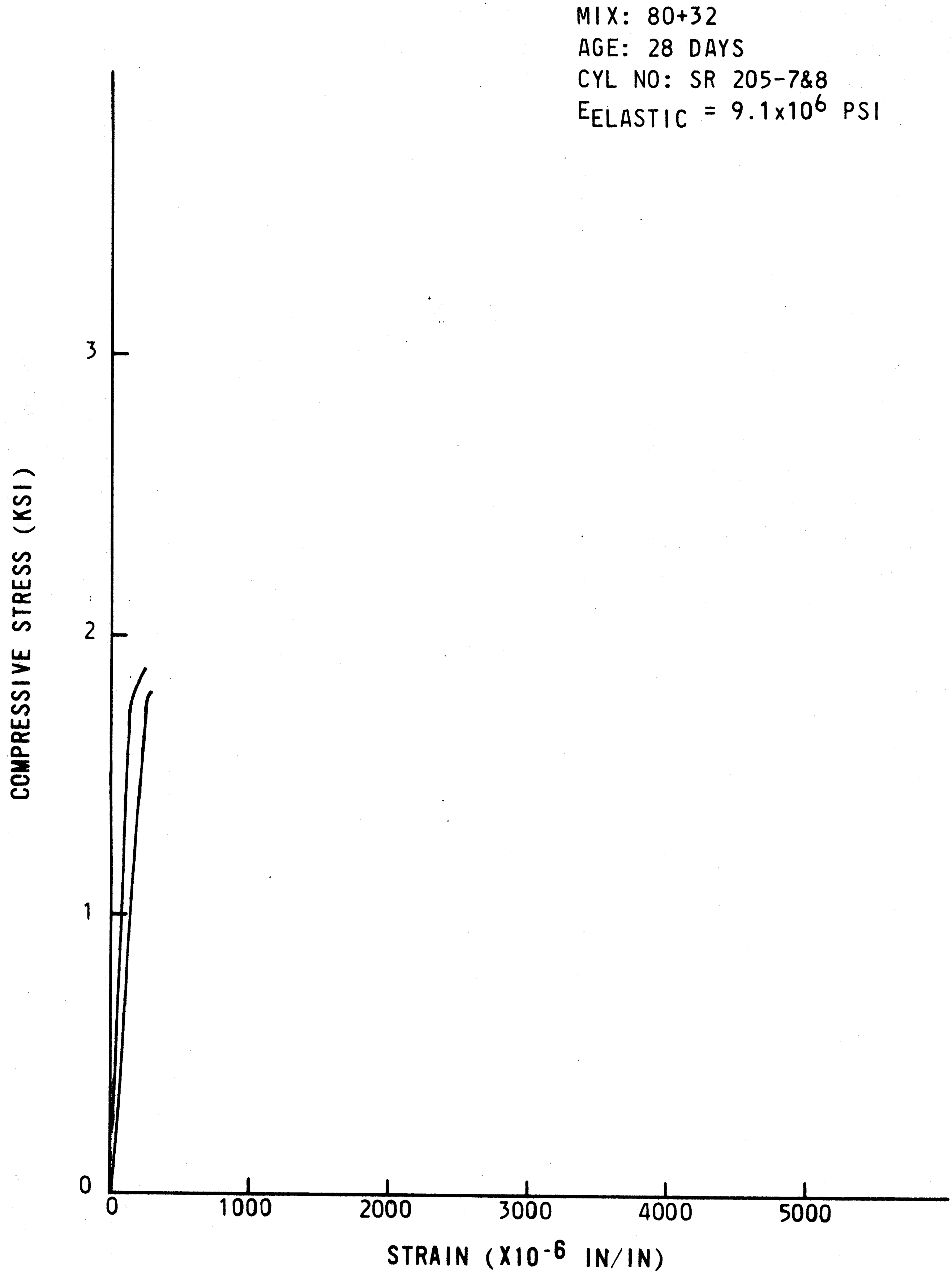

MIX: 80+32
AGE: 7 DAYS
CYL NO: SR 205 C&D
$E_{ELASTIC} = 5.0 \times 10^6$ PSI
COMPRESSIVE STRESS (KSI)
0
1
2
3
0
1000
2000
3000
4000
5000
STRAIN ($\times 10^{-6}$ IN/IN)

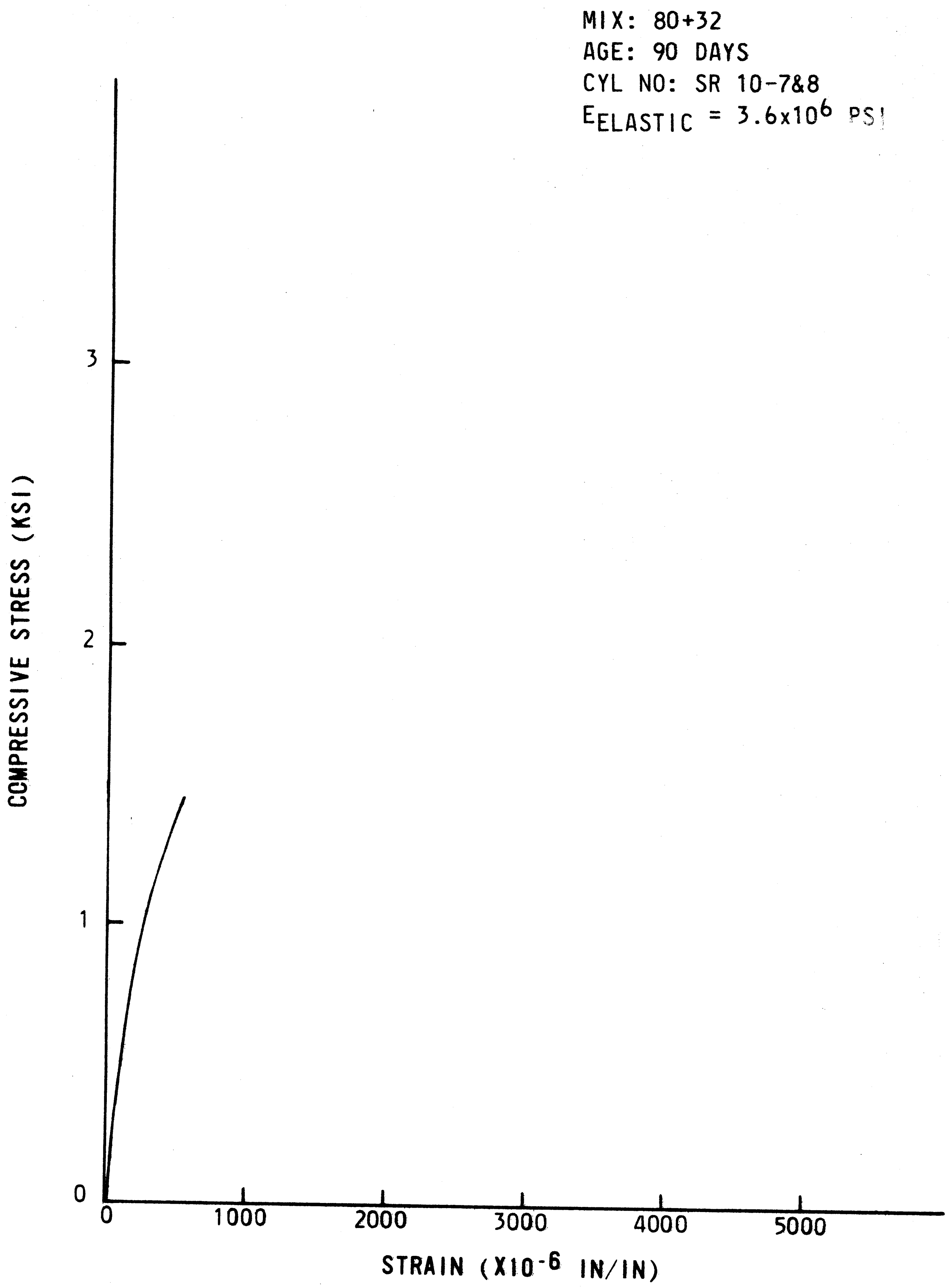

MIX: 80+32
AGE: 14 DAYS
CYL NO: SR 193 5&6
E ELASTIC = 6.0x10-6 PSI
COMPRESSIVE STRESS (KSI)
0
1
2
3
0
1000
2000
3000
4000
5000
STRAIN (X10-6 IN/IN)


MIX: 80+32
AGE: 14 DAYS
CYL NO: SR 205-5&6
E ELASTIC = 6.3x10^6 PSI
COMPRESSIVE STRESS (KSI)
0
1
2
3
0
1000
2000
3000
4000
5000
STRAIN (X10^-6 IN/IN)

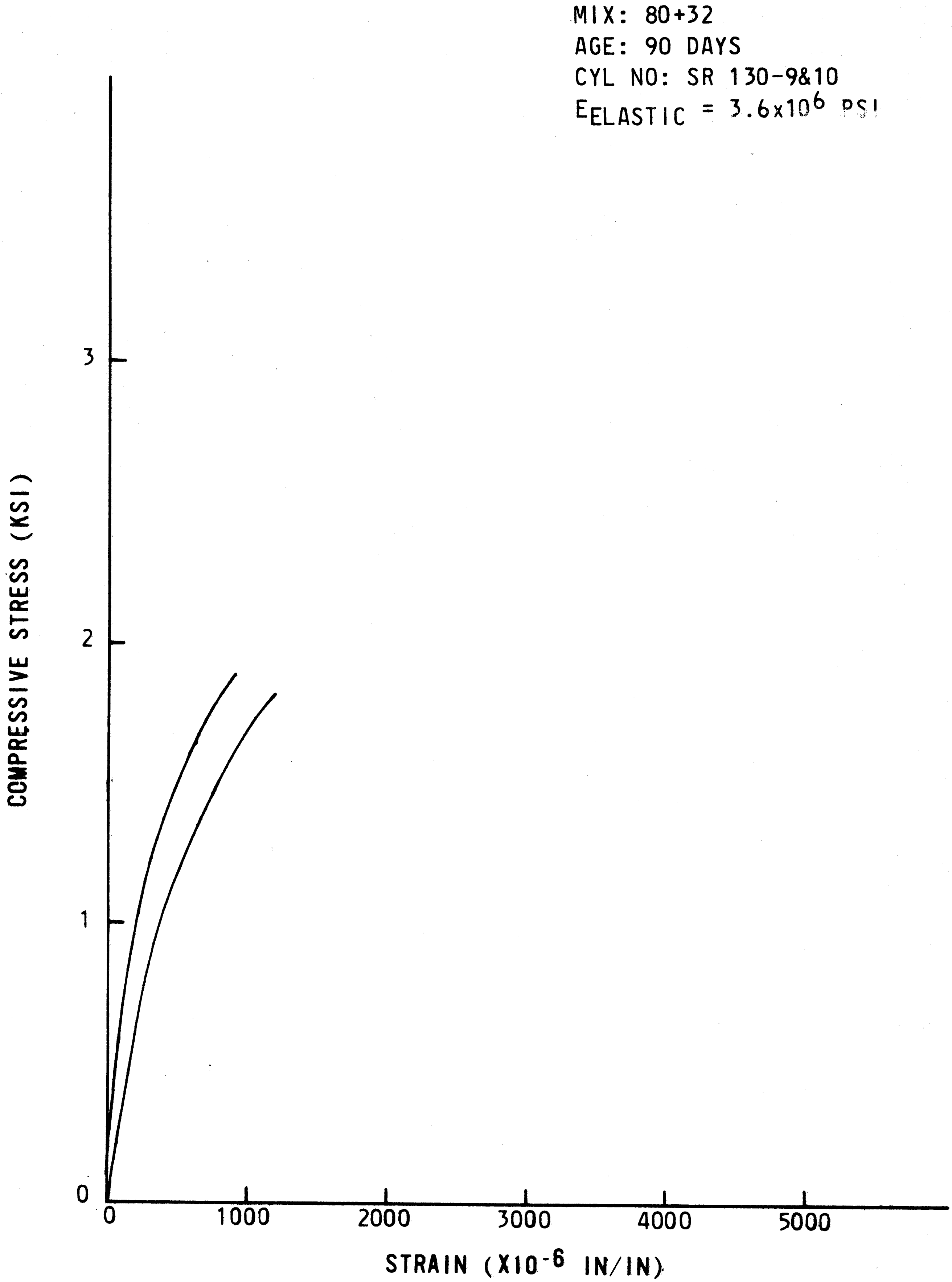


MIX: 80+32
AGE: 28 DAYS
CYL NO: SR 205-7+
$E_{ELASTIC} = 5 \times 10^6$ PSI
COMPRESSIVE STRESS (KSI)
3
2
1
0
0
1000
2000
3000
4000
5000
STRAIN ($\times 10^{-6}$ IN/IN)

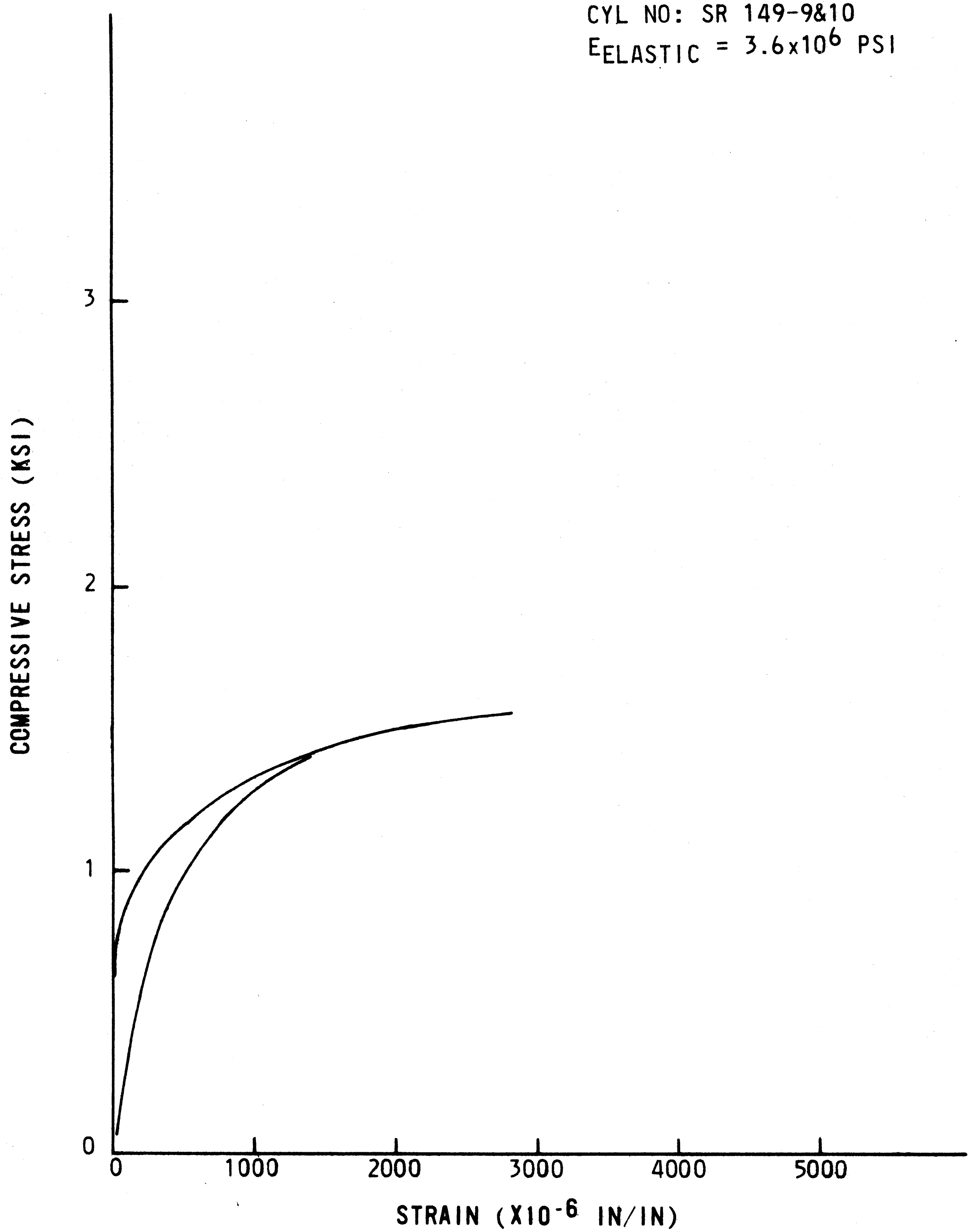

MIX: 80+32
AGE: 28 DAYS
CYL NO: SR 205-7&8
$E_{ELASTIC}$ = 9.1x10^6 PSI
COMPRESSIVE STRESS (KSI)
0
1
2
3
0
1000
2000
3000
4000
5000
STRAIN (X10^{-6} IN/IN)



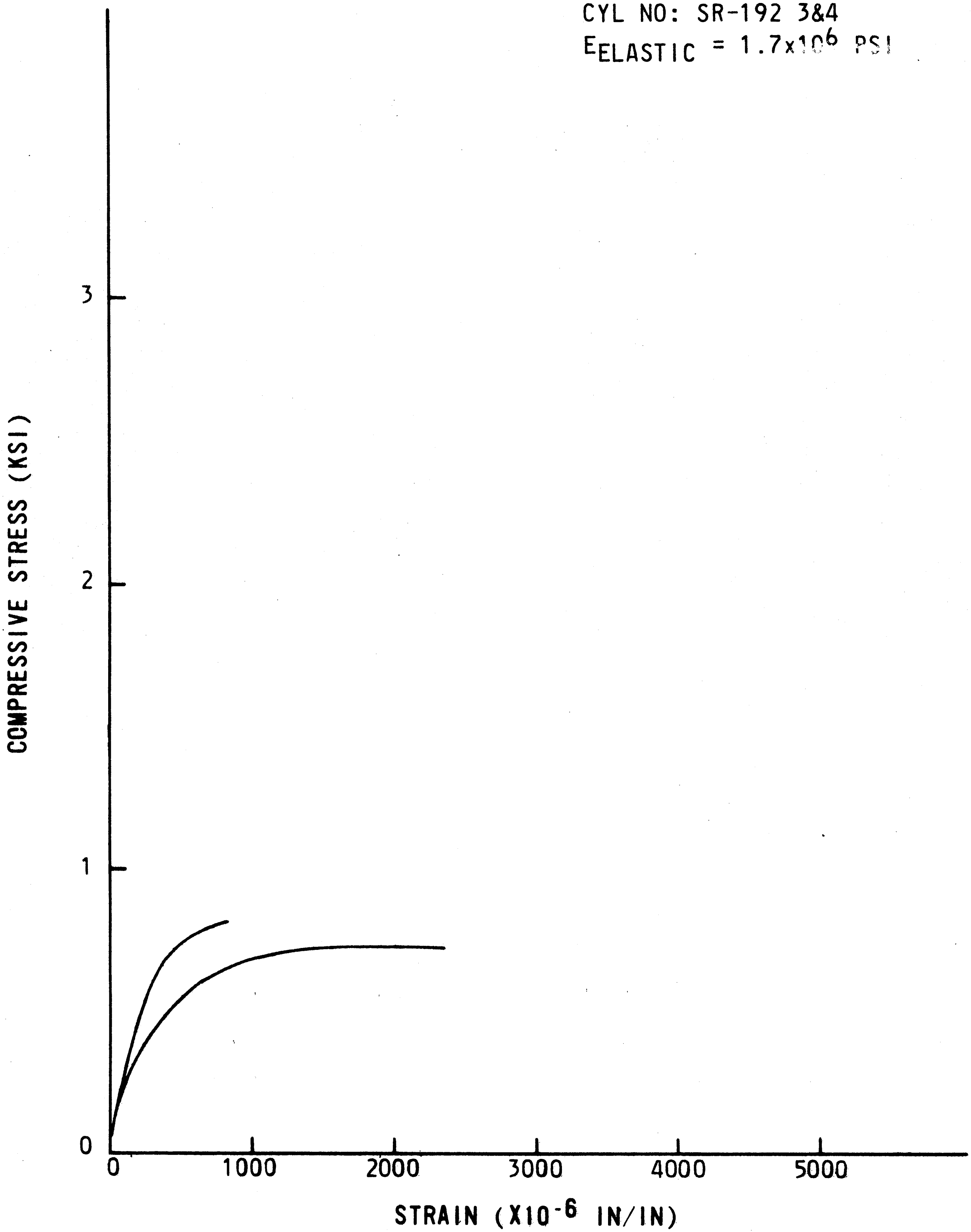
MIX: 80+32
AGE: 90 DAYS
CYL NO: SR 10-7&8
$E_{ELASTIC} = 3.6 \times 10^6$ PSI
COMPRESSIVE STRESS (KSI)
0
1
2
3
0
1000
2000
3000
4000
5000
STRAIN ($\times 10^{-6}$ IN/IN)


MIX: 80+32
AGE: 90 DAYS
CYL NO: SR 130-9&10
$E_{ELASTIC} = 3.6 \times 10^6$ PSI
COMPRESSIVE STRESS (KSI)
3
2
1
0
0
1000
2000
3000
4000
5000
STRAIN ($\times 10^{-6}$ IN/IN)

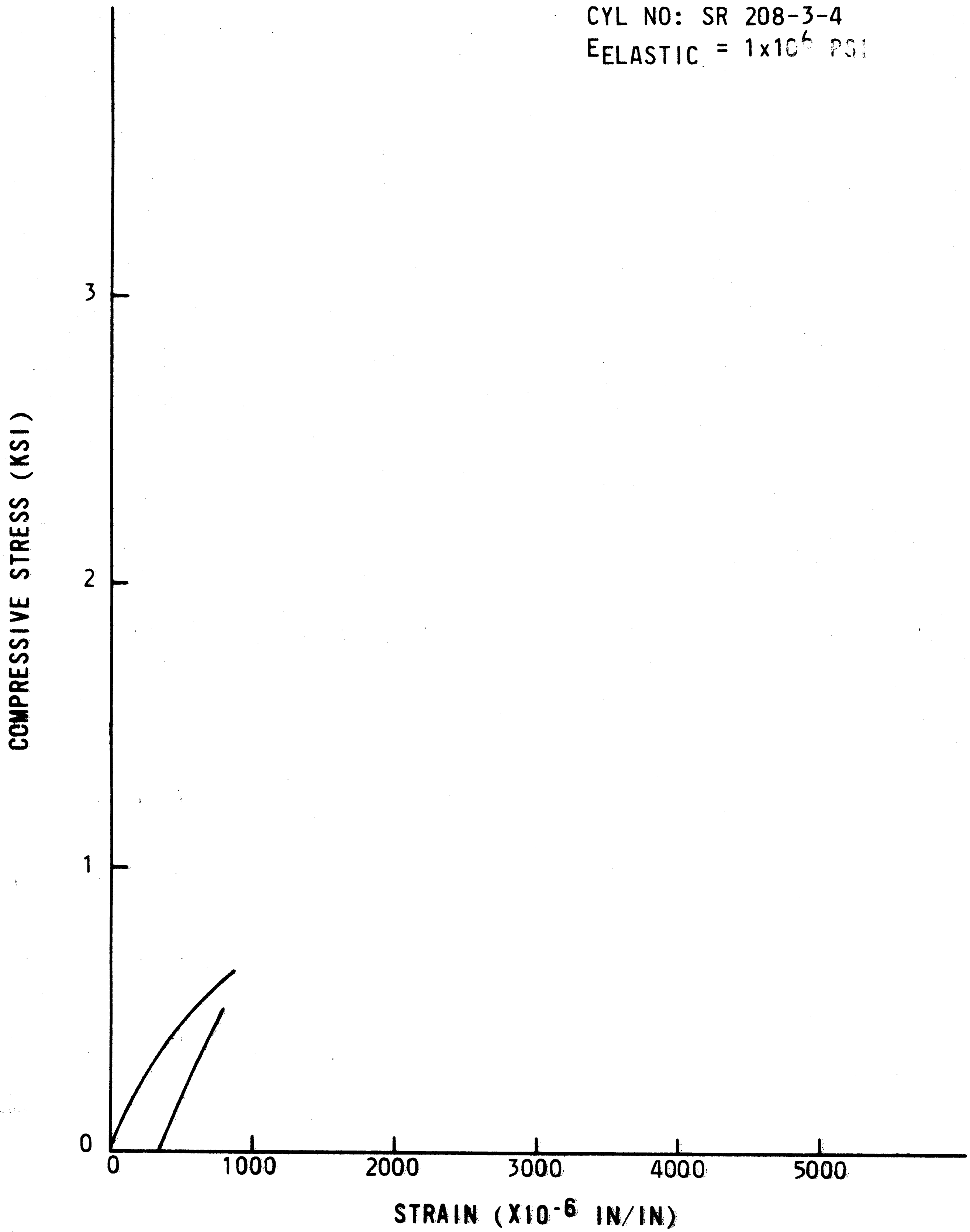
MIX: 80+32
AGE: 90 DAYS
CYL NO: SR 149-9&10
$E_{ELASTIC} = 3.6 \times 10^6$ PSI

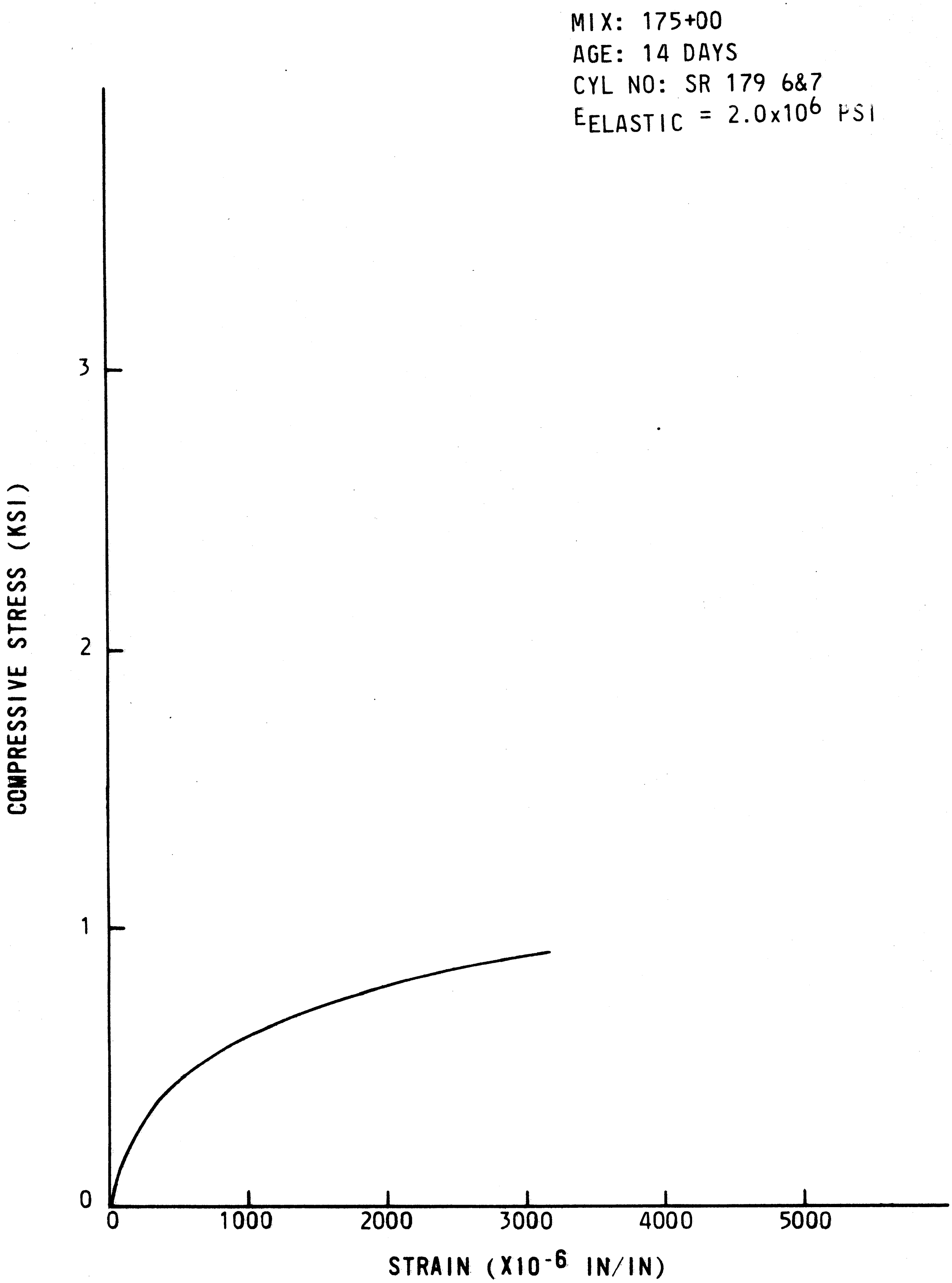


MIX: 175+00
AGE: 7 DAYS
CYL NO: SR-192 3&4
$E_{ELASTIC} = 1.7 \times 10^6$ PSI

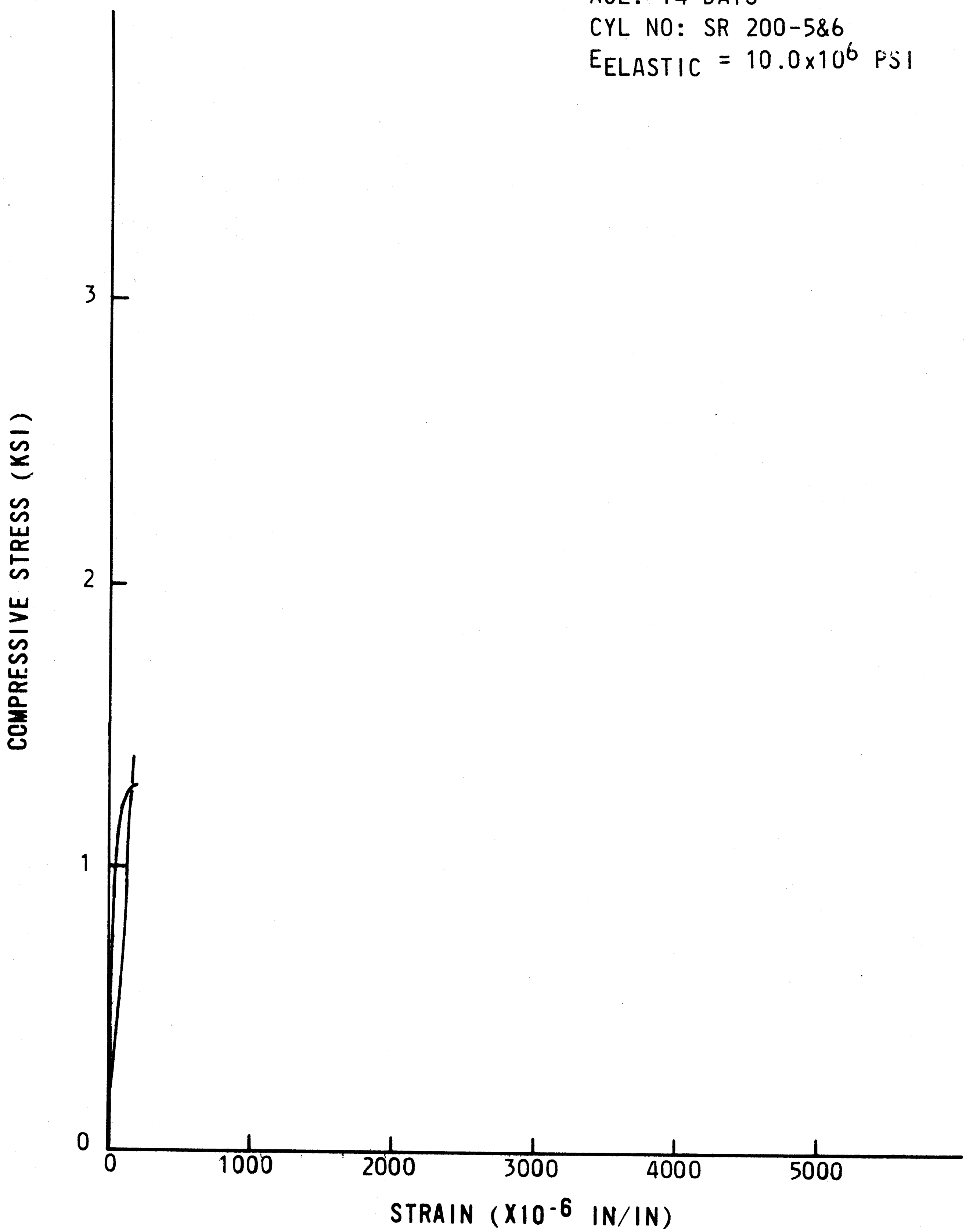


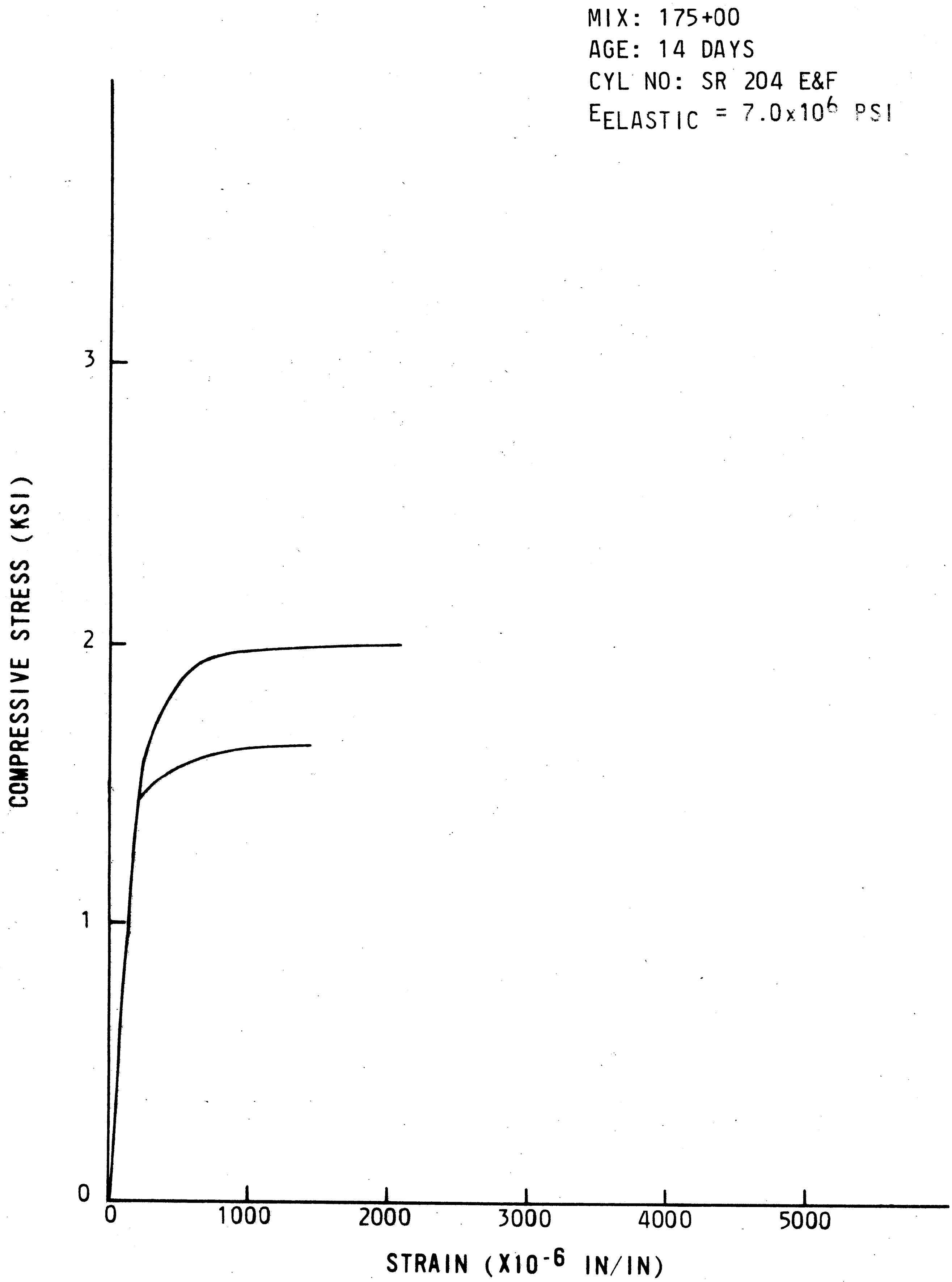
MIX: 175+00
AGE: 7 DAYS
CYL NO: SR 208-3-4
$E_{ELASTIC} = 1 \times 10^6$ PSI

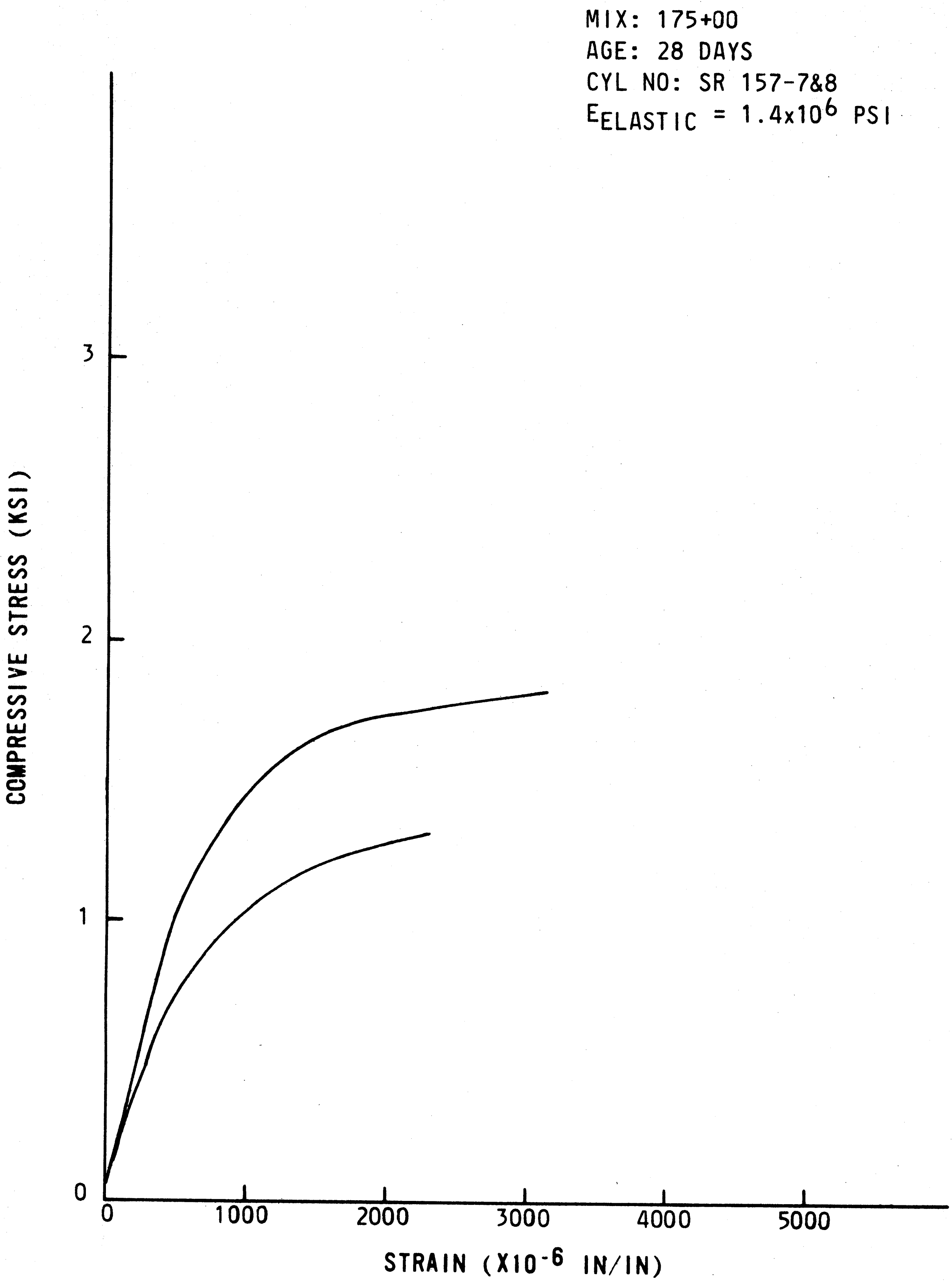



MIX: 175+00
AGE: 14 DAYS
CYL NO: SR 179 6&7
$E_{ELASTIC} = 2.0 \times 10^6$ PSI
COMPRESSIVE STRESS (KSI)
0
1
2
3
0
1000
2000
3000
4000
5000
STRAIN ($\times 10^{-6}$ IN/IN)

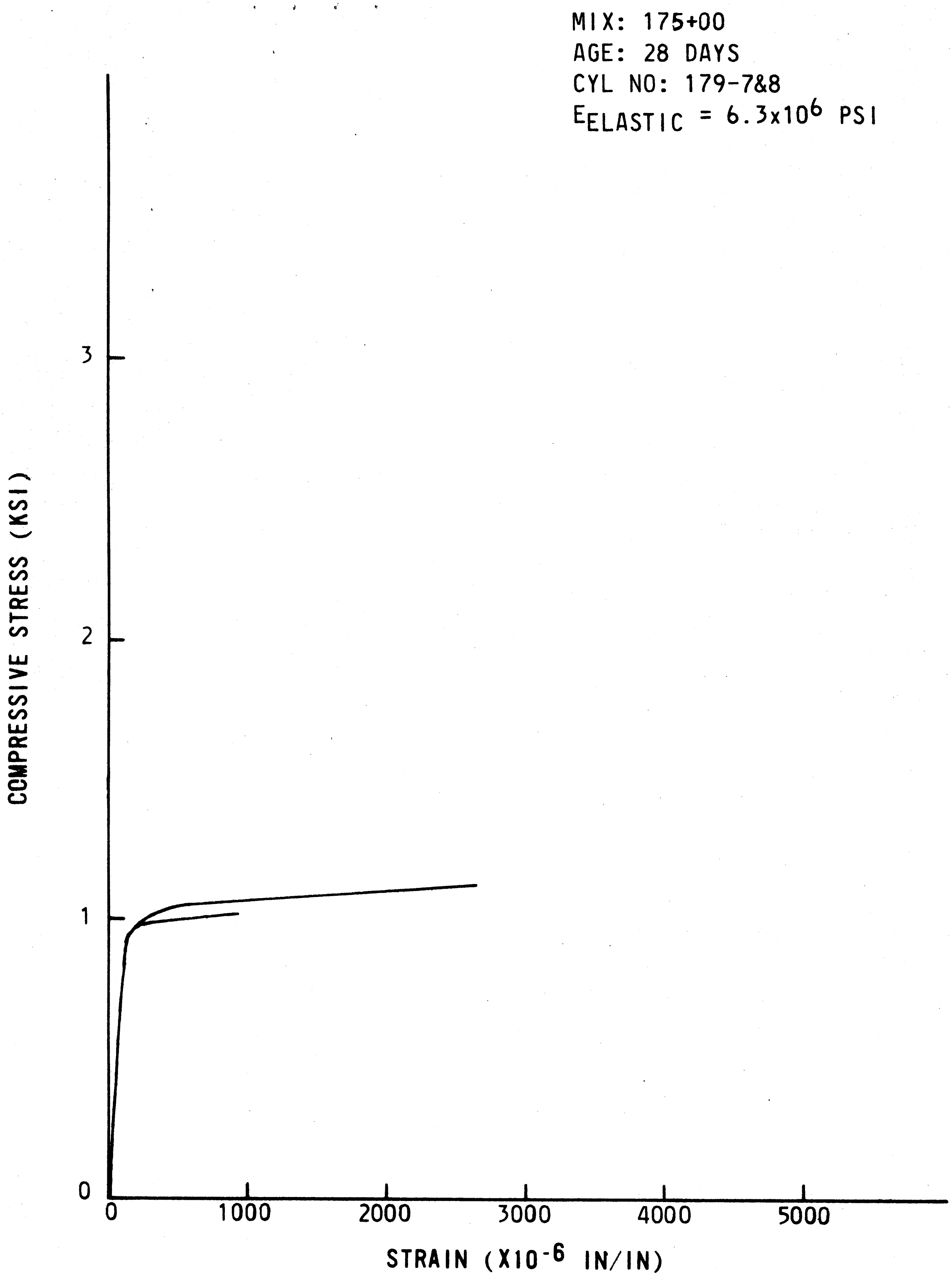
MIX: 175+00
AGE: 14 DAYS
CYL NO: SR 200-5&6
$E_{ELASTIC} = 10.0 \times 10^6$ PSI



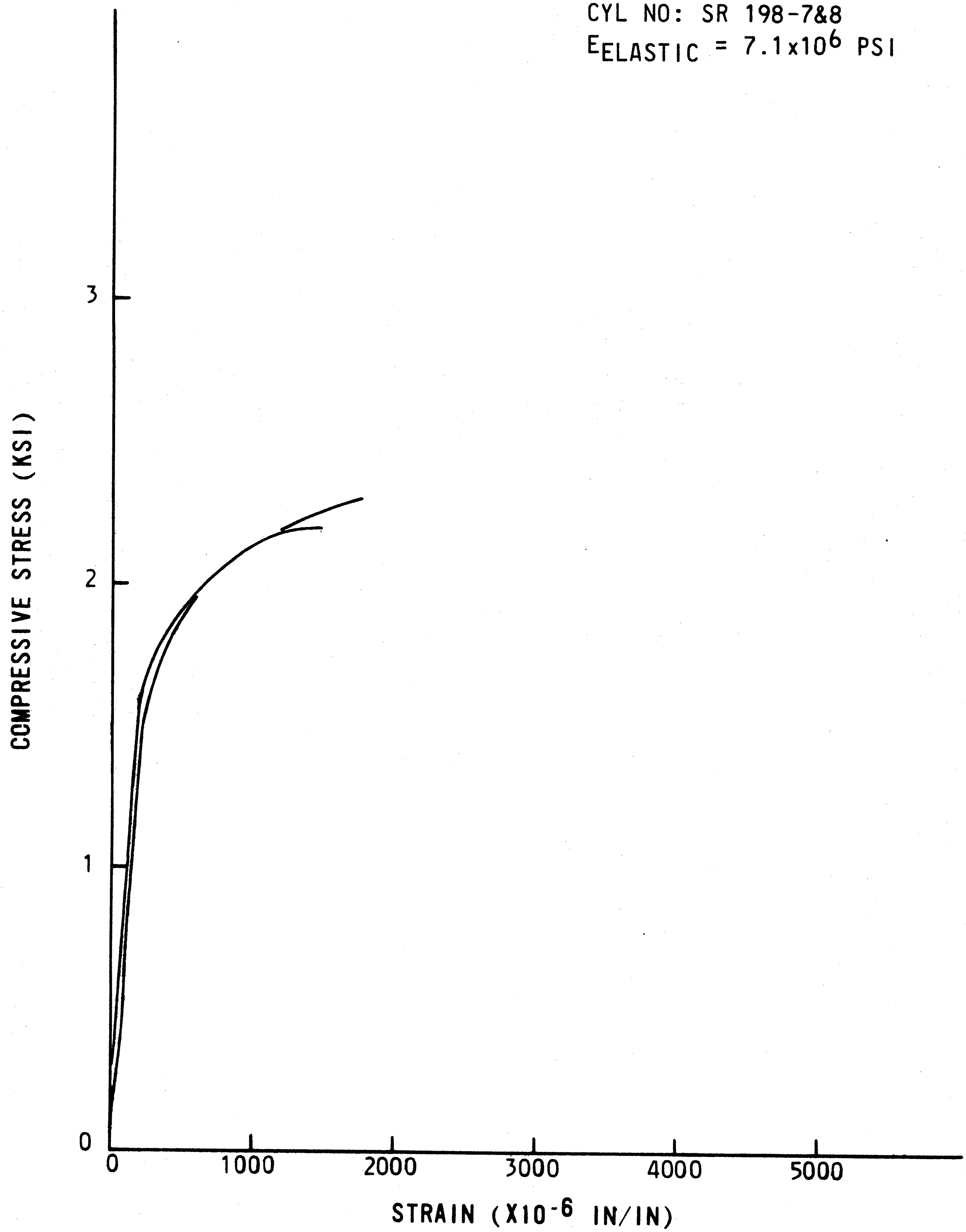

MIX: 175+00
AGE: 14 DAYS
CYL NO: SR 204 E&F
$E_{ELASTIC} = 7.0 \times 10^6$ PSI
COMPRESSIVE STRESS (KSI)
0
1
2
3
0
1000
2000
3000
4000
5000
STRAIN (X10^{-6} IN/IN)

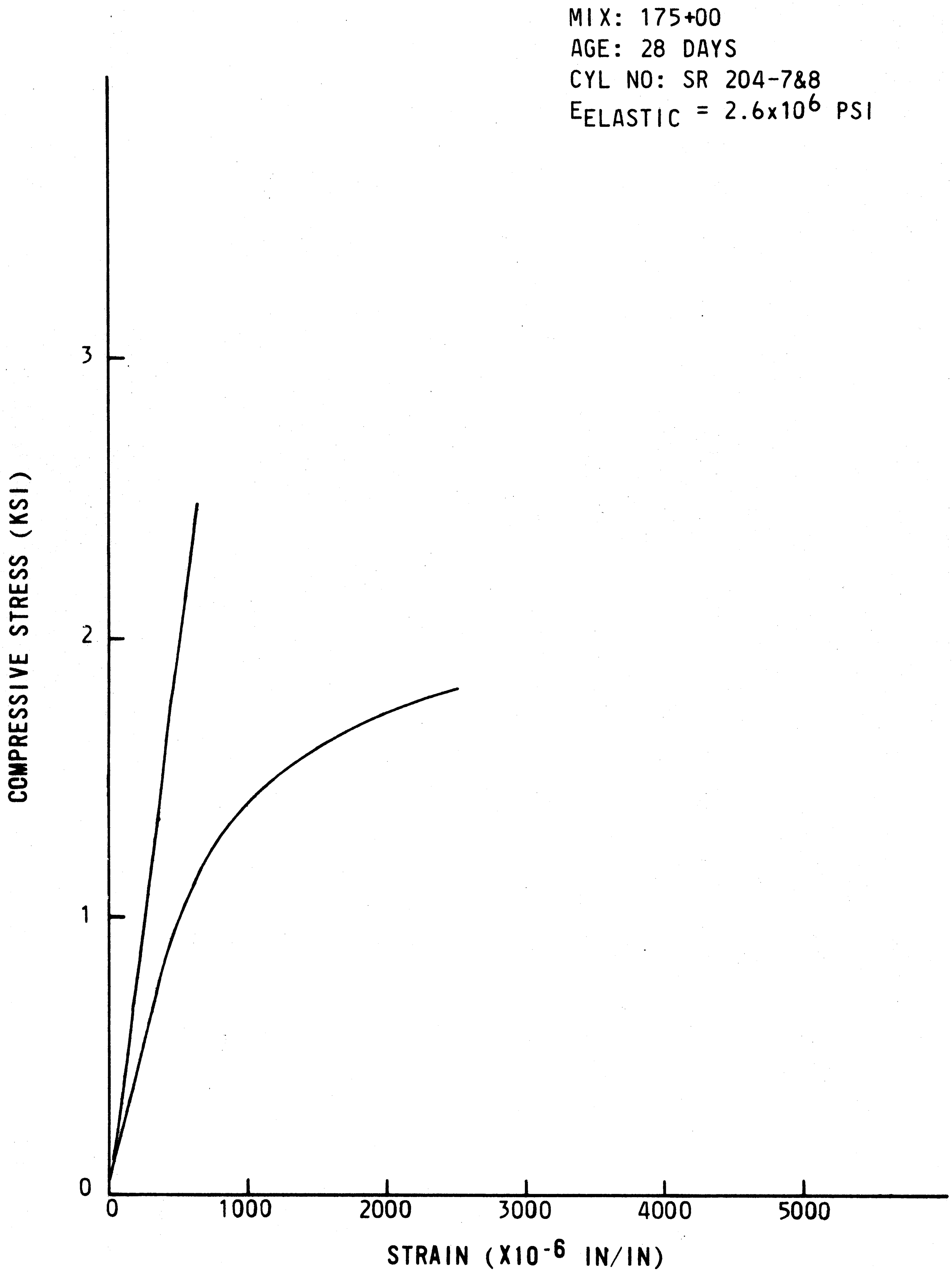


MIX: 175+00
AGE: 28 DAYS
CYL NO: SR 157-7&8
$E_{ELASTIC}$ = 1.4x10^6 PSI
COMPRESSIVE STRESS (KSI)
0
1
2
3
0
1000
2000
3000
4000
5000
STRAIN (X10^{-6} IN/IN)

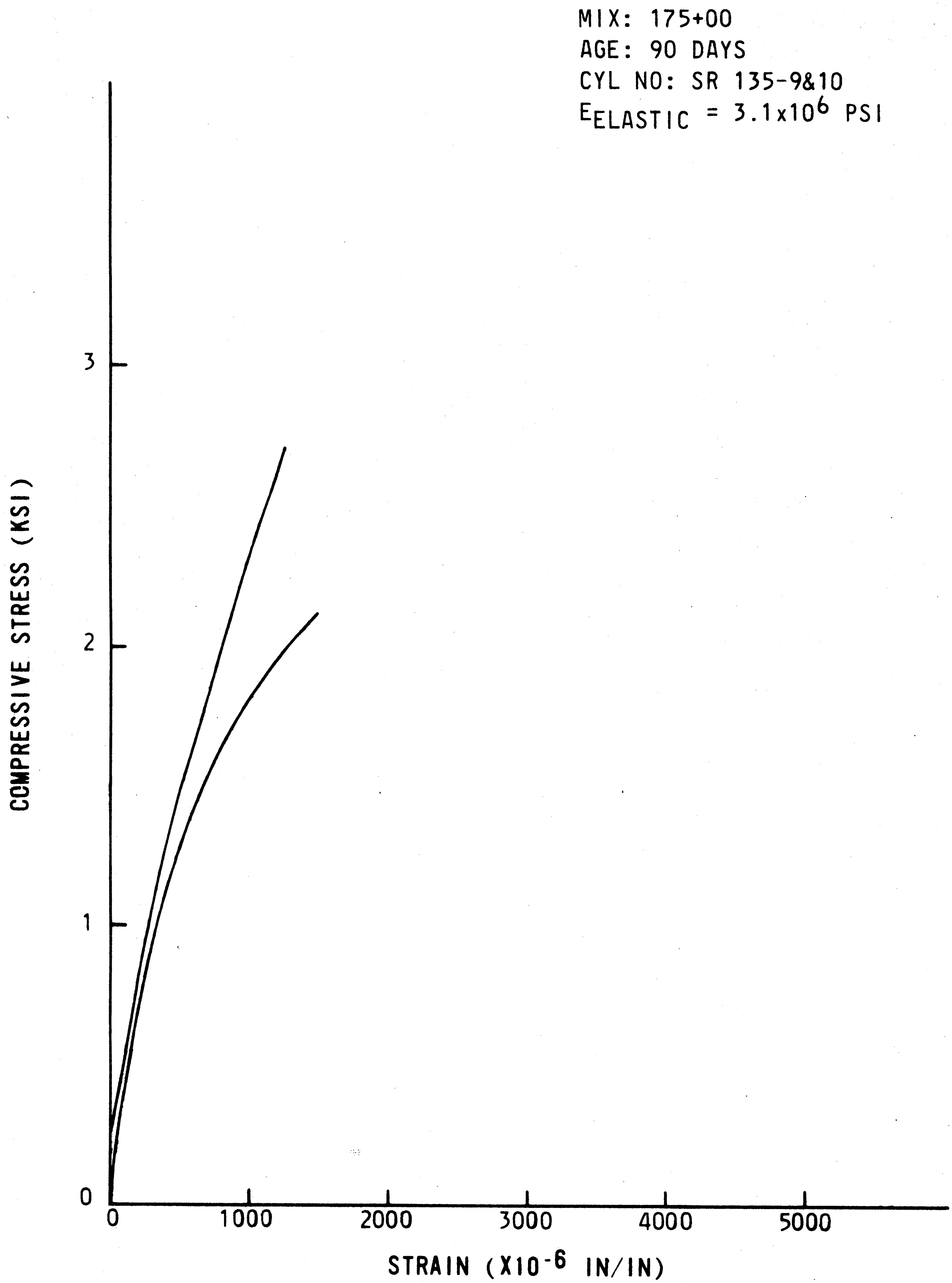

MIX: 175+00
AGE: 28 DAYS
CYL NO: 179-7&8
E ELASTIC = 6.3x10^6 PSI
COMPRESSIVE STRESS (KSI)
0
1
2
3
0
1000
2000
3000
4000
5000
STRAIN (X10^-6 IN/IN)

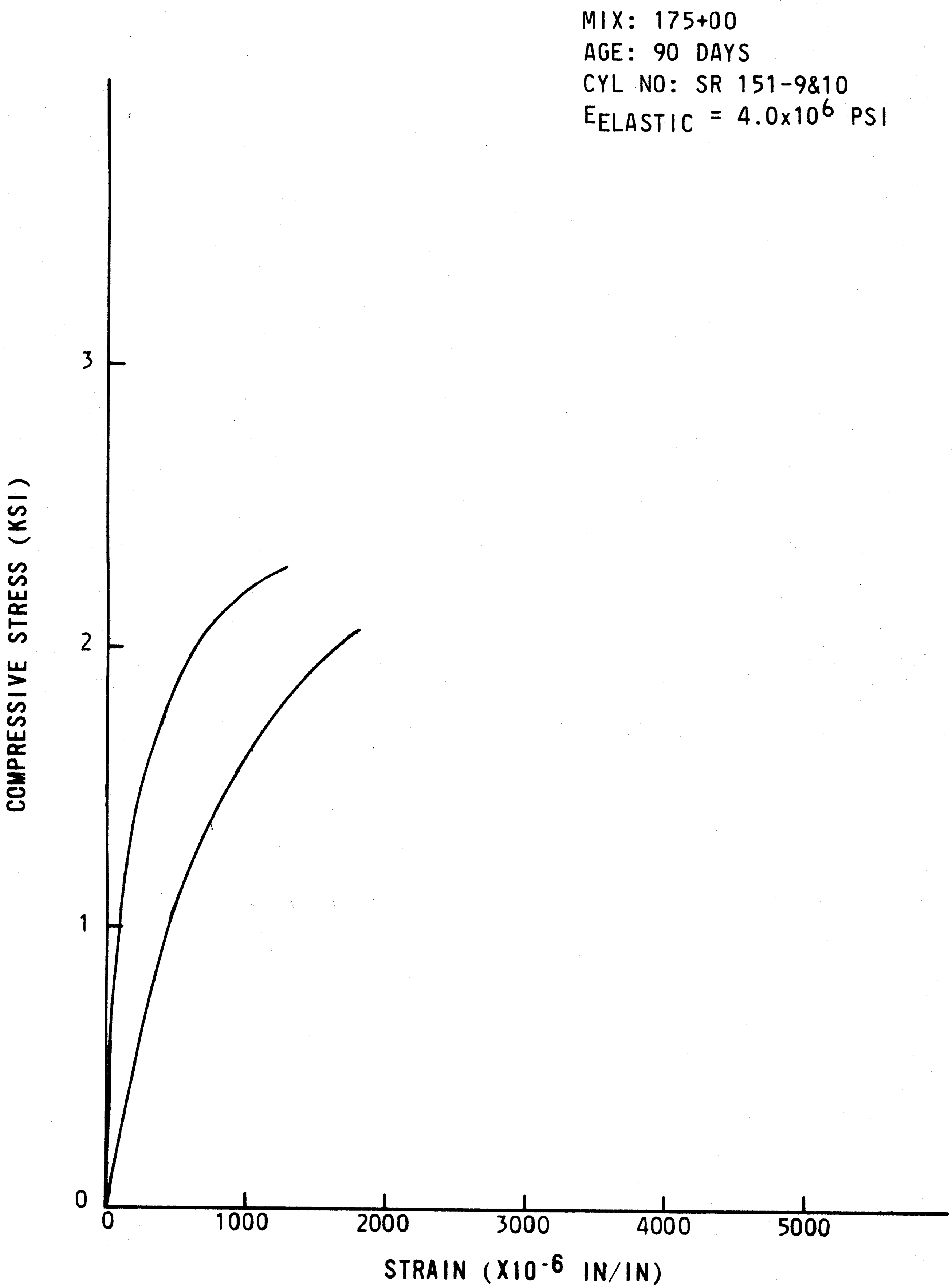
MIX: 175+00
AGE: 28 DAYS
CYL NO: SR 198-7&8
$E_{ELASTIC} = 7.1 \times 10^6$ PSI





MIX: 175+00
AGE: 28 DAYS
CYL NO: SR 204-7&8
$E_{ELASTIC} = 2.6x10^6$ PSI
COMPRESSIVE STRESS (KSI)
0
1
2
3
0
1000
2000
3000
4000
5000
STRAIN ($X10^{-6}$ IN/IN)


MIX: 175+00
AGE: 90 DAYS
CYL NO: SR 135-9&10
$E_{ELASTIC}$ = $3.1x10^6$ PSI
COMPRESSIVE STRESS (KSI)
0
1
2
3
0
1000
2000
3000
4000
5000
STRAIN ($X10^{-6}$ IN/IN)


MIX: 175+00
AGE: 90 DAYS
CYL NO: SR 151-9&10
$E_{ELASTIC} = 4.0 \times 10^6$ PSI
COMPRESSIVE STRESS (KSI)
0
1
2
3
0
1000
2000
3000
4000
5000
STRAIN ($X10^{-6}$ IN/IN)

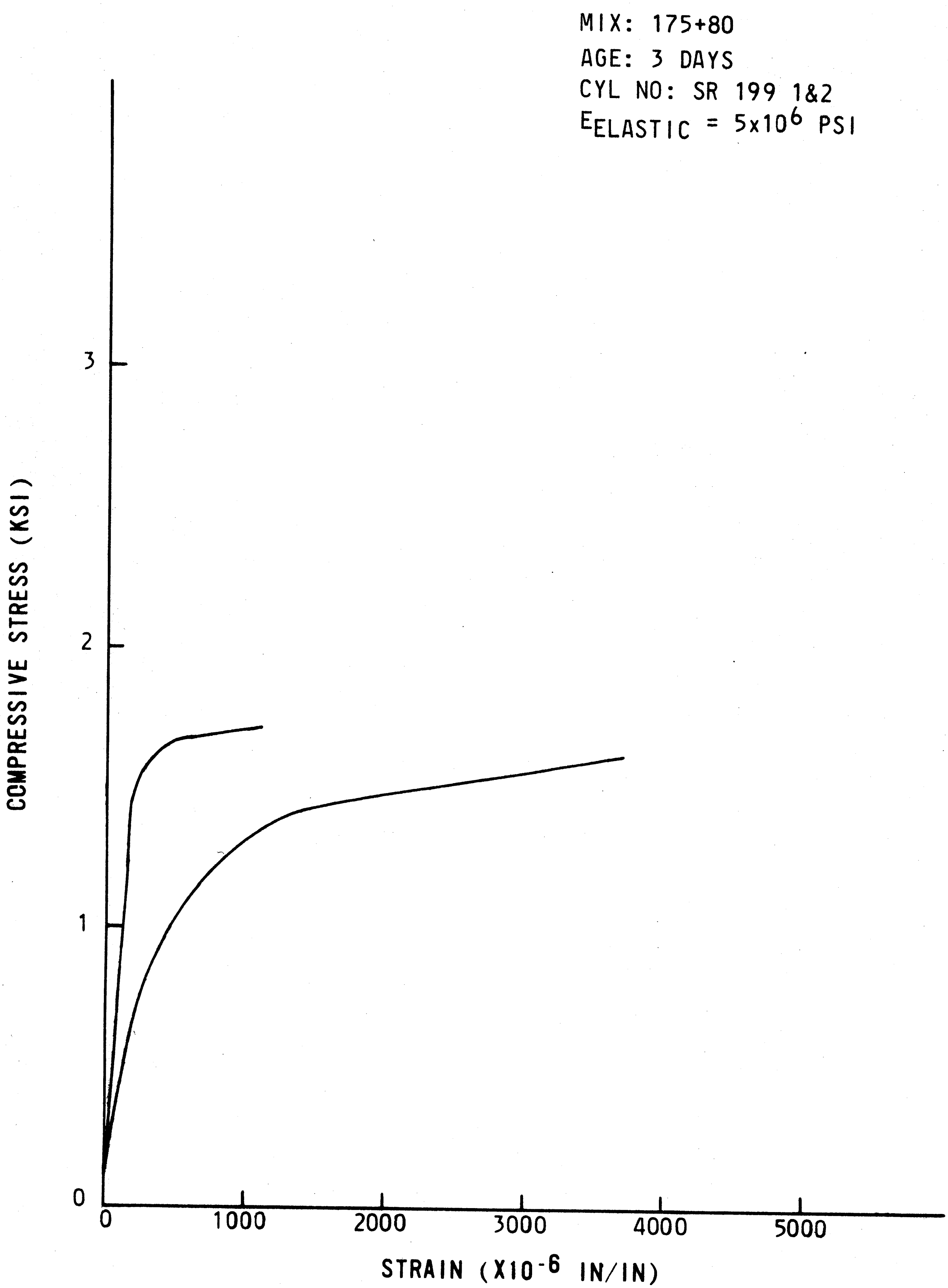
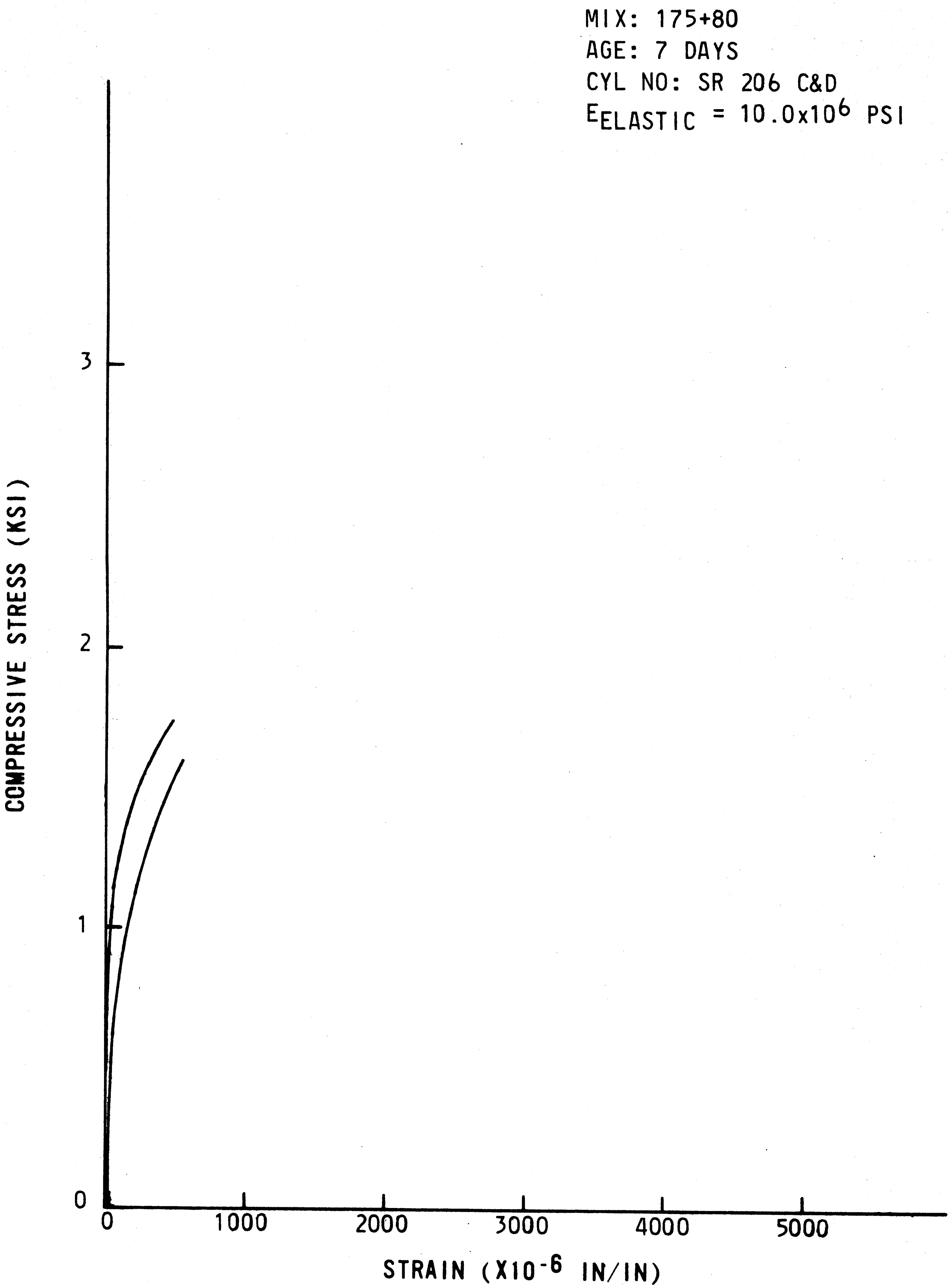
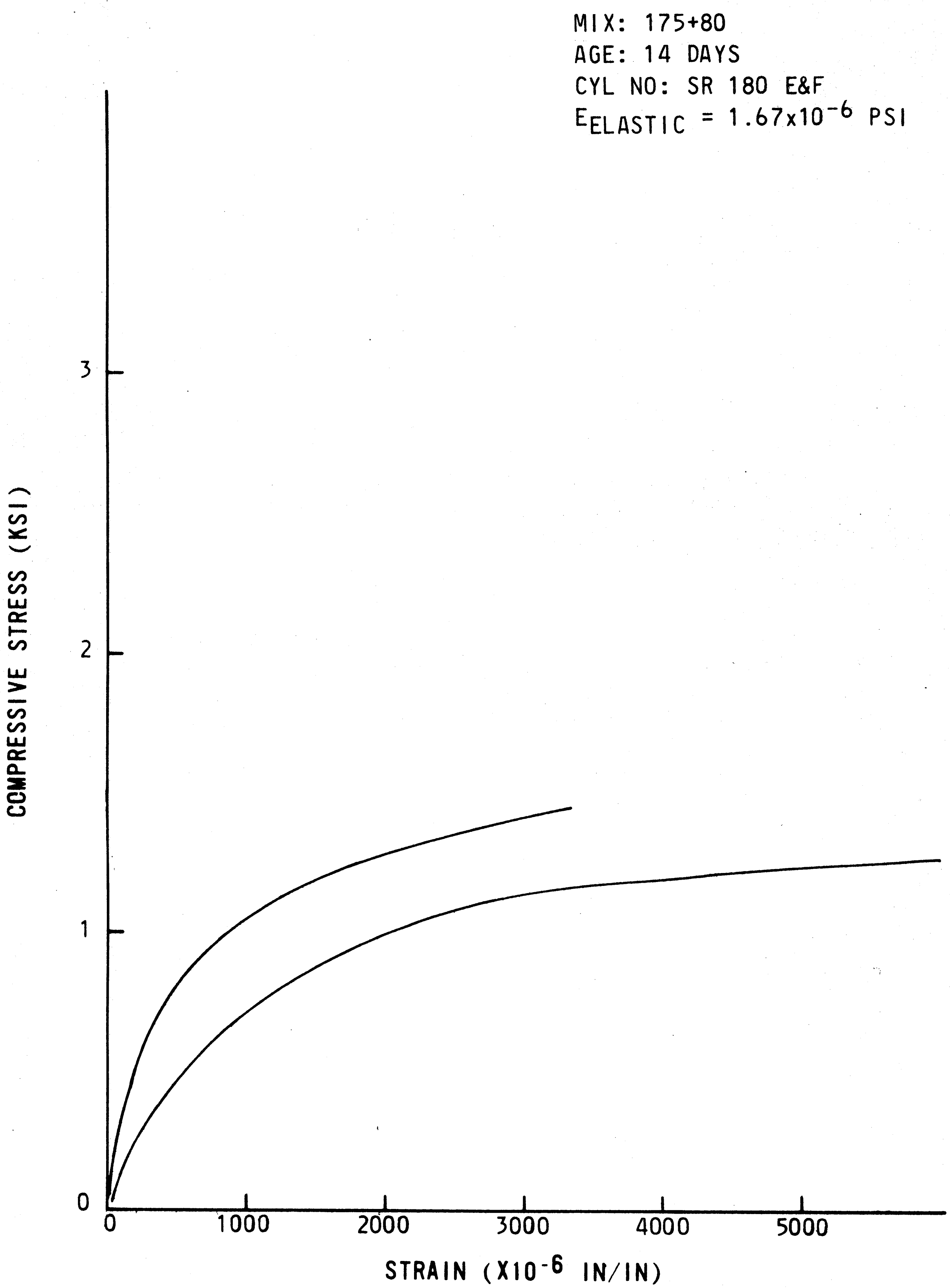


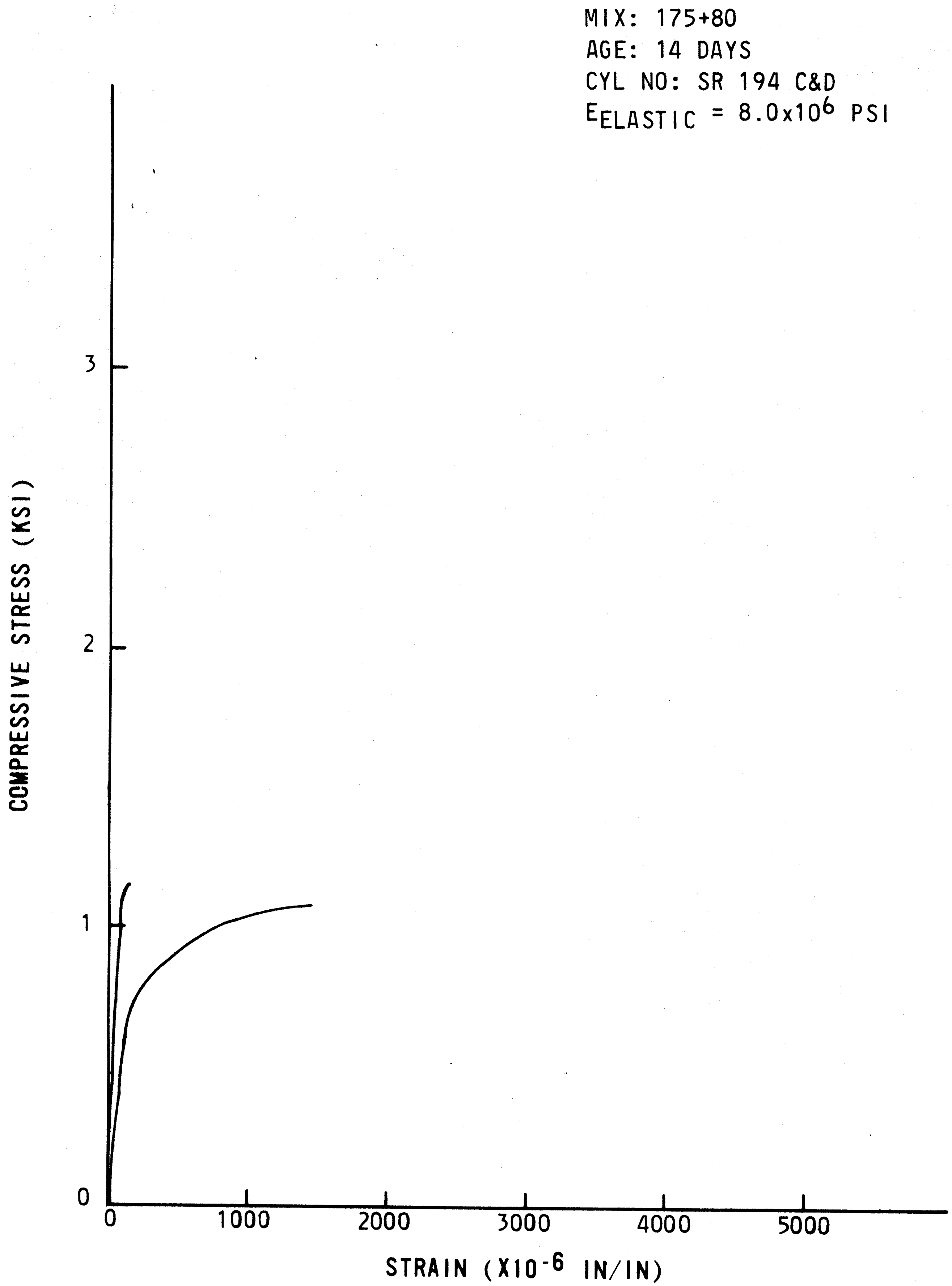
EXHIBIT 13.1
Sheet 22 of 42

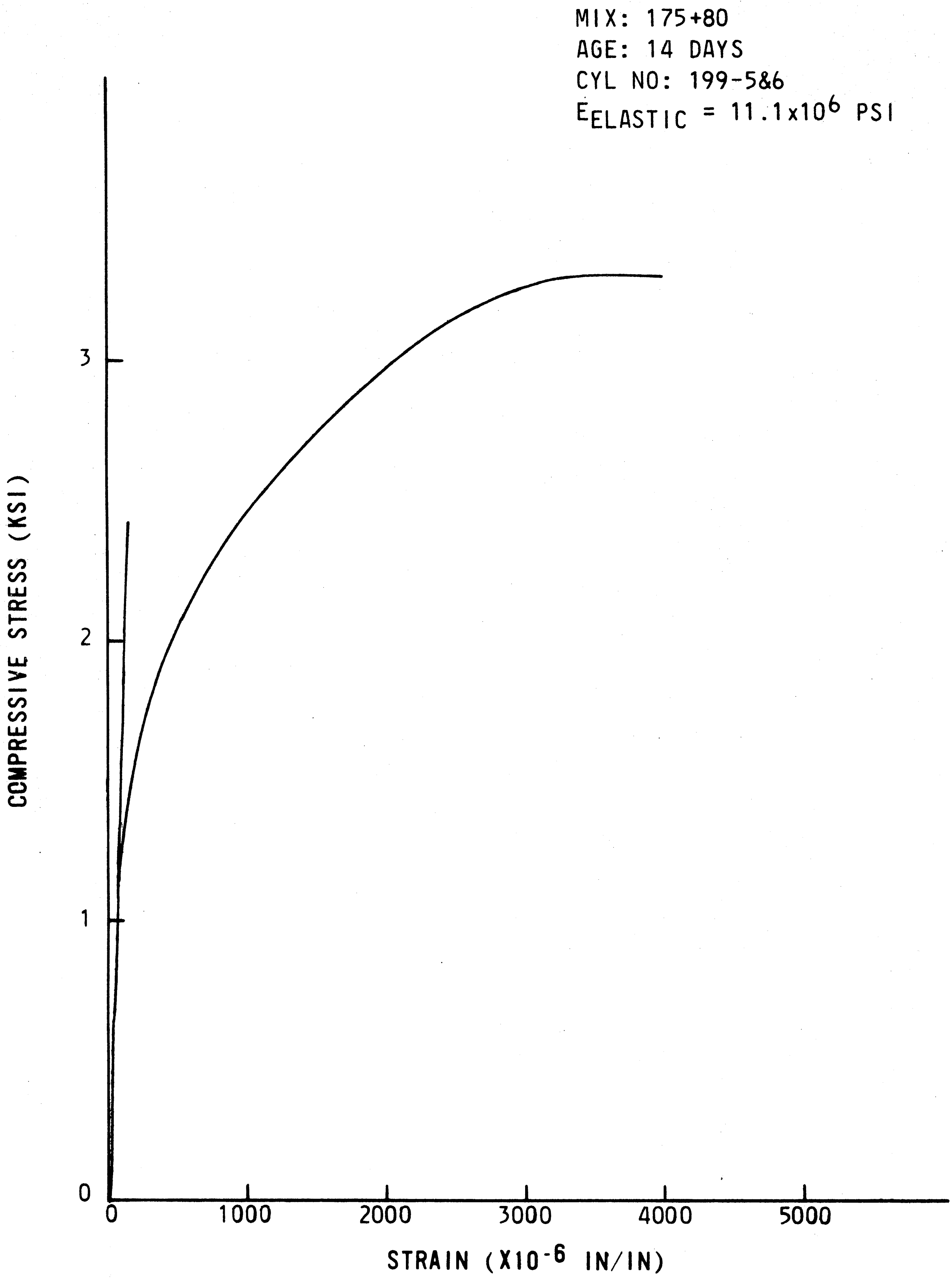


MIX: 175+80
AGE: 7 DAYS
CYL NO: SR 206 C&D
$E_{ELASTIC} = 10.0 \times 10^6$ PSI
COMPRESSIVE STRESS (KSI)
3
2
1
0
0
1000
2000
3000
4000
5000
STRAIN ($\times 10^{-6}$ IN/IN)

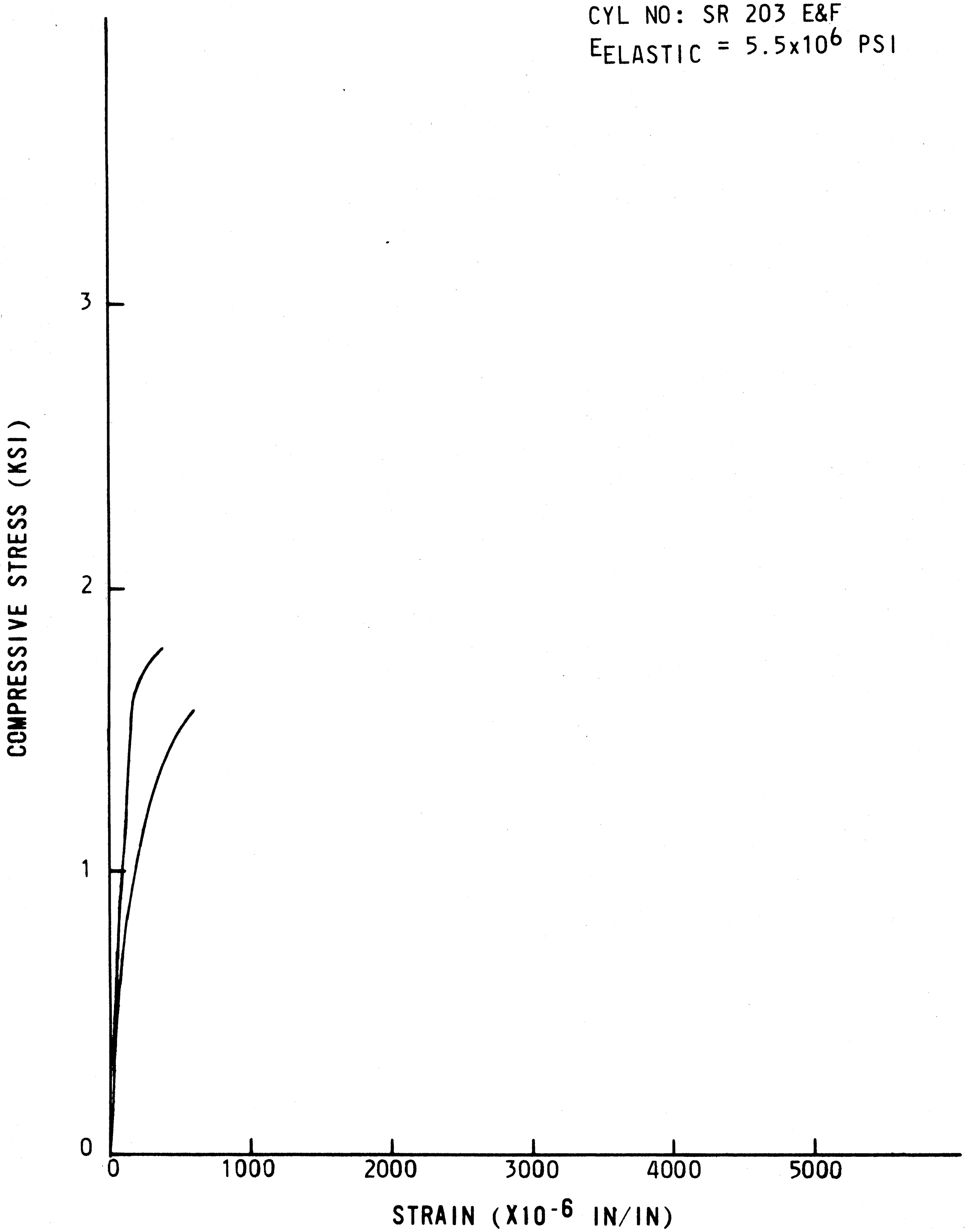


MIX: 175+80
AGE: 14 DAYS
CYL NO: SR 180 E&F
EELASTIC = 1.67x10-6 PSI
COMPRESSIVE STRESS (KSI)
0
1
2
3
0
1000
2000
3000
4000
5000
STRAIN (X10-6 IN/IN)

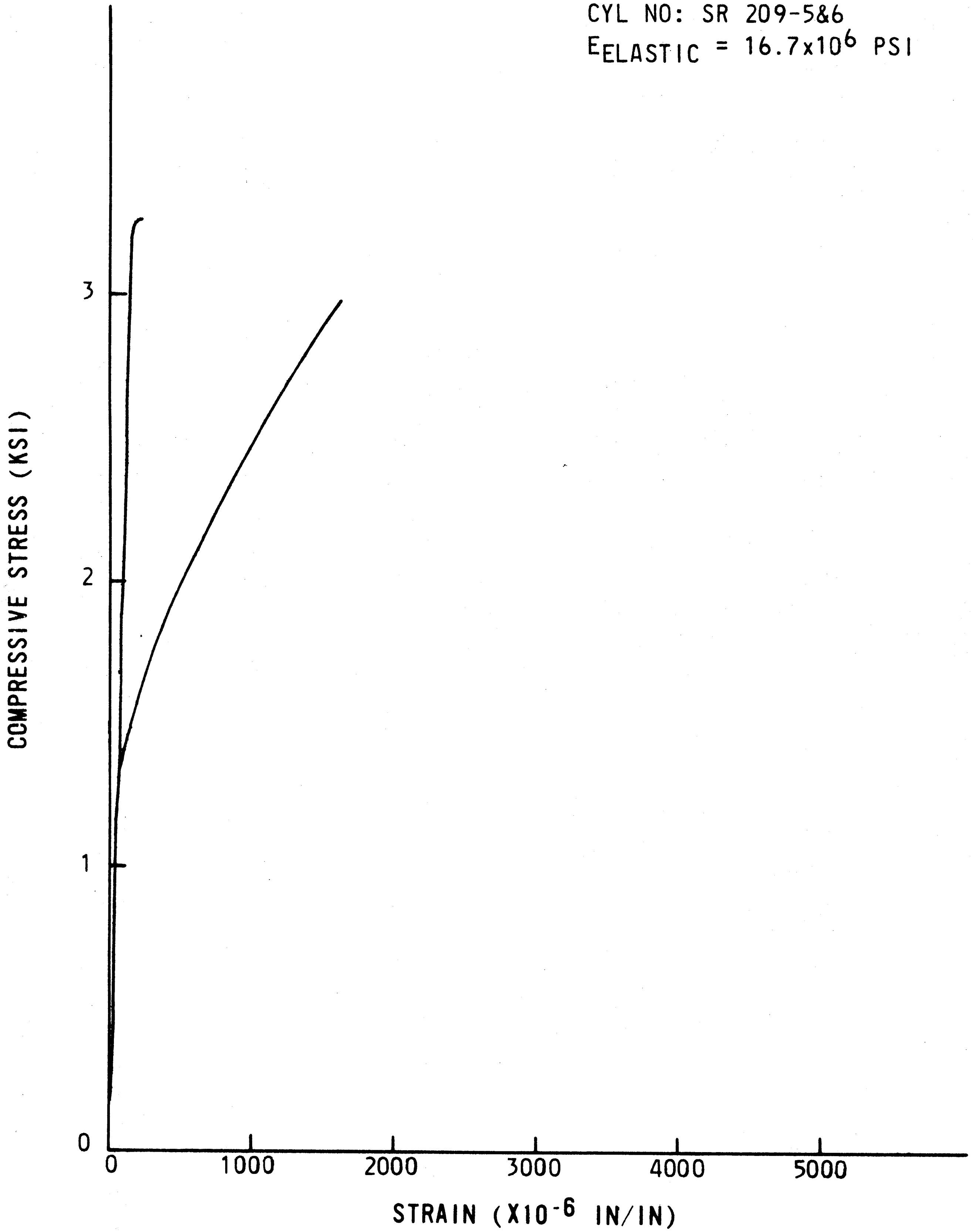

MIX: 175+80
AGE: 14 DAYS
CYL NO: SR 194 C&D
$E_{ELASTIC} = 8.0 \times 10^6$ PSI
COMPRESSIVE STRESS (KSI)
0
1
2
3
0
1000
2000
3000
4000
5000
STRAIN ($X10^{-6}$ IN/IN)

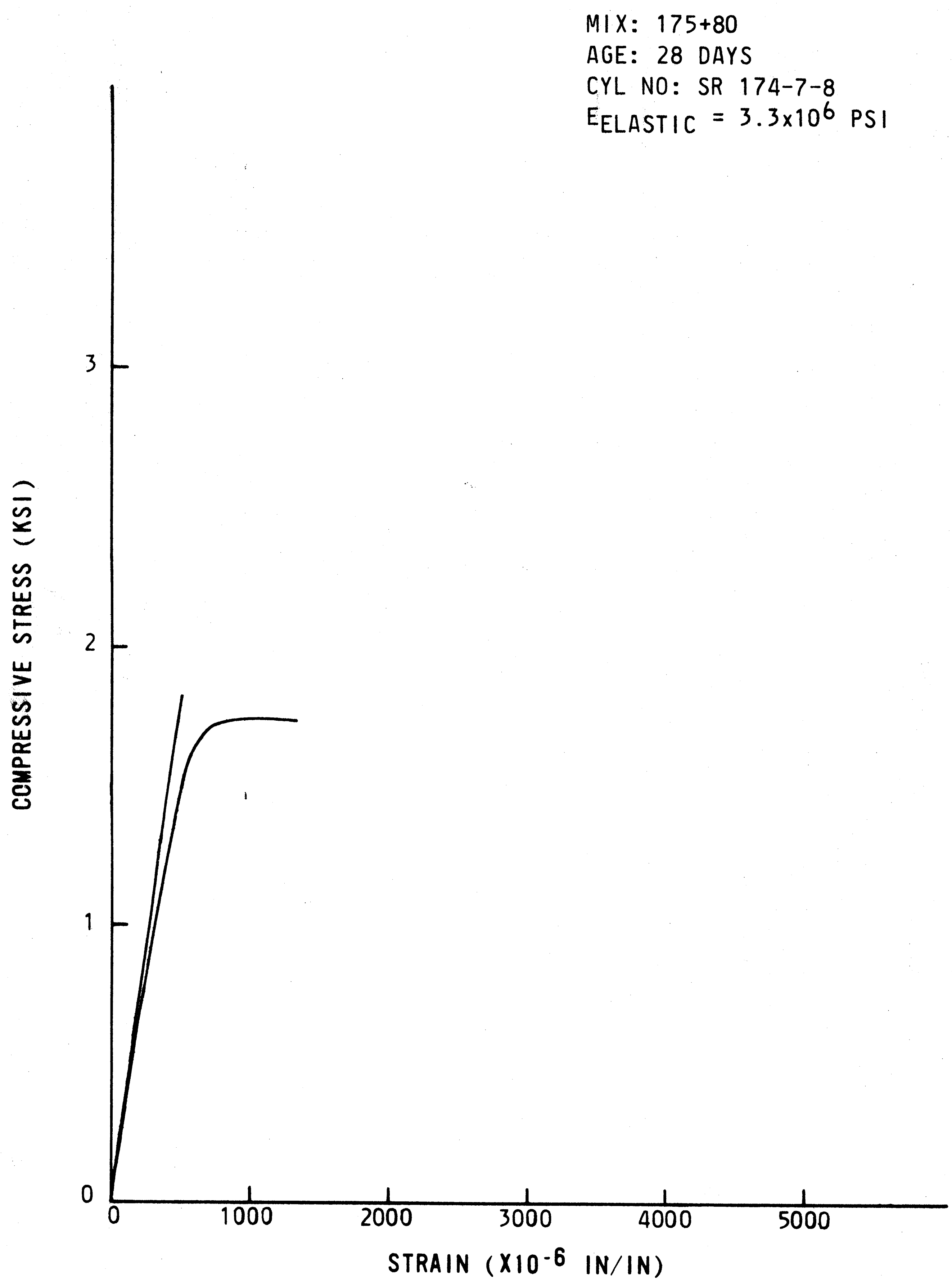

MIX: 175+80
AGE: 14 DAYS
CYL NO: 199-5&6
E ELASTIC = 11.1x10^6 PSI
COMPRESSIVE STRESS (KSI)
0
1
2
3
0
1000
2000
3000
4000
5000
STRAIN (X10^-6 IN/IN)

MIX: 175+80
AGE: 14 DAYS
CYL NO: SR 203 E&F
$E_{ELASTIC} = 5.5x10^6$ PSI

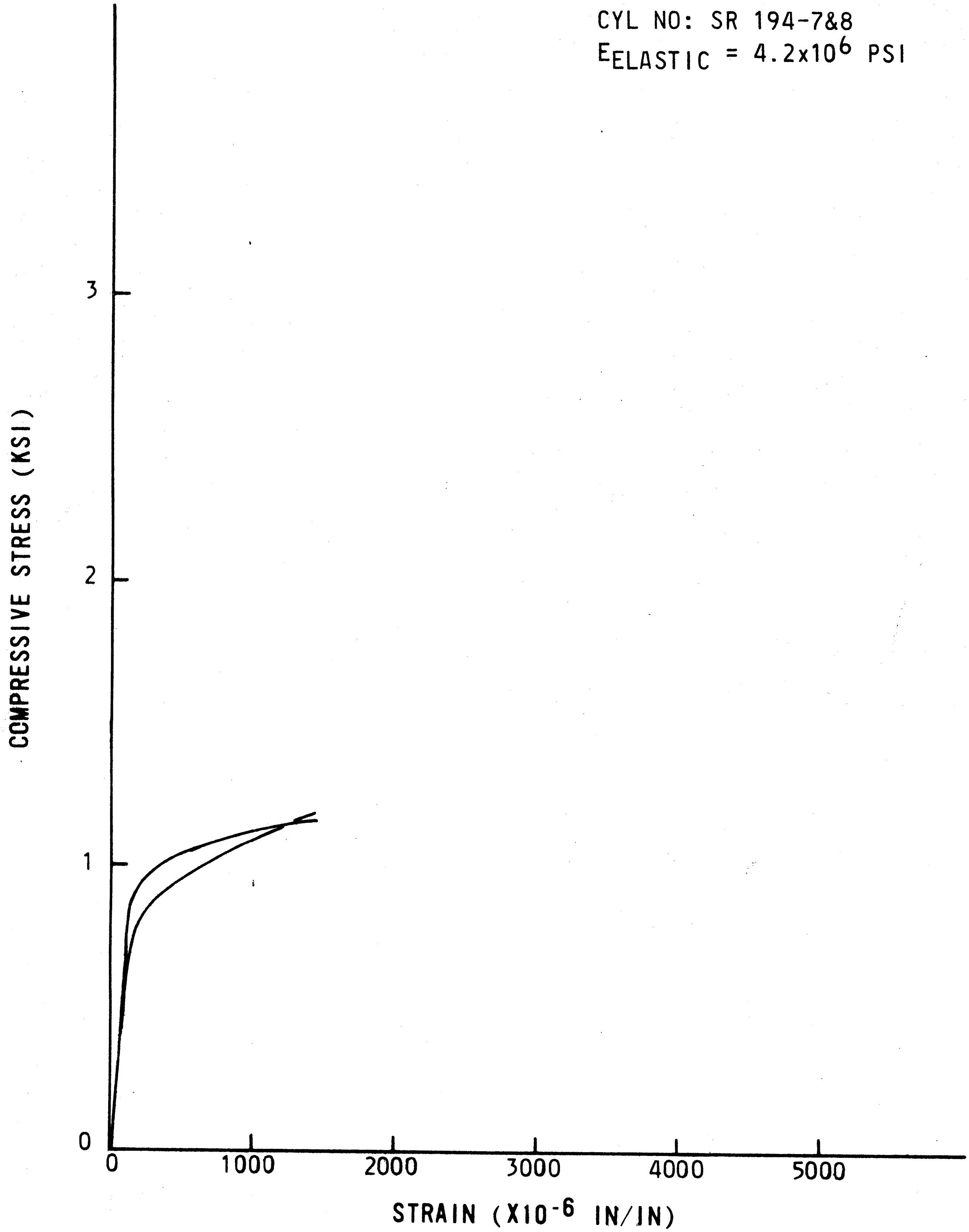


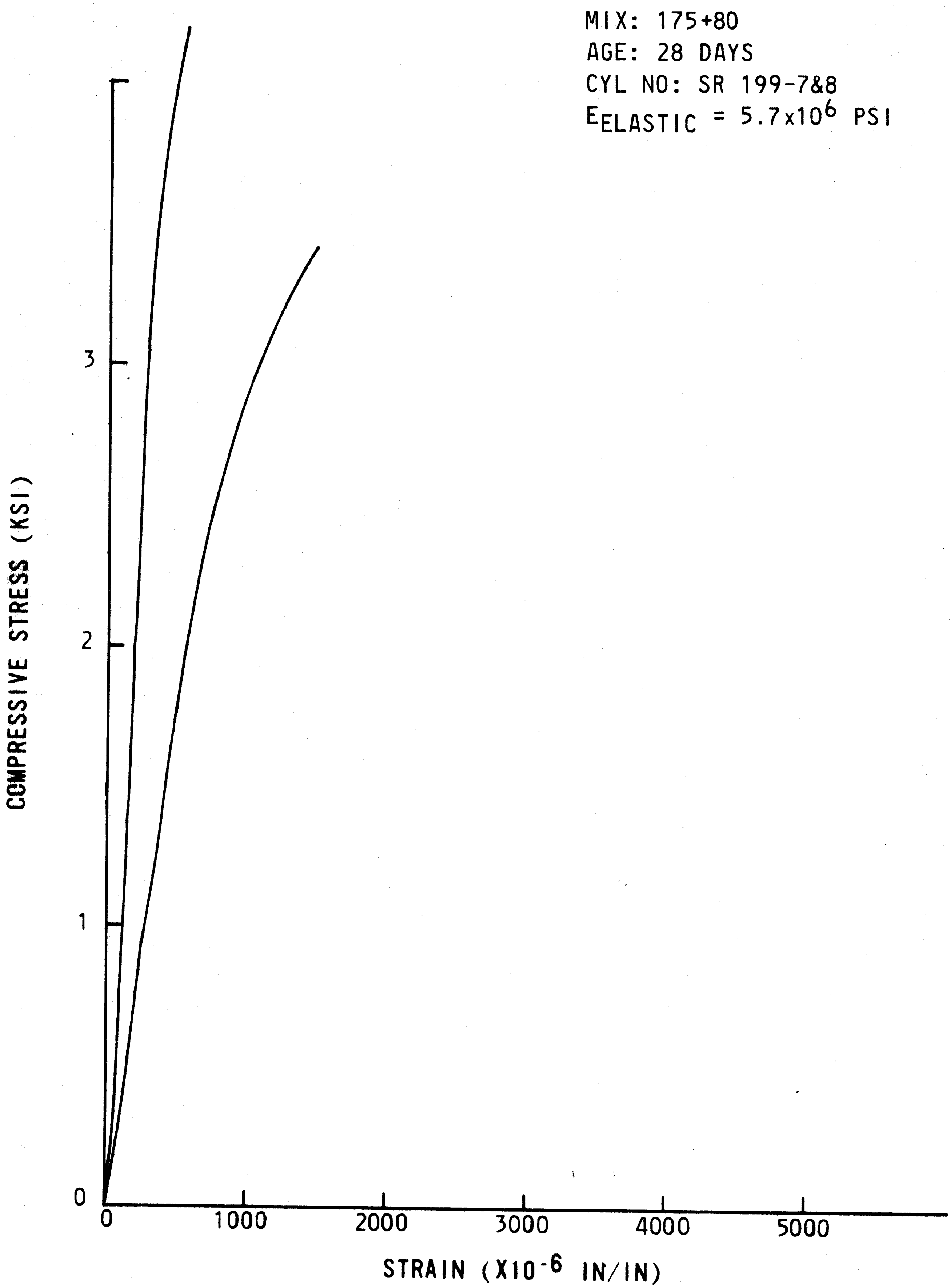
MIX: 175+80
AGE: 14 DAYS
CYL NO: SR 209-5&6
$E_{ELASTIC} = 16.7x10^6$ PSI

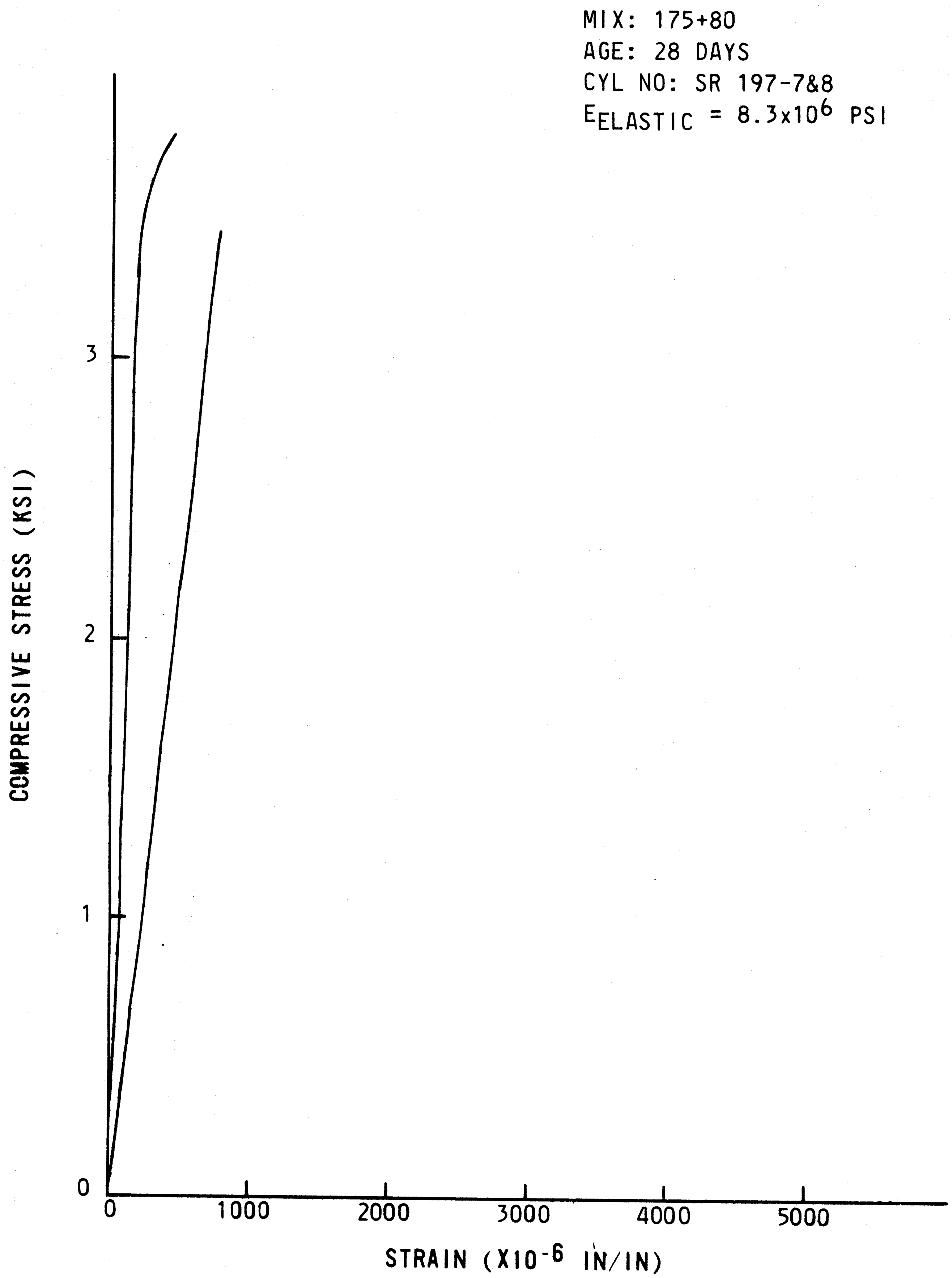


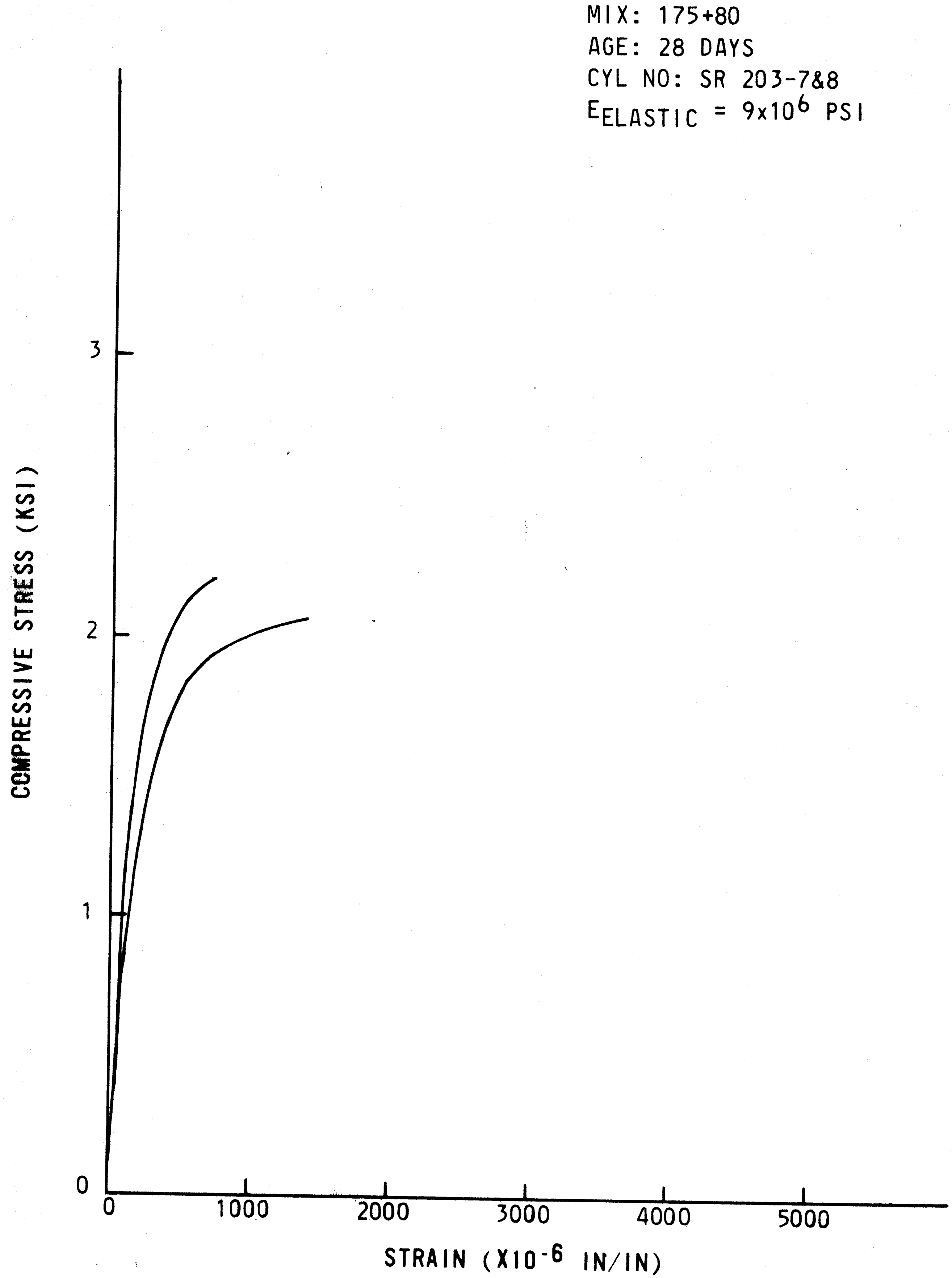

MIX: 175+80
AGE: 28 DAYS
CYL NO: SR 174-7-8
$E_{ELASTIC} = 3.3x10^6$ PSI
COMPRESSIVE STRESS (KSI)
0
1
2
3
0
1000
2000
3000
4000
5000
STRAIN ($X10^{-6}$ IN/IN)

MIX: 175+80
AGE: 28 DAYS
CYL NO: SR 194-7&8
$E_{ELASTIC} = 4.2 \times 10^6$ PSI

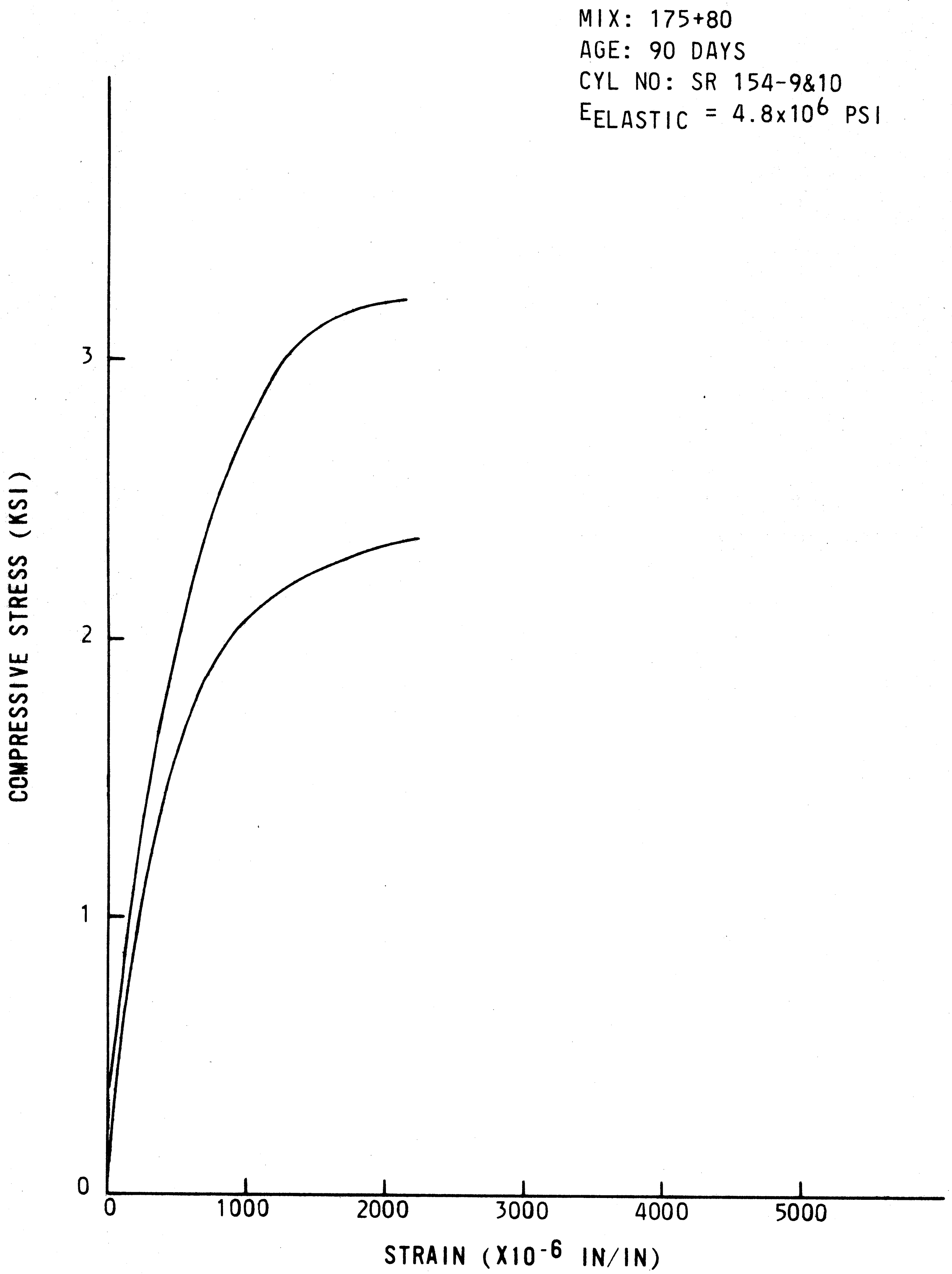



MIX: 175+80
AGE: 28 DAYS
CYL NO: SR 199-7&8
E ELASTIC = 5.7x10^6 PSI
COMPRESSIVE STRESS (KSI)
0
1
2
3
0
1000
2000
3000
4000
5000
STRAIN (X10^-6 IN/IN)

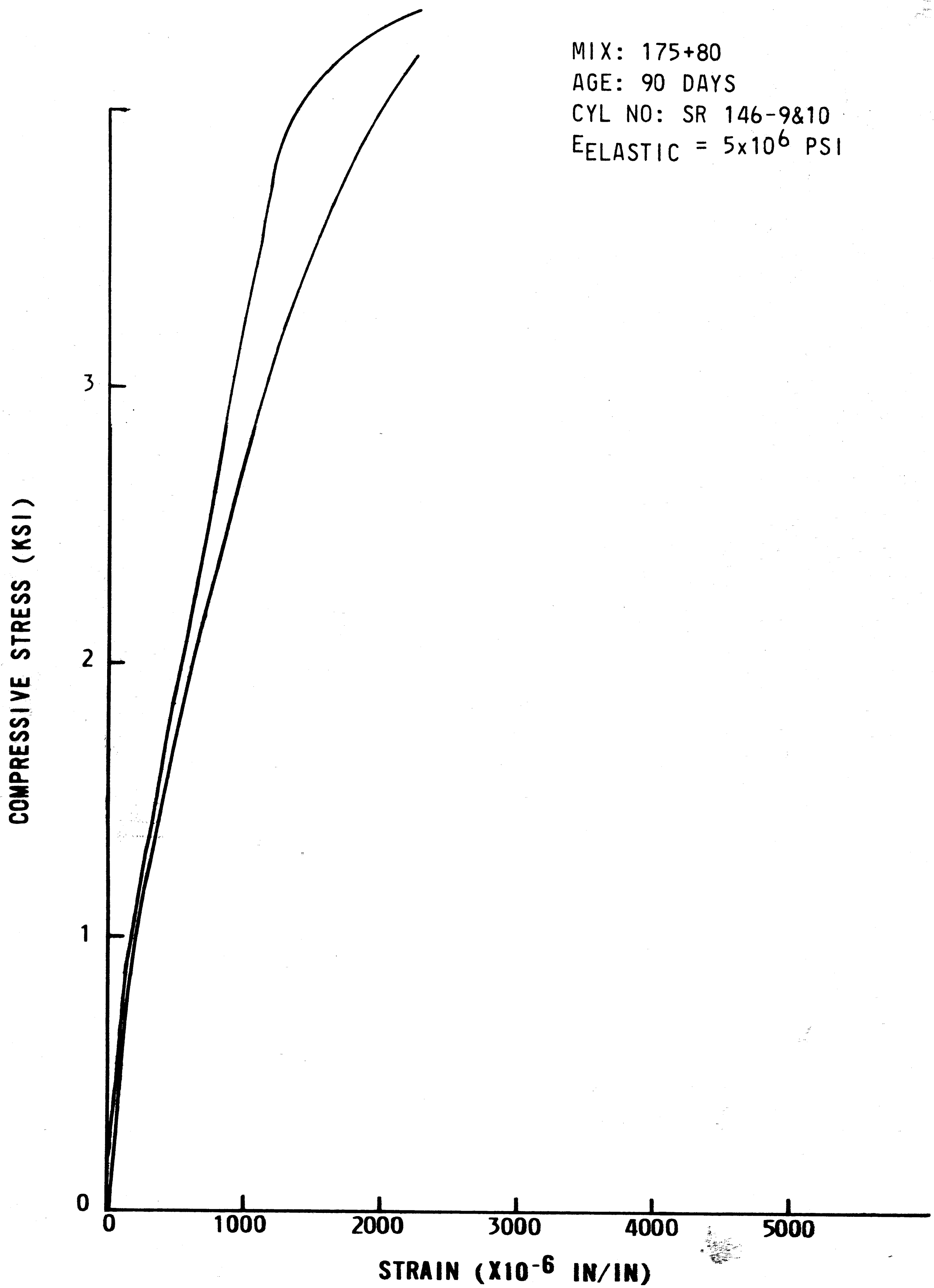

MIX: 175+80
AGE: 28 DAYS
CYL NO: SR 197-7&8
$E_{ELASTIC} = 8.3 x 10^6$ PSI
COMPRESSIVE STRESS (KSI)
0
1
2
3
0
1000
2000
3000
4000
5000
STRAIN (X10^-6 IN/IN)



MIX: 175+80
AGE: 28 DAYS
CYL NO: SR 203-7&8
$E_{ELASTIC} = 9 \times 10^6$ PSI
COMPRESSIVE STRESS (KSI)
0
1
2
3
0
1000
2000
3000
4000
5000
STRAIN ($X10^{-6}$ IN/IN)



MIX: 175+80
AGE: 90 DAYS
CYL NO: SR 154-9&10
$E_{ELASTIC} = 4.8 \times 10^6$ PSI
COMPRESSIVE STRESS (KSI)
0
1
2
3
0
1000
2000
3000
4000
5000
STRAIN ($\times 10^{-6}$ IN/IN)


MIX: 175+80
AGE: 90 DAYS
CYL NO: SR 146-9&10
$E_{ELASTIC} = 5x10^6$ PSI
COMPRESSIVE STRESS (KSI)
0
1
2
3
0
1000
2000
3000
4000
5000
STRAIN ($X10^{-6}$ IN/IN)

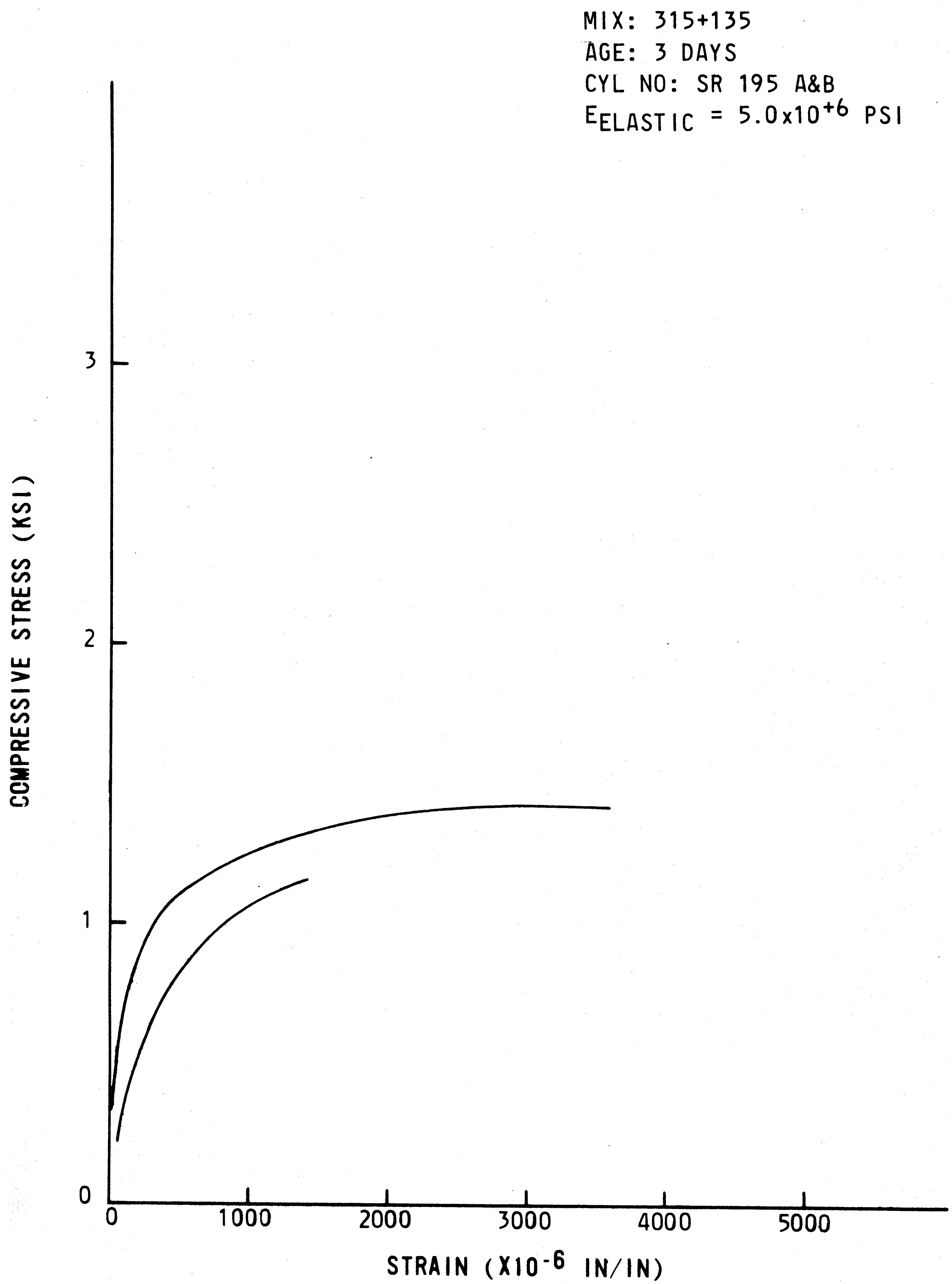
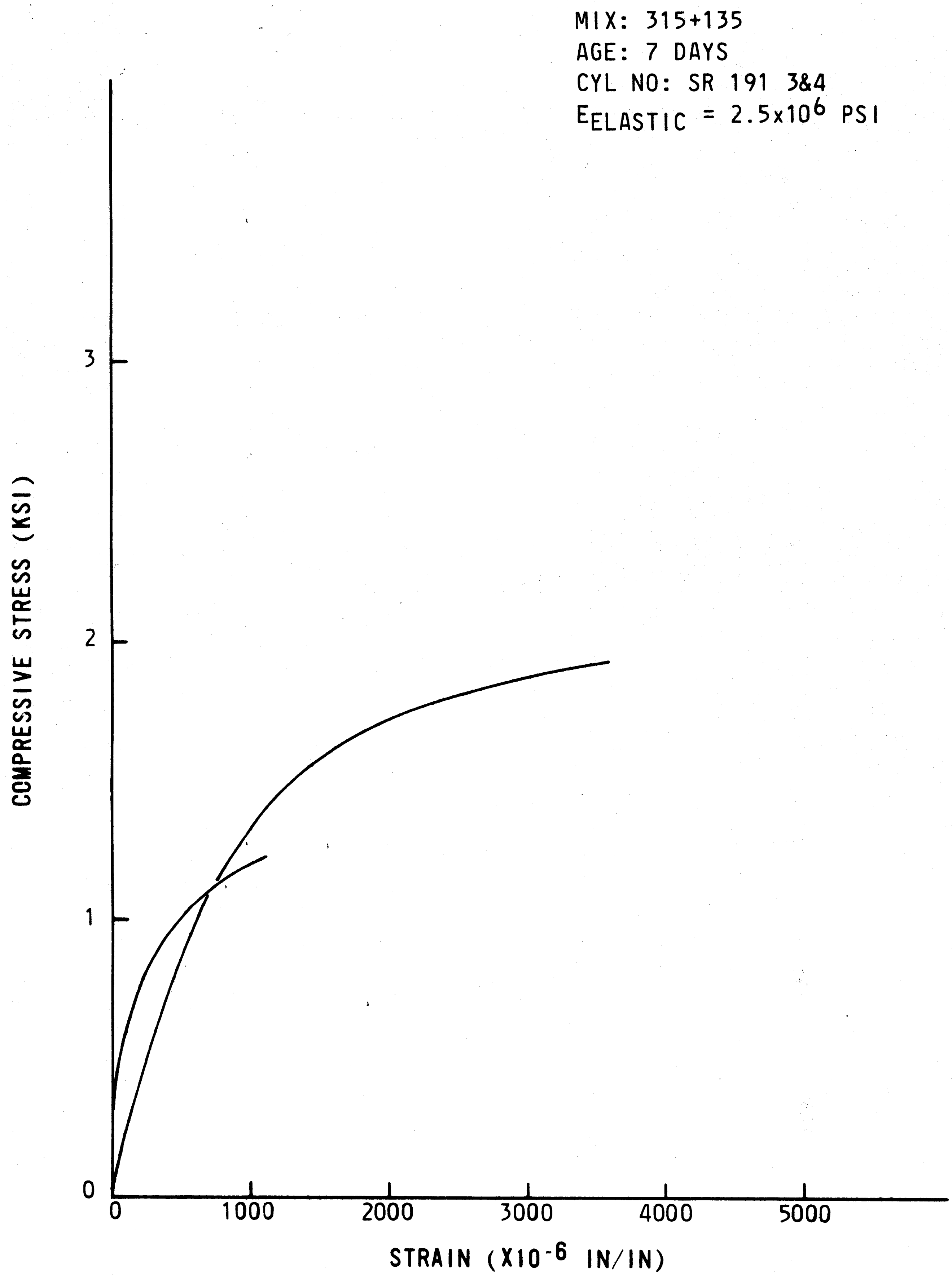
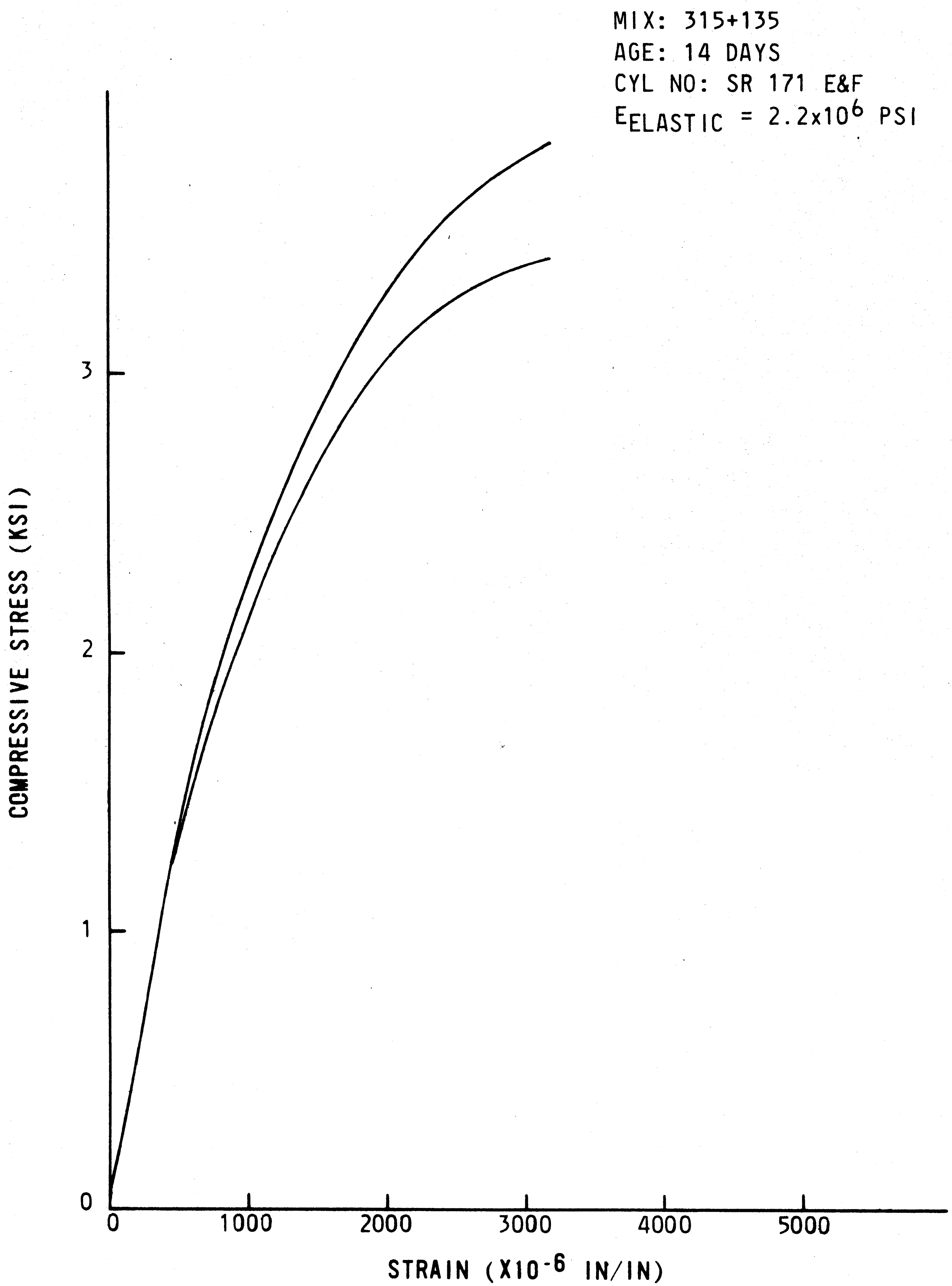
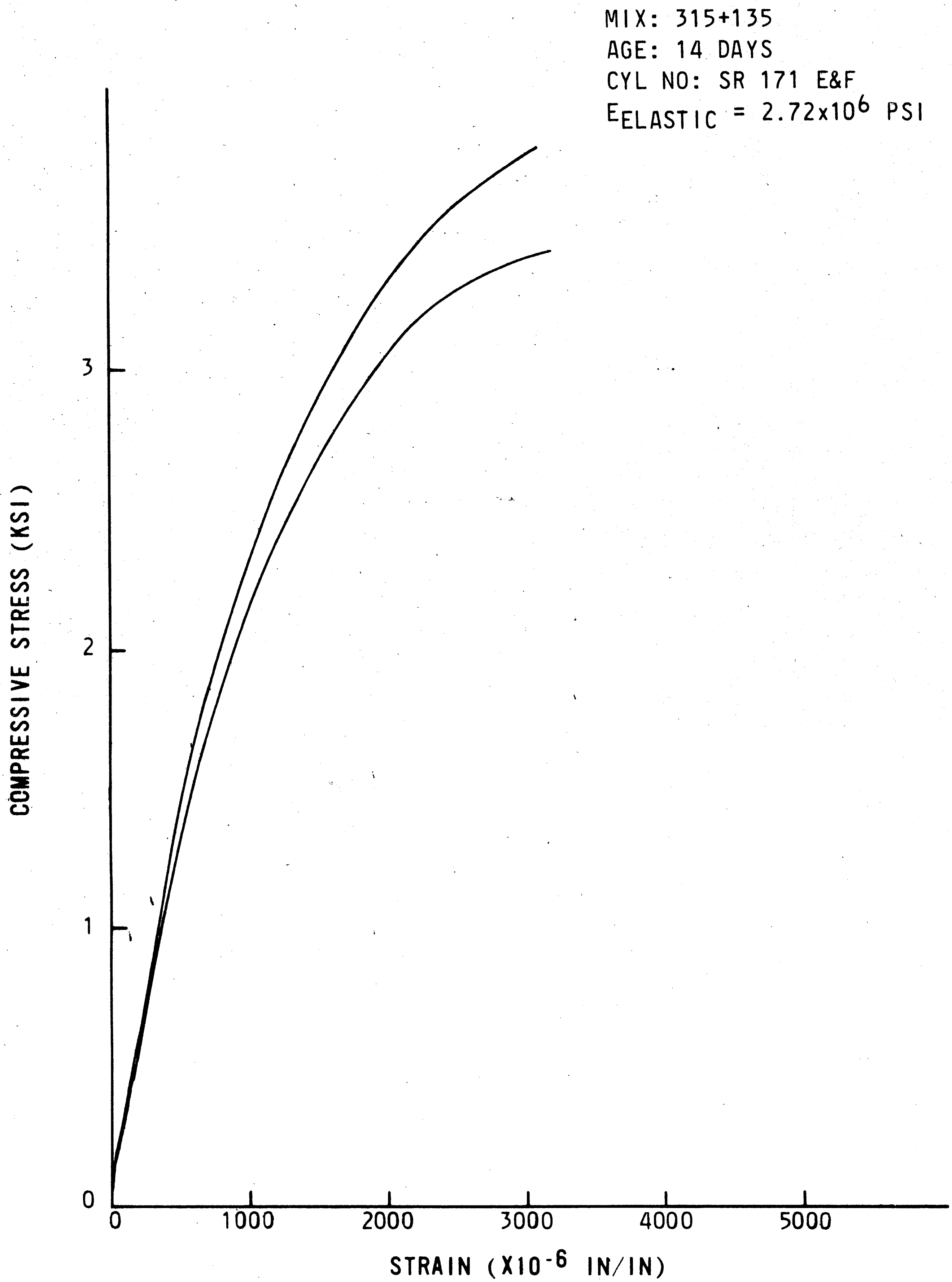


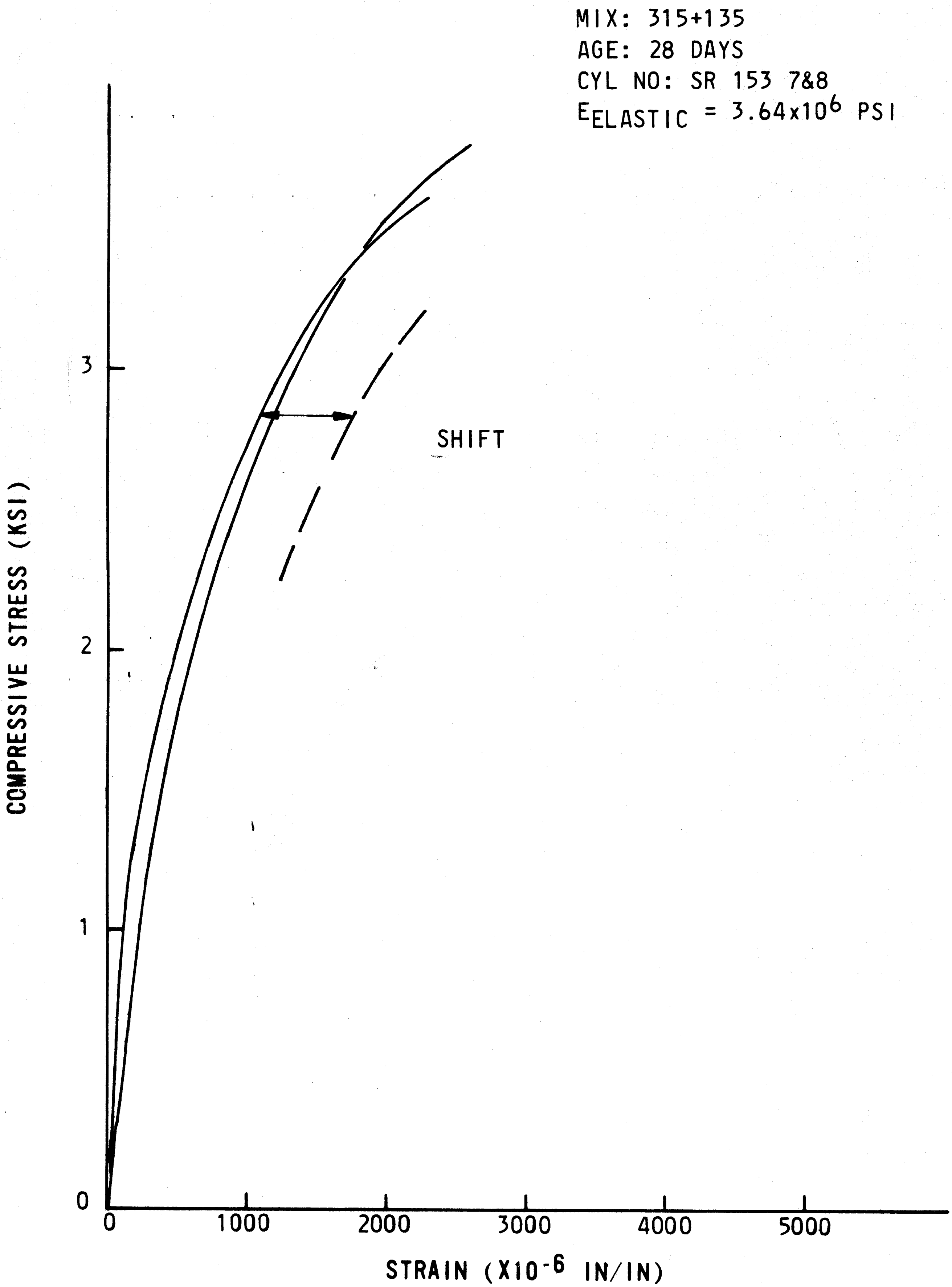
EXHIBIT 13.1
Sheet 36 of 42


MIX: 315+135
AGE: 7 DAYS
CYL NO: SR 191 3&4
E ELASTIC = 2.5x10^6 PSI
COMPRESSIVE STRESS (KSI)
0
1
2
3
0
1000
2000
3000
4000
5000
STRAIN (X10^-6 IN/IN)

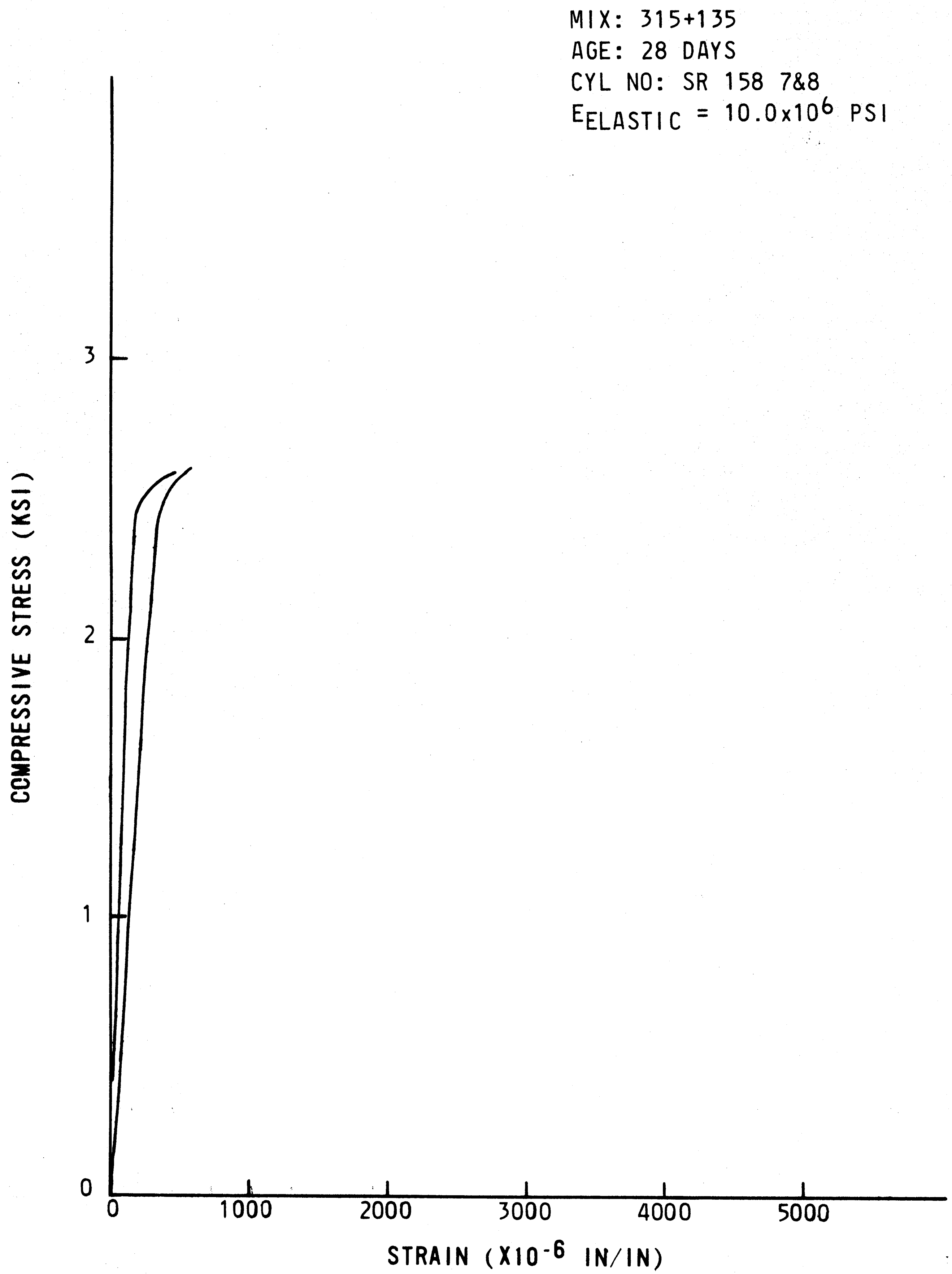

MIX: 315+135
AGE: 14 DAYS
CYL NO: SR 171 E&F
$E_{ELASTIC} = 2.2x10^6$ PSI
COMPRESSIVE STRESS (KSI)
0
1
2
3
0
1000
2000
3000
4000
5000
STRAIN (X10^{-6} IN/IN)

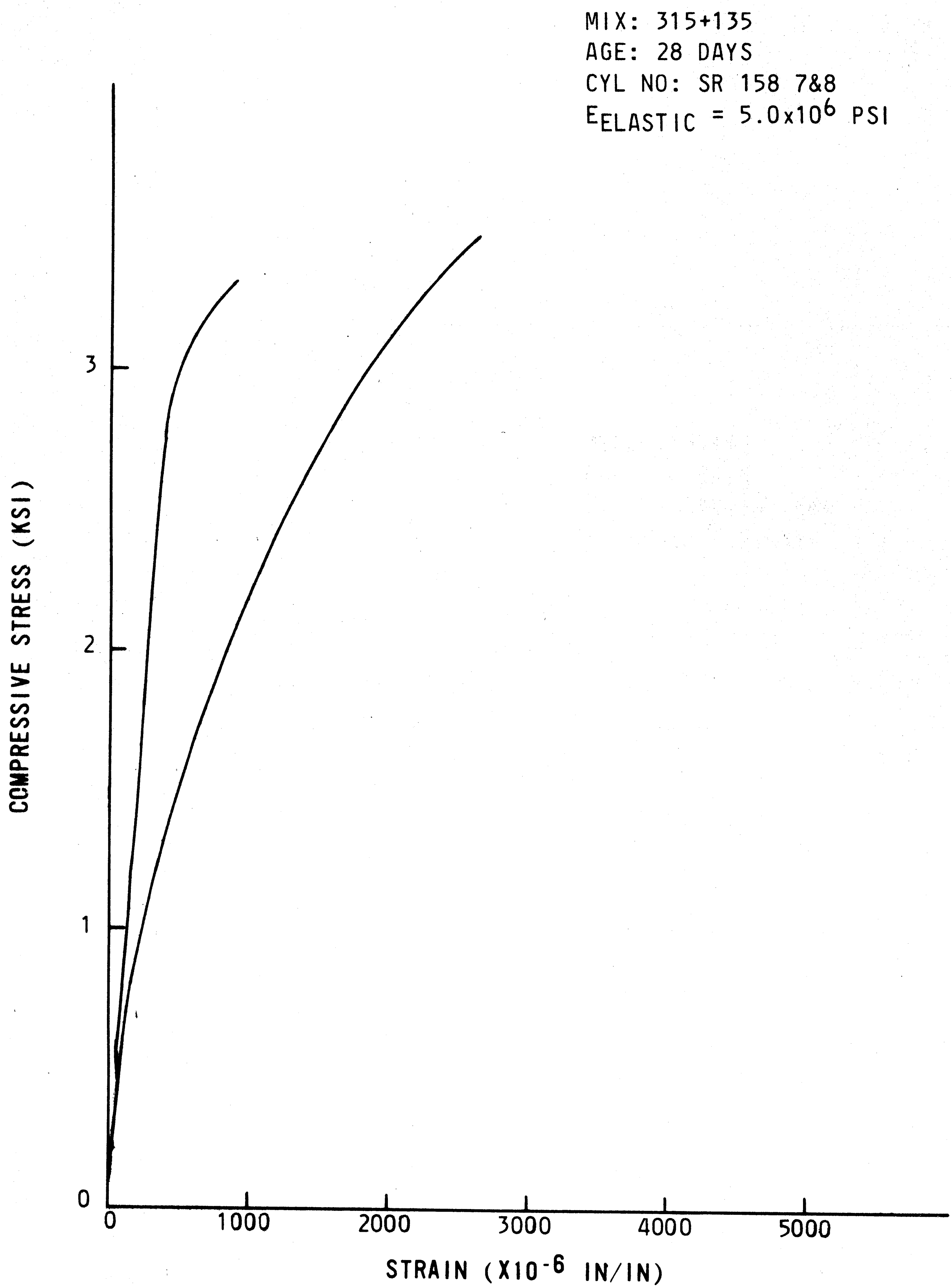


MIX: 315+135
AGE: 14 DAYS
CYL NO: SR 171 E&F
$E_{ELASTIC} = 2.72 x 10^6$ PSI
COMPRESSIVE STRESS (KSI)
0
1
2
3
0
1000
2000
3000
4000
5000
STRAIN ($X10^{-6}$ IN/IN)



MIX: 315+135
AGE: 28 DAYS
CYL NO: SR 153 7&8
$E_{ELASTIC} = 3.64 \times 10^6$ PSI
SHIFT
COMPRESSIVE STRESS (KSI)
0
1
2
3
0
1000
2000
3000
4000
5000
STRAIN ($\times 10^{-6}$ IN/IN)


MIX: 315+135
AGE: 28 DAYS
CYL NO: SR 158 7&8
$E_{ELASTIC} = 10.0 \times 10^6$ PSI
COMPRESSIVE STRESS (KSI)
0
1
2
3
0
1000
2000
3000
4000
5000
STRAIN ($X10^{-6}$ IN/IN)


MIX: 315+135
AGE: 28 DAYS
CYL NO: SR 158 7&8
$E_{ELASTIC} = 5.0x10^6$ PSI
COMPRESSIVE STRESS (KSI)
0
1
2
3
0
1000
2000
3000
4000
5000
STRAIN ($X10^{-6}$ IN/IN)

CHAPTER 14

DIRECT TENSION TESTS

A group of 10 blocks from both the spillway mix (1-1/2-inch aggregate, 315 pounds of cement per cubic yard and 135 pounds of fly ash per cubic yard), and the downstream face mix (3-inch aggregate, 175 pounds of cement per cubic yard and 80 pounds of fly ash per cubic yard) were cut from the dam and tested in direct tension. Plate 14.1 shows removal of the blocks. They were approximately 1 cubic foot in size and went through the full lift thickness. The samples were sawn and removed early on a Monday morning from material placed on Saturday night, about 36 hours earlier. The temperature of the concrete during this time varied with ambient conditions that ranged from 58 to 75 degrees F. The samples were moved to the standard moist cure room where they remained until testing and preparation for testing.

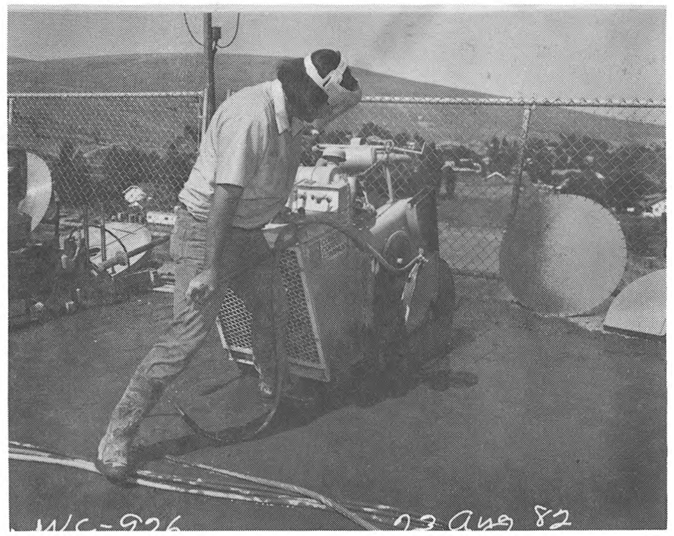
Because the samples were taken near the unconfined downstream face, it was expected that they may not have achieved the same degree of compaction as the mix did in the interior. It was readily apparent from the saw-cut faces that the mix received the same or very nearly the same compaction as the interior mix. Apparently only about the outside foot or less of material was not fully compacted. These samples were about 2 feet in from the edge.

Coring of RCC at an early age has resulted in very poor quality samples severely damaged by the coring operation. However, the saw-cutting operation with careful handling resulted in little or no damage. All 20 of the 20 samples cut were successfully retrieved. Asphalt impregnated roofing paper was used as a bond breaker between the RCC layer being cut and the lift below. Even with this precaution, the blocks had to be carefully wedged, pried, and pulled with a strap to remove them. In all samples, the lower portion of the mix was compacted into the roofing paper. Close examination indicated a tight mechanical contact conforming to the shape of the top of the lower lift surface. Surface area contact, although quite good, did not appear to be 100 percent over the interface.

The samples were tested in direct tension by epoxying heavy stiffened steel plates to opposite sawn faces and pulling these in the field laboratory testing machine. Gages were attached to the plates on opposite sides of the specimen during the test to measure elongation with increasing load. The results were averaged and used to compute both strain capacity and modulus of elasticity. The purpose of these tests was to obtain material property information on the actual construction mix as placed in the field and to use this information to determine when or if insulation was needed to prevent surface cracking from thermal shock during the cool fall nights. Each of the mixes was tested at ages of 2-1/2-, 4-, 6-, 10-, and 20-days age. Two companion tests were made of each mix at each test age.

Plate 14.2 shows the tensile strength of each mix as a function of age. Plate 14.3 shows the strain capacities as a function of age. Using the graphed line defined by the data (a statistical least square fit), tensile strain capacities at 1 week of 74 and 110 millionths are indicated for the 175+80 and 315+135 mixes, respectively. For comparative purposes, strain capacities previously determined by the Division laboratory on fast load beams at 1 week were 54 and 100 millionths, respectively. It should be noted that most of the scatter of data for strain is attributed to the fact that electronic strain gages were not available in the field, so "ten thousandth" dial gages with less accuracy were used.

Based on a composite analysis of data from this series of tests, it was concluded that the modulus of elasticity was fairly constant for the age of 3 to 10 days at a value of 1.00×10^6 psi for the 175+80 mix, and 1.15×10^6 psi for the 315+135 mix.



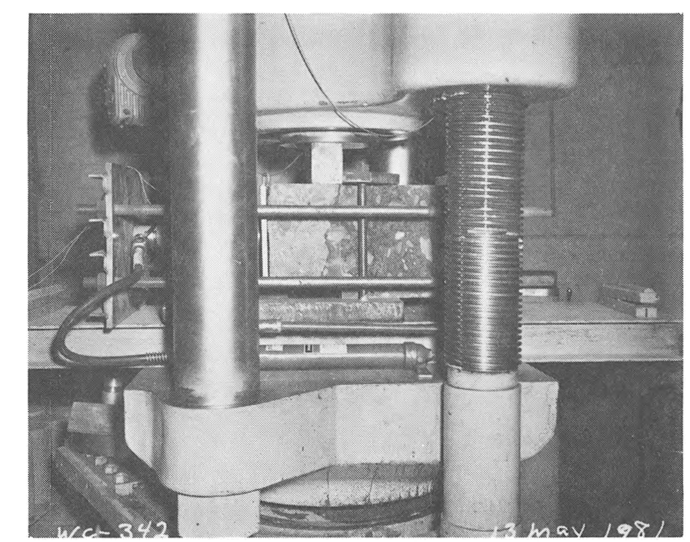
SAWING TEST BLOCK FROM THE DAM.

REMOVING TEST BLOCKS FROM THE DAM.

TEST BLOCK AT AN AGE OF 36 HOURS.

READING EMBEDDED RESISTANCE THERMOMETERS.

NUCLEAR DENSITY AND MOISTURE.



SHEAR TEST ALONG A JOINT UNDER CONFINING PRESSURE.

FIELD TESTING AND SHEAR TEST

DIRECT TENSION STRENGTH

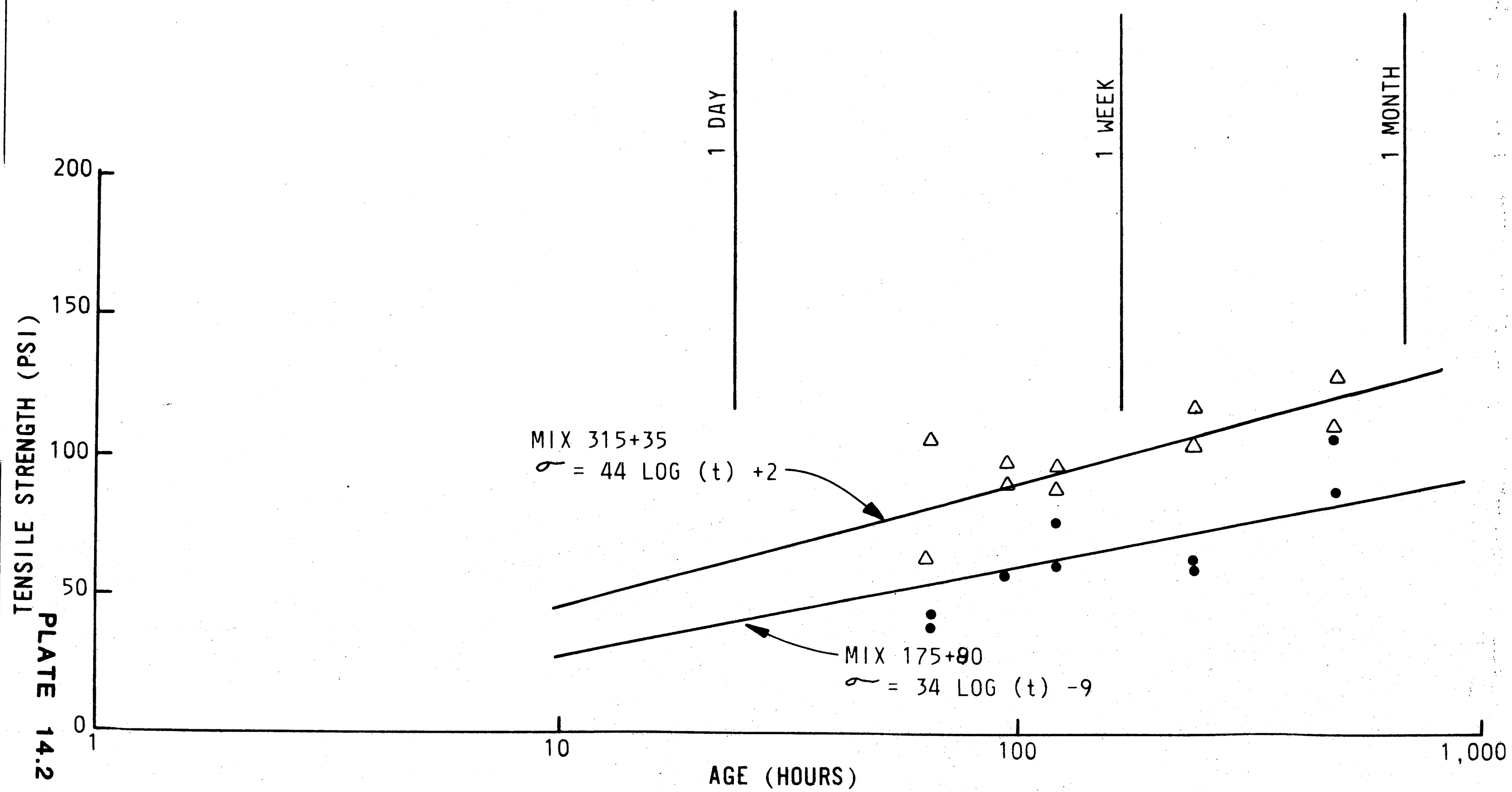


PLATE 14.2

DIRECT TENSION STRAIN CAPACITY

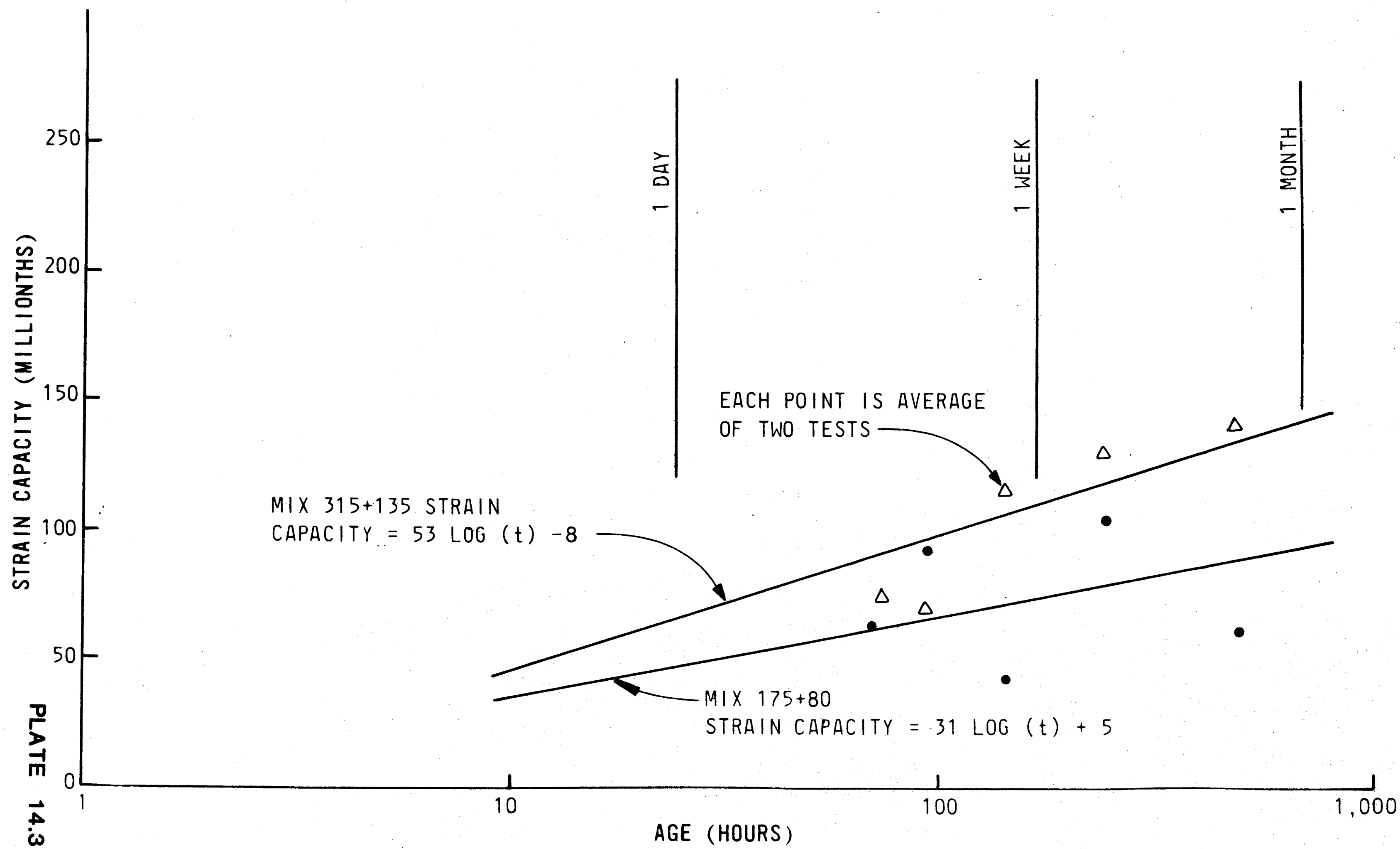


PLATE 14.3

CHAPTER 15

JOINTS AND SHEAR BETWEEN RCC LAYERS

As discussed in Chapter 18, "Temperatures and Thermal Behavior," and in the project design memorandum, monolith joints were not necessary at Willow Creek Dam. Detailed analysis showed that with the placing controls and at the production rates required by contract, the RCC mass mix had sufficient strain capacity and creep to accommodate long-term internal cooling with no vertical joints. Other projects could require monolith jointing or a form of controlled cracking. Procedures for doing this are available if needed.

An idea of the typical condition across layer-to-layer RCC joints can be developed from inspecting cores obtained to date. Plates 8.1 through 8.5 show typical photographs of these cores and Chapter 8, "Cores," discusses them. A better feel of joint integrity can be developed from inspection of the saw cut across a series of about five consecutive layers made in the interior lean mix from the gallery. This is shown in the photograph on Plate 17.1. It is difficult or nearly impossible to easily identify the interface between the layers. A conclusive evaluation of joint integrity will be made from inspection, pressure tests, shear tests, and direct tension tests of the large diameter cores to be obtained out of the dam in the summer of 1983 as discussed in Chapter 24, "Future Evaluations and Testing."

Substantial study was done concerning the interface between successive layers of RCC and the resulting strength or resistance to sliding. Large blocks were sawn from the Corps test fill (constructed with full-size production equipment) and subjected to direct shear across the layer-to-layer contact. Various confining pressures were used corresponding to different loads that would actually occur in the structure. The test setup is shown in the photograph on Plate 14.1. The shear load was hydraulically applied by a loading block. The confining load was maintained at a constant level through independent hydraulics so that the behavior with continued sliding could be monitored and so that overriding of surface irregularities was permitted without increasing the confining pressure. The results shown on Plate 15.1 were very impressive. Cohesion (the unconfined bond strength) varied from about 100 to 180 psi, depending on the cement plus fly-ash content, but the "phi" angle (increasing resistance to sliding with increasing confining load) was essentially constant at about 60 to 65 degrees. By itself, the range in cohesion values indicates that there could be significant differences in the resistance to sliding for the various mixes but, because the actual energy required to slide the mass is a function of area under the curve, the total resistance to sliding is quite similar for each mix. It is worth noting that using standard structural analysis, a shear of only 30 psi and a 0-degree phi angle would have provided a statically stable structure at Willow Creek Dam.

This first set of tests was run at ages between 200 and 300 days. The samples were compacted with the 10-ton vibratory roller and there was about 3 hours time between placing of the lifts.

Based on observations of mix behavior, the apparent time of set, and the response to rolling, it was judgmentally determined that adequate joint integrity for Willow Creek Dam could be achieved if the surface of each layer was kept clean and damp and if it was covered with the succeeding layer before the surface reached a maturity of 1,600 degree F hours. This would easily provide the necessary resistance to sliding and was thought to also result in a reasonably watertight joint that might initially allow some seepage but that would effectively seal itself with time. The 1,600-degree-hour requirement was used in the contract and increased to 2,000 degree hours during construction. As discussed below, joint maturity is now better understood and allowable limits can be estimated with more confidence. Maturity was determined by recording the surface temperature with clock-type continuous graphical recorders placed on the surface, and cumulatively adding the temperatures at 1-hour intervals.

A series of followup tests was run during construction to help better define the factors affecting shear between successive RCC layers for this and for future projects. For these tests a series of slabs, two lifts thick, was made in the Division laboratory using different treatments, mixes, test ages, and delays between lift placement. Compaction was with a single drum walk-behind vibratory roller delivering approximately 130 pounds of dynamic force per inch of drum width rather than with the 10-ton production roller which delivers 400 to 500 pounds of dynamic force per inch of drum width. Large test blocks (approximately 1 square foot of shear surface area) were sawn from these test slabs and tested with the same procedure described earlier.

Results of the tests are shown in Plates 15.2 through 15.16. The graphed lines shown on the plates are based on a statistical least squares fit of the data points. Several conclusions can be positively made and others can be inferred from the results.

1. Shear strength along joints of RCC layers can be accurately predicted. It follows a predictable pattern of increasing resistance to sliding with increasing confining load.

2. The reduction in compactive effort from about 400 or 500 pounds per inch of drum width for the production roller to about 130 pounds per inch of drum width for the walk-behind roller reduces the phi angle from about 60 degrees to about 45 degrees.

3. Cohesion or unconfined bond strength is relatively unaffected by compactive effort within the range of normal vibratory rollers used in the construction industry regardless of whether they are the small walk-behind type or the large self-propelled type.

4. Increasing the cement plus fly-ash content increases cohesion (unconfined bond strength) but does not appreciably affect the phi angle. When fully analyzed, the overall benefit from increasing the cement content has little effect on total sliding stability. It probably benefits watertightness of the joints (cohesion) but the benefit should be carefully considered along with the offsetting undesired effects of higher internal temperature, faster hardening of the surface, and cost. It is suspected that increasing the fines content through aggregate gradation will also increase watertightness without the same undesirable effects.

5. Cohesion (unconfined bond strength) increases with age of the concrete. As with increasing cement content, cohesion increases with age but the overall total resistance to sliding when fully analyzed is not greatly increased.

6. Increasing age of the concrete does not appreciably affect the phi angle.

7. Assuming that the joint surface is kept continuously damp until it is covered with the next layer of RCC, shear strength and bond are essentially the same regardless of whether the layer is placed after the joint reaches a maturity of 1,200, 1,600, or 2,000 degree F hours. This condition was found to hold true for different mixes and test ages although there is an indication that after about 2,000 degree hours long-term total shear resistance may begin to be adversely affected. Based on the test results and observations during construction, there probably are three maturity conditions to be recognized.

(a) Less than about 400 degree hours: There will be a tight, well bonded, high strength joint. It may be difficult to locate the joint after sawing across it in a mature sample.

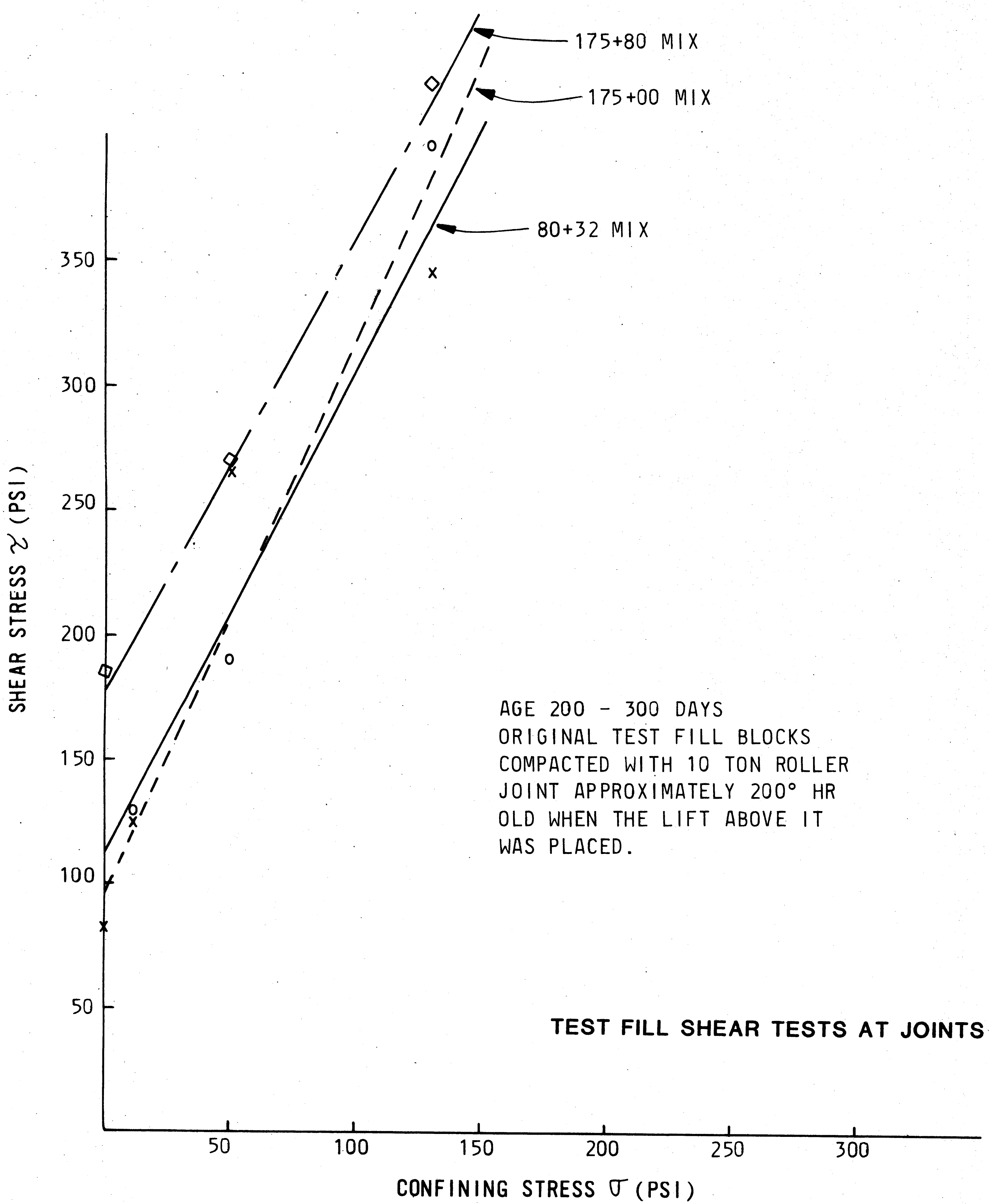
(b) About 400 degree hours to about 3,000 degree hours: There will be more than adequate shear strength across the joint and reasonable bond integrity in the mass but a definite weakened plane will occur at the interface. Depending on cement content and the amount of fines in the aggregate, the joint may be susceptible to some seepage. If carefully cored or sawn after the concrete has matured, the joint location will be fairly obvious but normally hold together under its own weight. If jarred or struck with a hammer in an unconfined condition, it probably will separate at the joint. Within the 400 to 3,000 degree hour range, the quality of joint probably begins to decrease at about 2,000 degree hours.

(c) In excess of about 3,000 degree hours: A cold joint condition exists. Resistance to sliding will be adequate but the joint probably will not be watertight. If cored or saw cut, the joint will be apparent and separate relatively easily.

8. The idea that the RCC surface <u>must</u> be kept continually damp until placing the next lift may be in error. In fact, the adverse effects that can result from overwatering, tracking mud, etc., during construction as discussed in Chapter 6, "Transporting and Spreading RCC," may outweigh the benefits (if they actually occur). There is limited test data so the results should be used cautiously, but Plate 15.16 shows that RCC placed on a clean previous layer of RCC which was allowed to air dry over a 1,600 degree hour period had a higher bond strength (cohesion) than the companion sample that was kept damp. However, another sample that was allowed to air dry but also used an RCC "bedding" mix at the interface to the next layer fell apart before it could even be tested. This probably was the result of the bedding mix as discussed below.

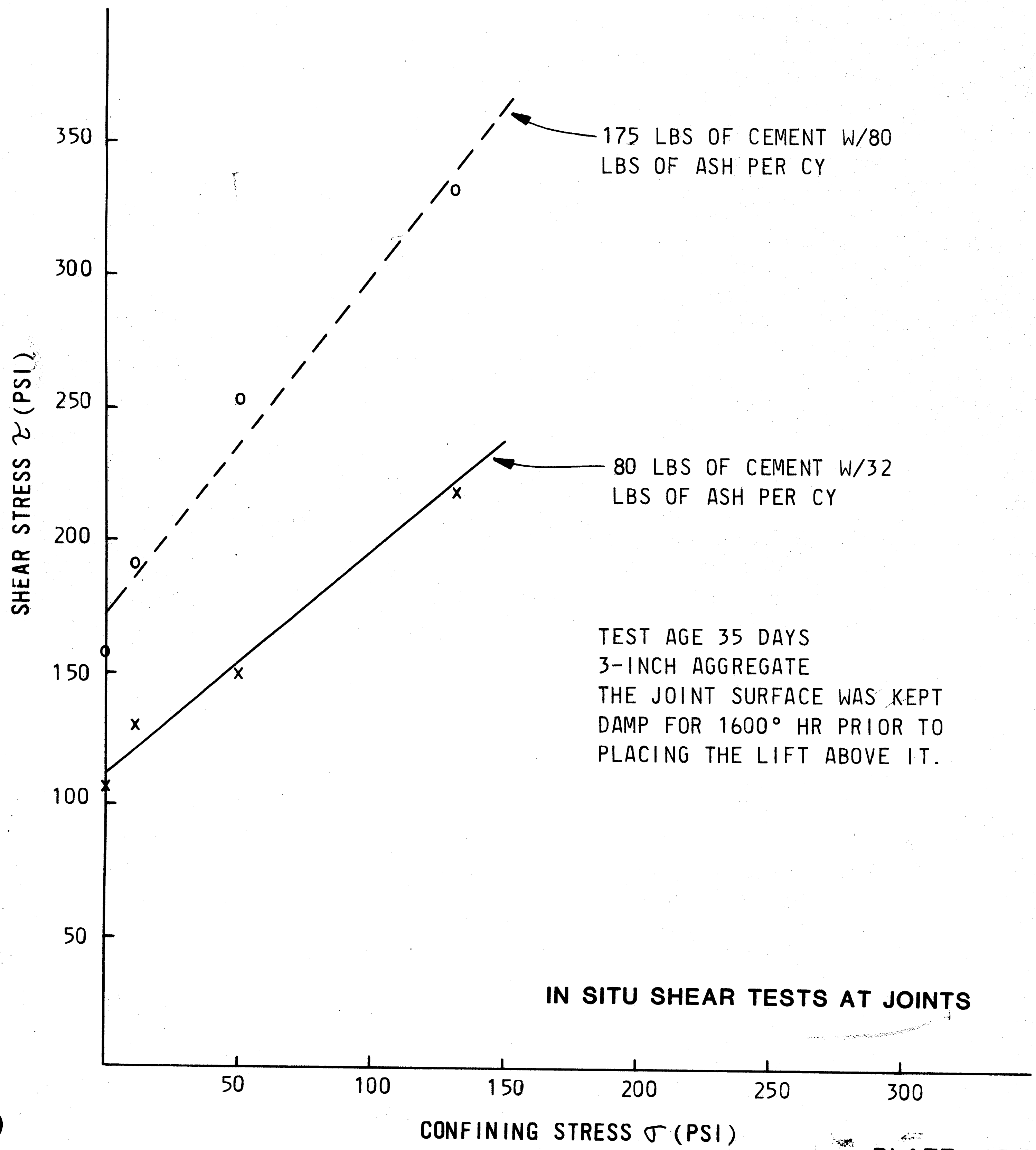
9. The RCC bedding mix (high cement factor RCC mix with 3/4-inch aggregate) is expensive; difficult to mix, spread, and work with in the field; and it probably does more harm than good. In the laboratory it can be carefully applied to the lift surface and tested, but even there it showed no significant improvement in the best test (Plate 15.15). In another test (which also allowed the surface to air dry) the sample fell apart at the joint (Plate 15.16). The bedding is discussed further in Chapter 17, "Bedding Mix, Gallery, and Reinforcing Steel."

A series of triaxial shear tests has been run on the limited number of 6-inch cores obtained earlier from the dam. These cores crossed the layer-to-layer joint interface at an angle of about 25 degrees to the core axis. The tests were run at confining loads equivalent to 0 and 55 feet of dead load concrete mass, and at an internal pore pressure representing full hydrostatic uplift of 55 feet of water for the confining load of 55 feet of concrete mass. Testing was done in a stabilized condition of saturation. The resulting shear resistance was extraordinary. At no confining load the average shear resistance was 660 psi. At the confining load of 55 feet of concrete with 55 feet of hydrostatic uplift, the shear resistance averaged 766 psi with values as high as 1,415 psi.



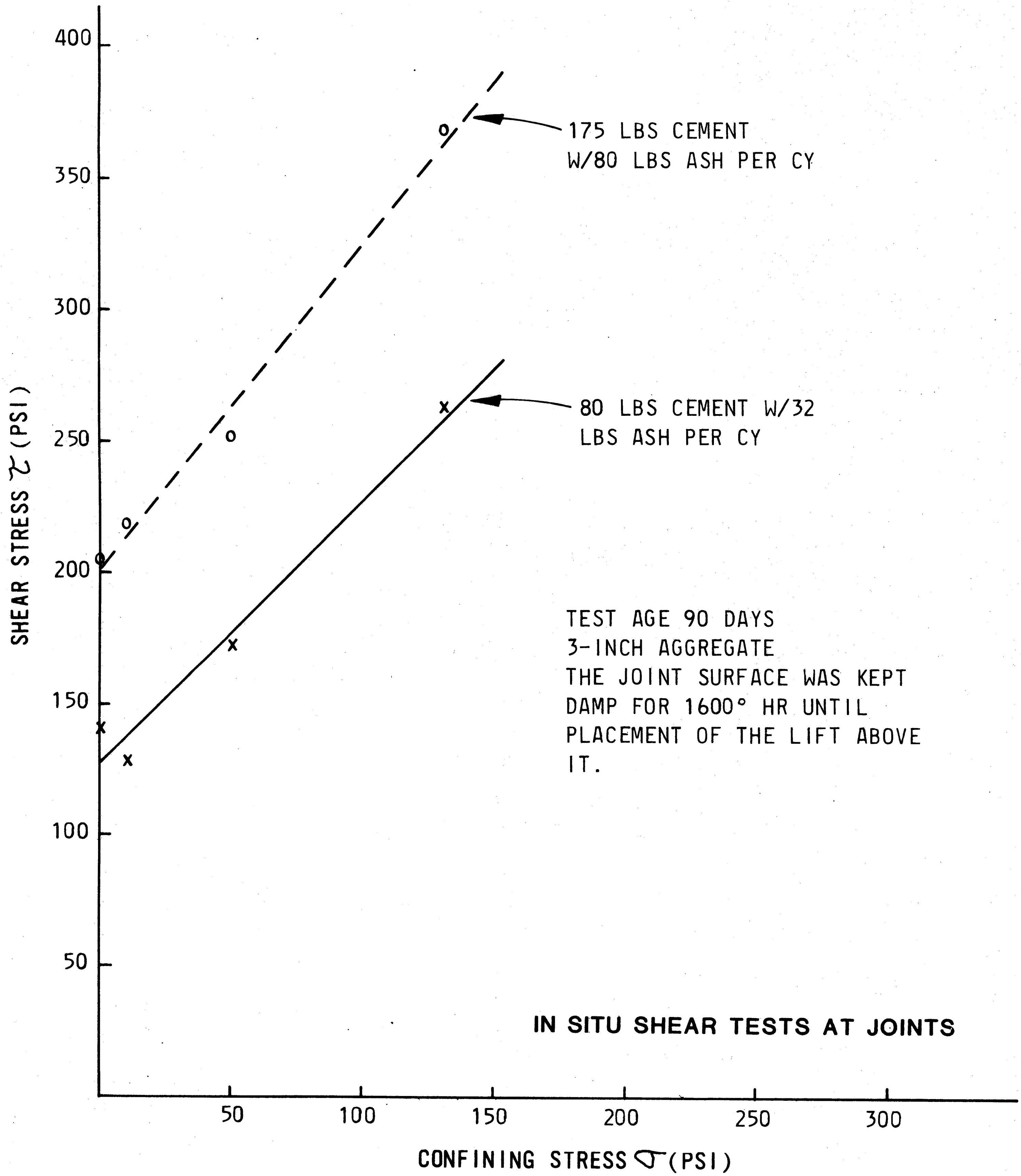
TEST FILL SHEAR TESTS AT JOINTS

PLATE 15.1



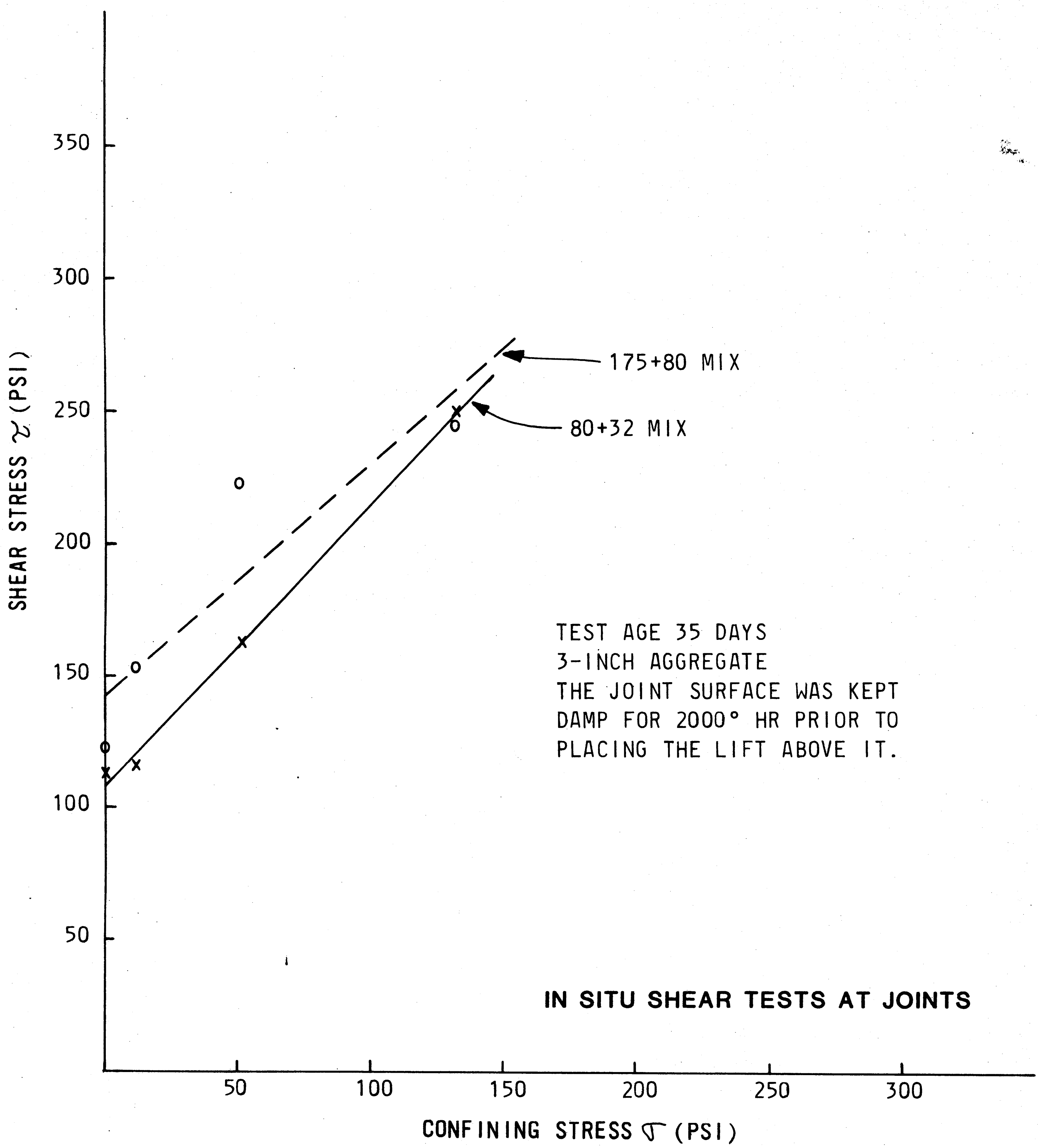
IN SITU SHEAR TESTS AT JOINTS

PLATE 15.2



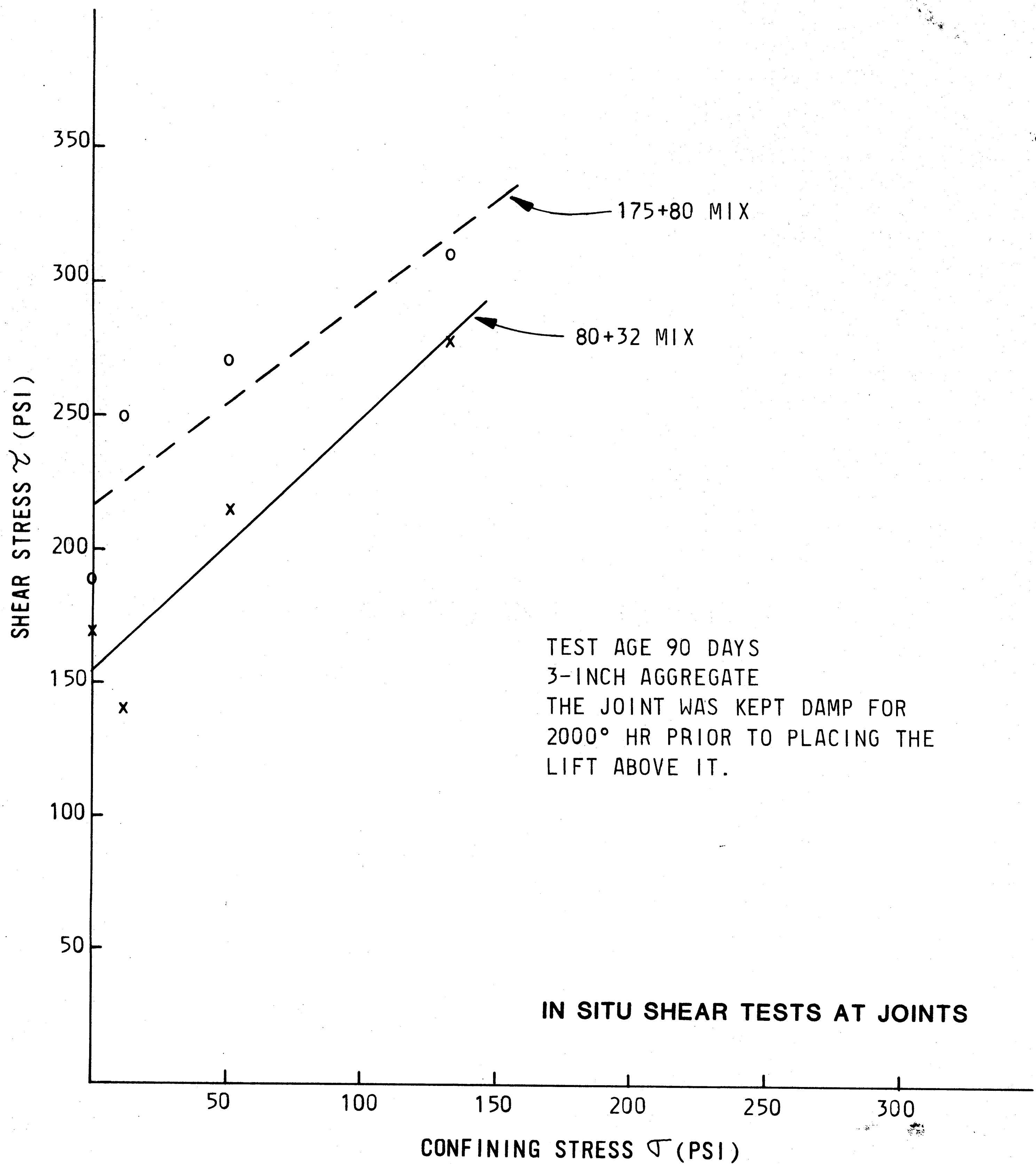
IN SITU SHEAR TESTS AT JOINTS

PLATE 15.3



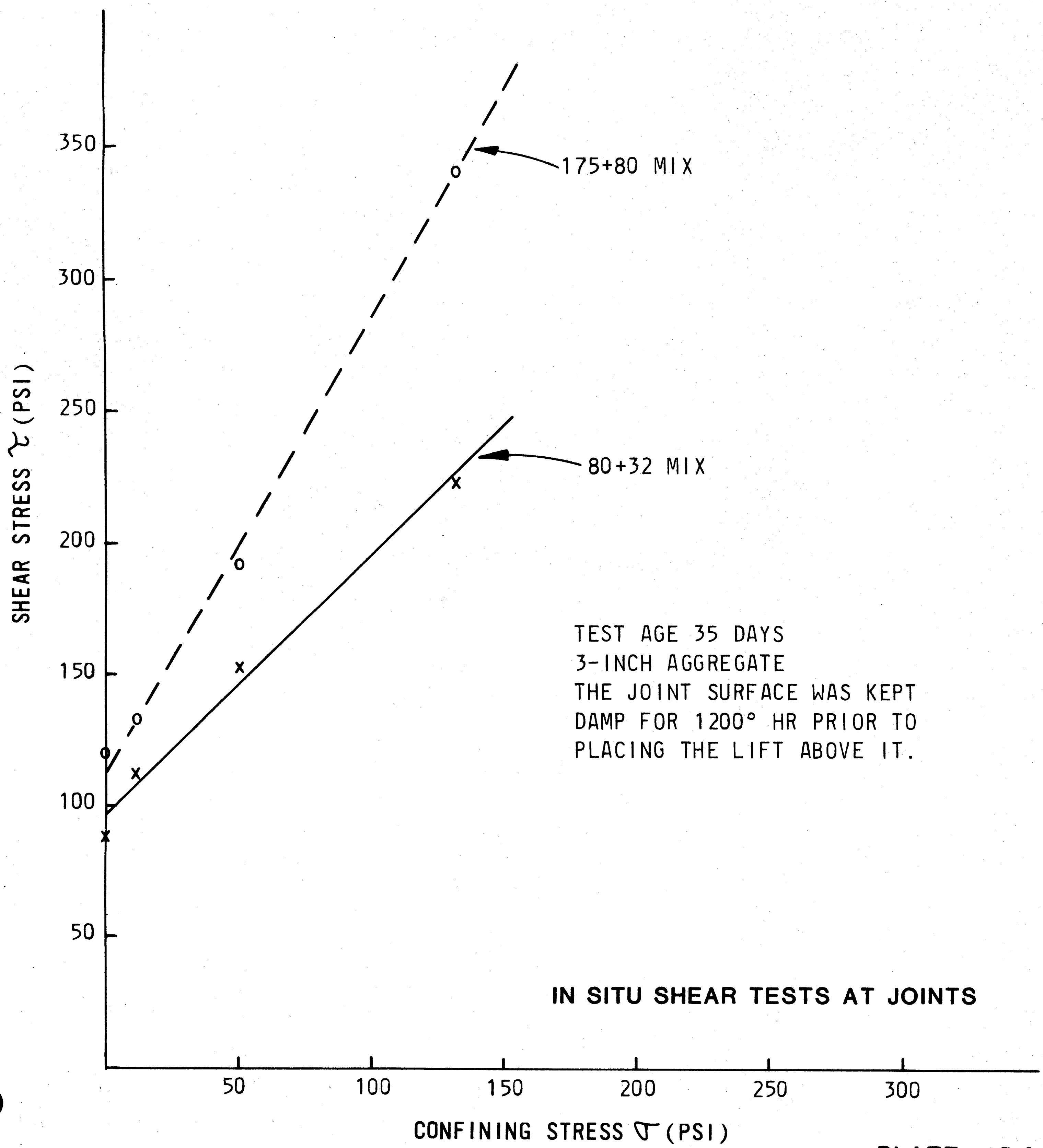
IN SITU SHEAR TESTS AT JOINTS

PLATE 15.4



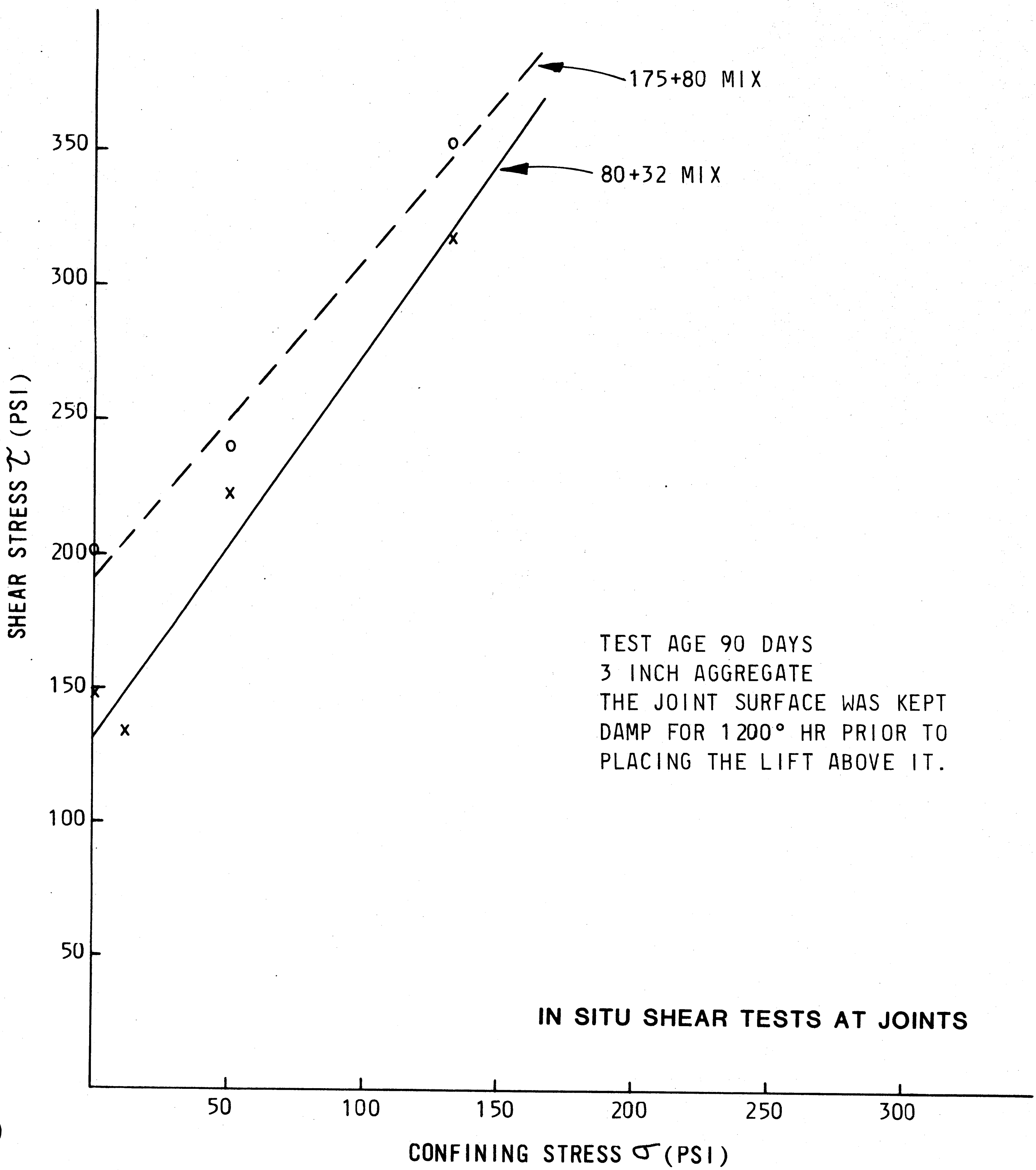
IN SITU SHEAR TESTS AT JOINTS

PLATE 15.5



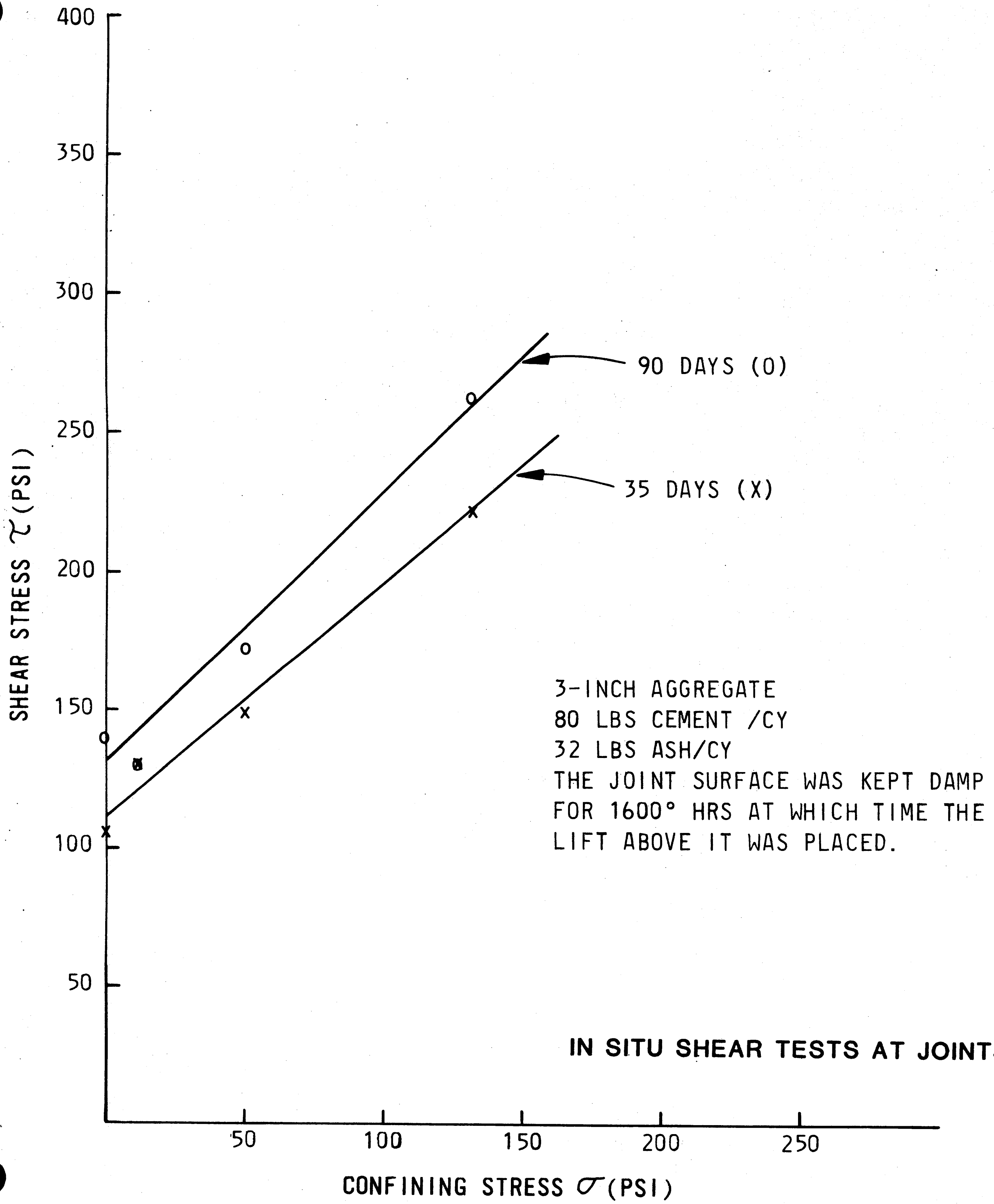
SHEAR STRESS τ (PSI)
350
300
250
200
150
100
50
175+80 MIX
80+32 MIX
TEST AGE 35 DAYS
3-INCH AGGREGATE
THE JOINT SURFACE WAS KEPT
DAMP FOR 1200° HR PRIOR TO
PLACING THE LIFT ABOVE IT.
IN SITU SHEAR TESTS AT JOINTS
50
100
150
200
250
300
CONFINING STRESS σ (PSI)

PLATE 15.6



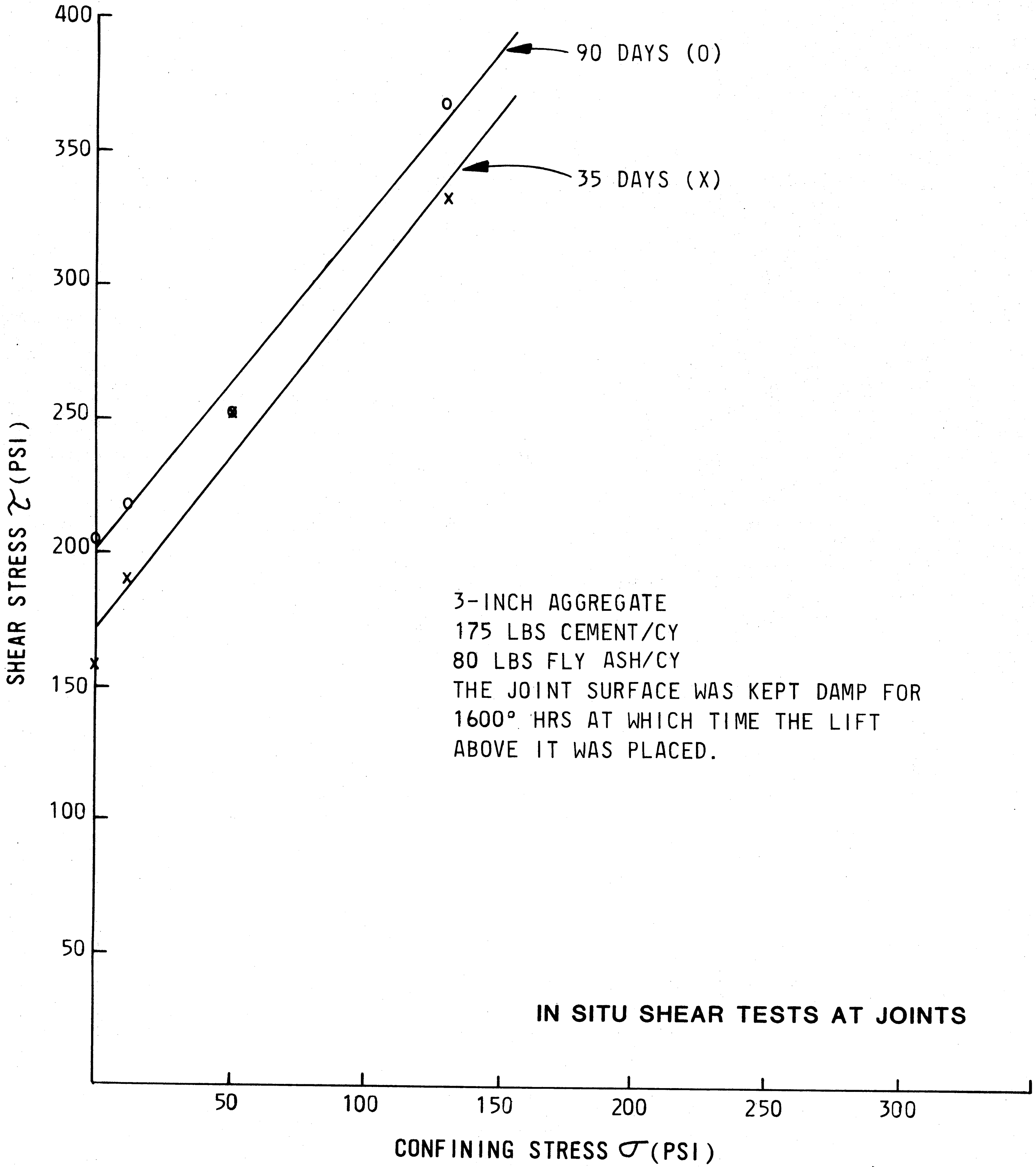
IN SITU SHEAR TESTS AT JOINTS

PLATE 15.7



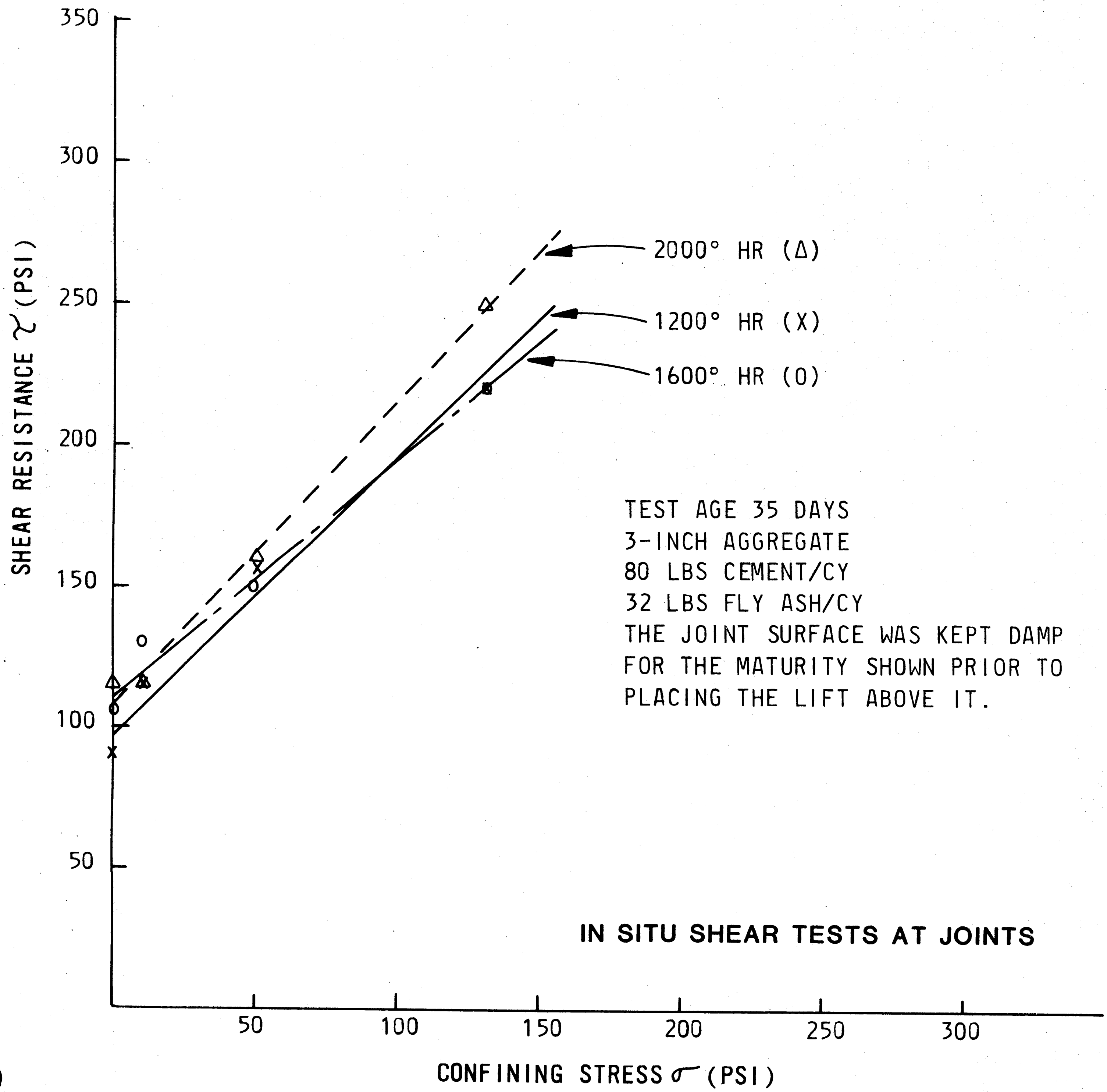
IN SITU SHEAR TESTS AT JOINTS

PLATE 15.8



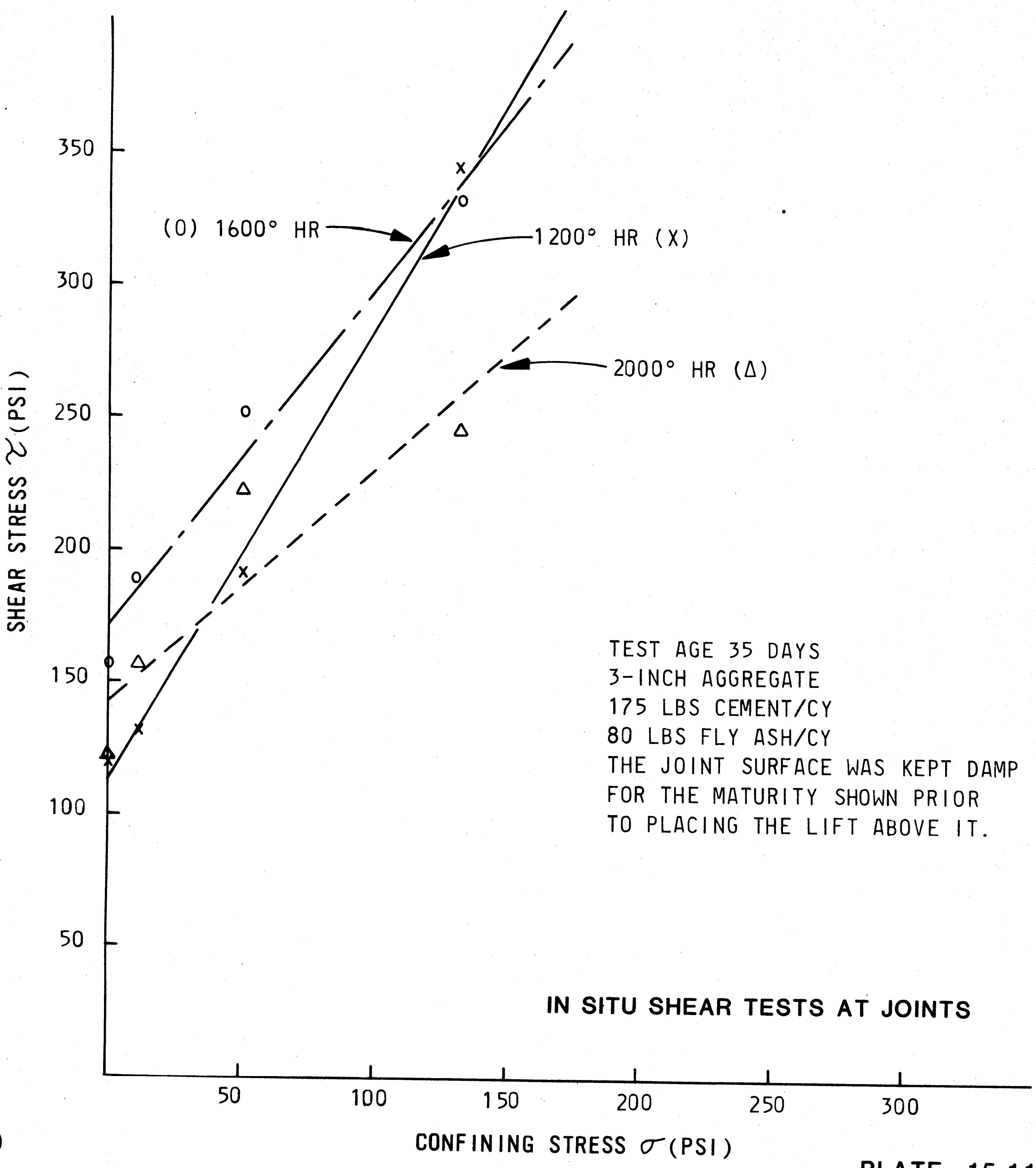
IN SITU SHEAR TESTS AT JOINTS

PLATE 15.9



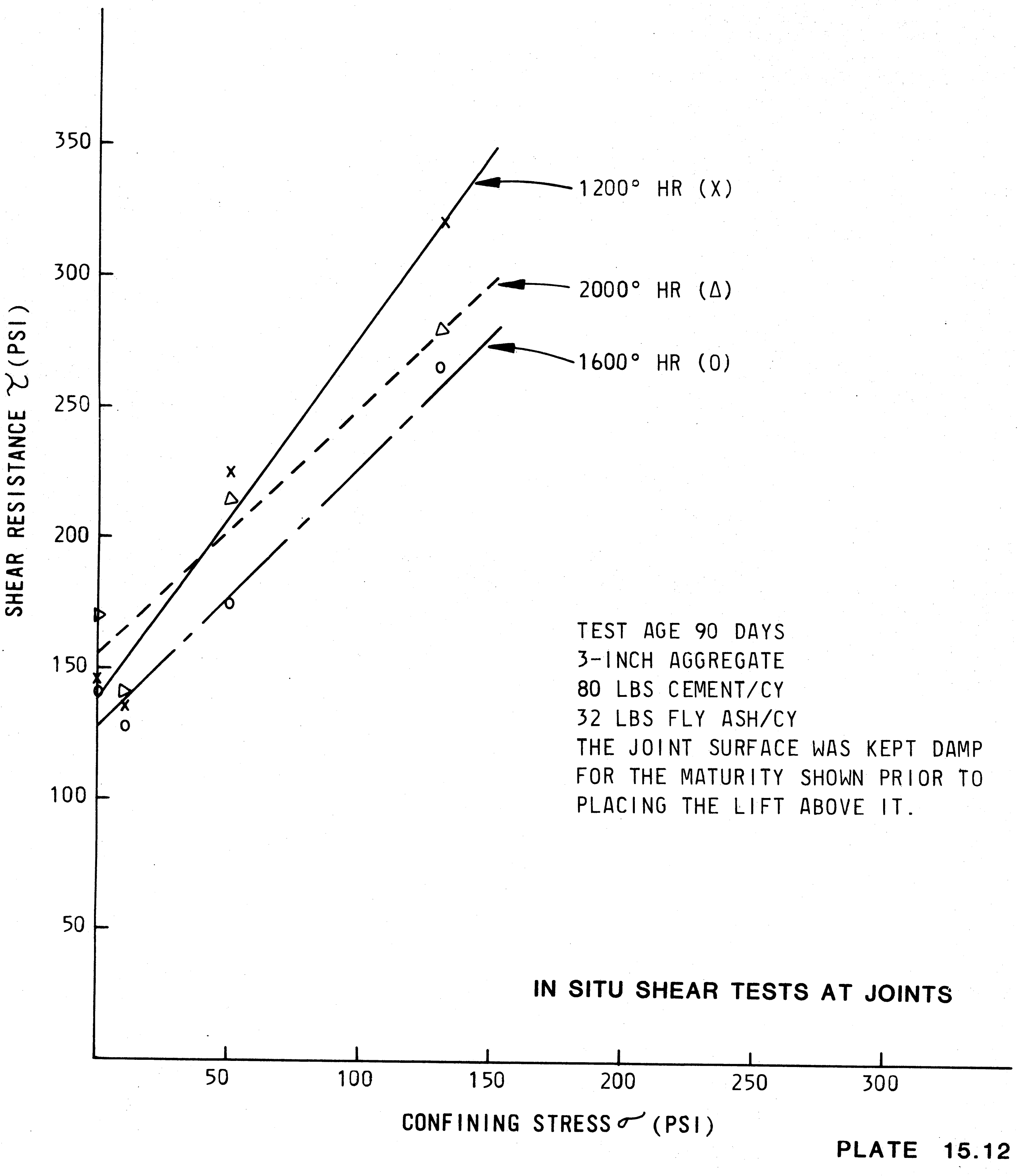
IN SITU SHEAR TESTS AT JOINTS

PLATE 15.10



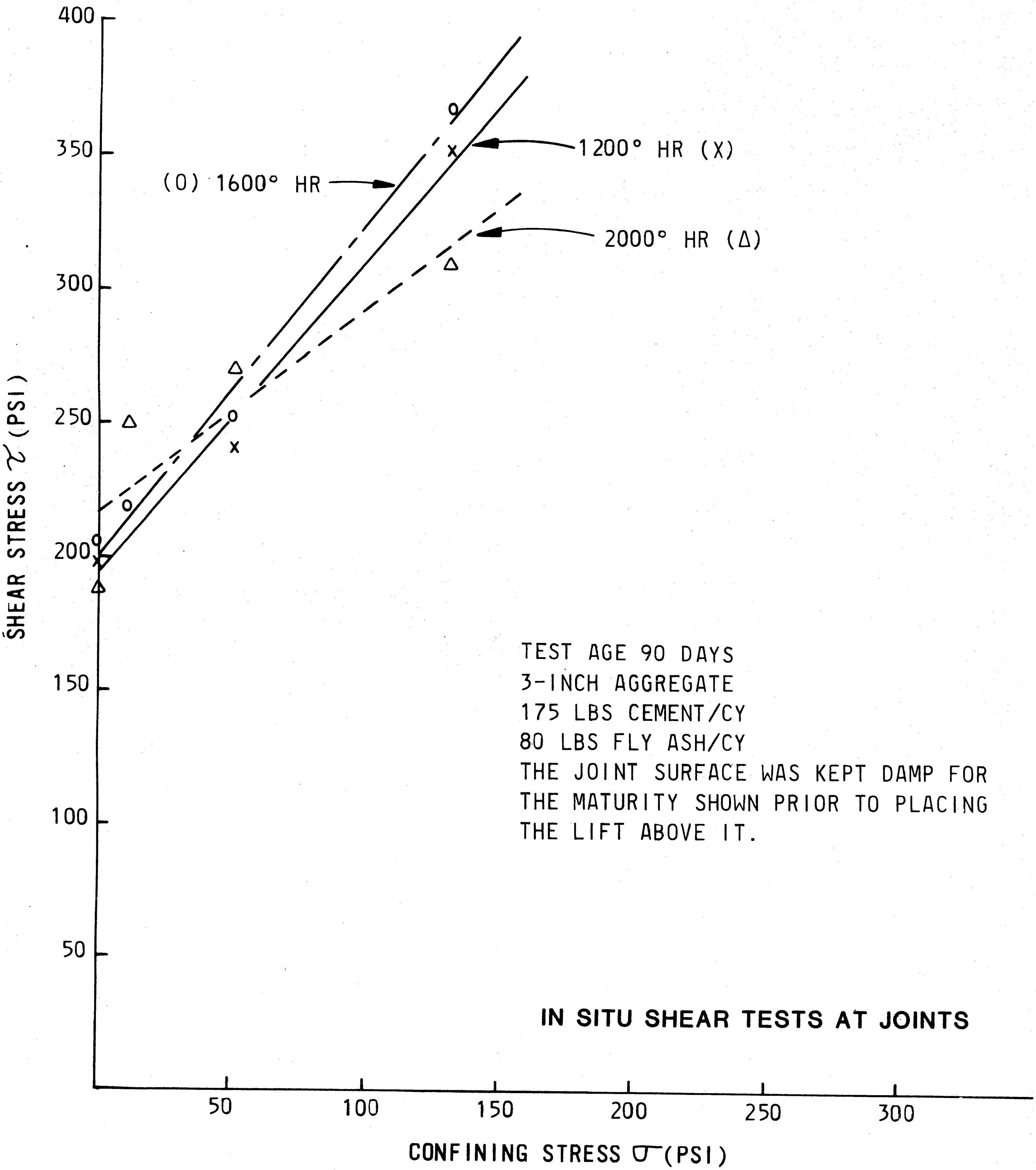
IN SITU SHEAR TESTS AT JOINTS

PLATE 15.11



IN SITU SHEAR TESTS AT JOINTS

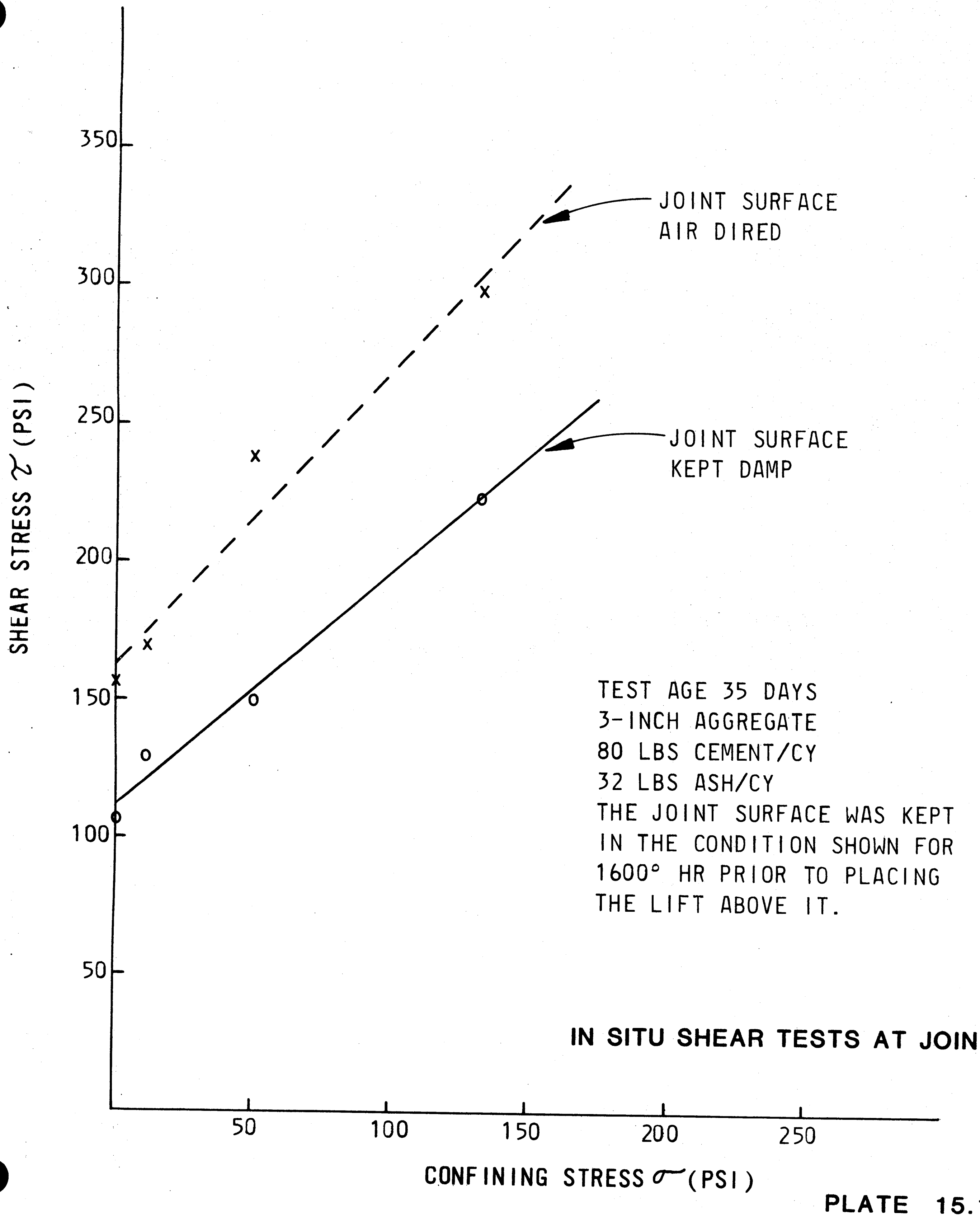
PLATE 15.12



TEST AGE 90 DAYS
3-INCH AGGREGATE
175 LBS CEMENT/CY
80 LBS FLY ASH/CY
THE JOINT SURFACE WAS KEPT DAMP FOR THE MATURITY SHOWN PRIOR TO PLACING THE LIFT ABOVE IT.

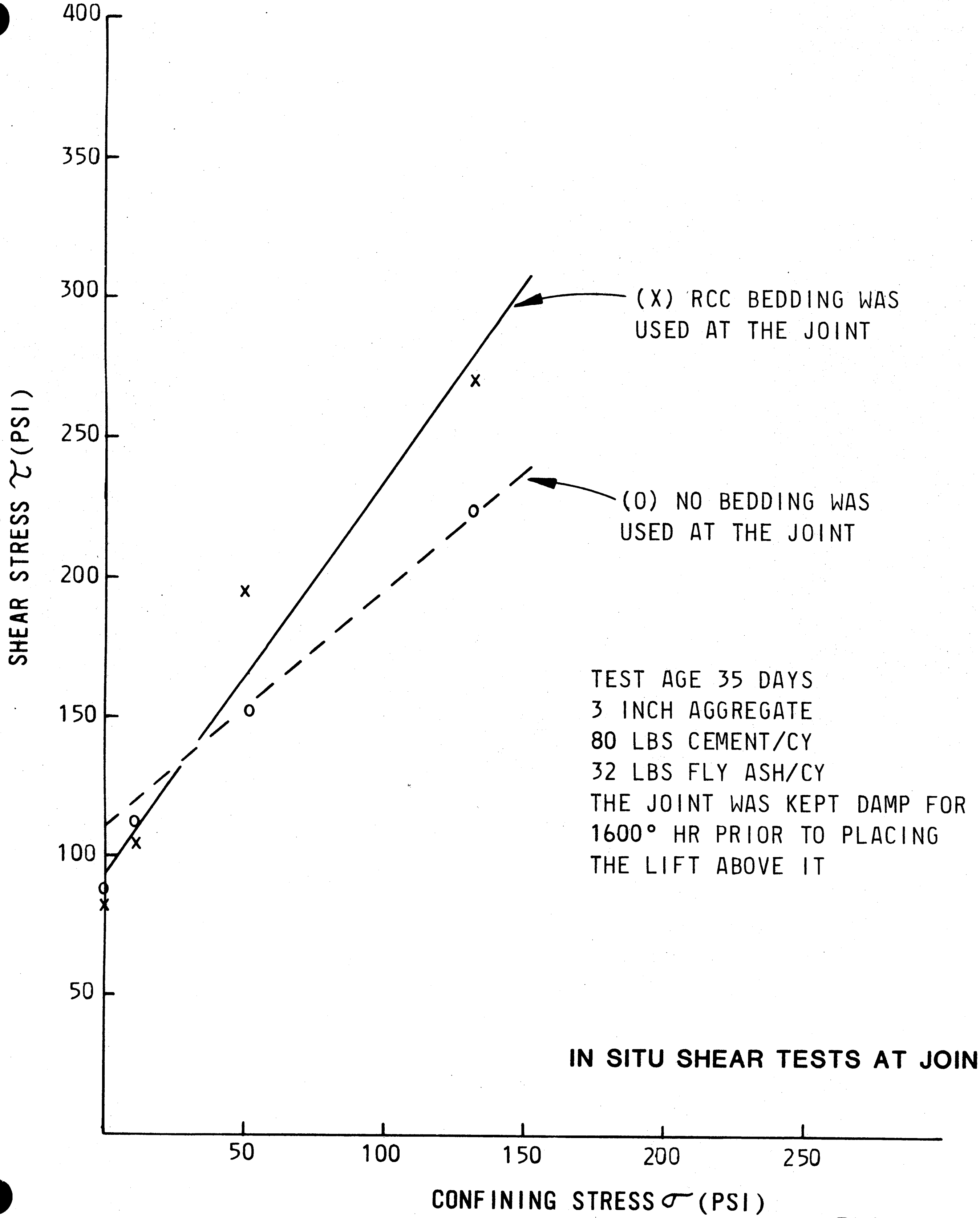
IN SITU SHEAR TESTS AT JOINTS

PLATE 15.13



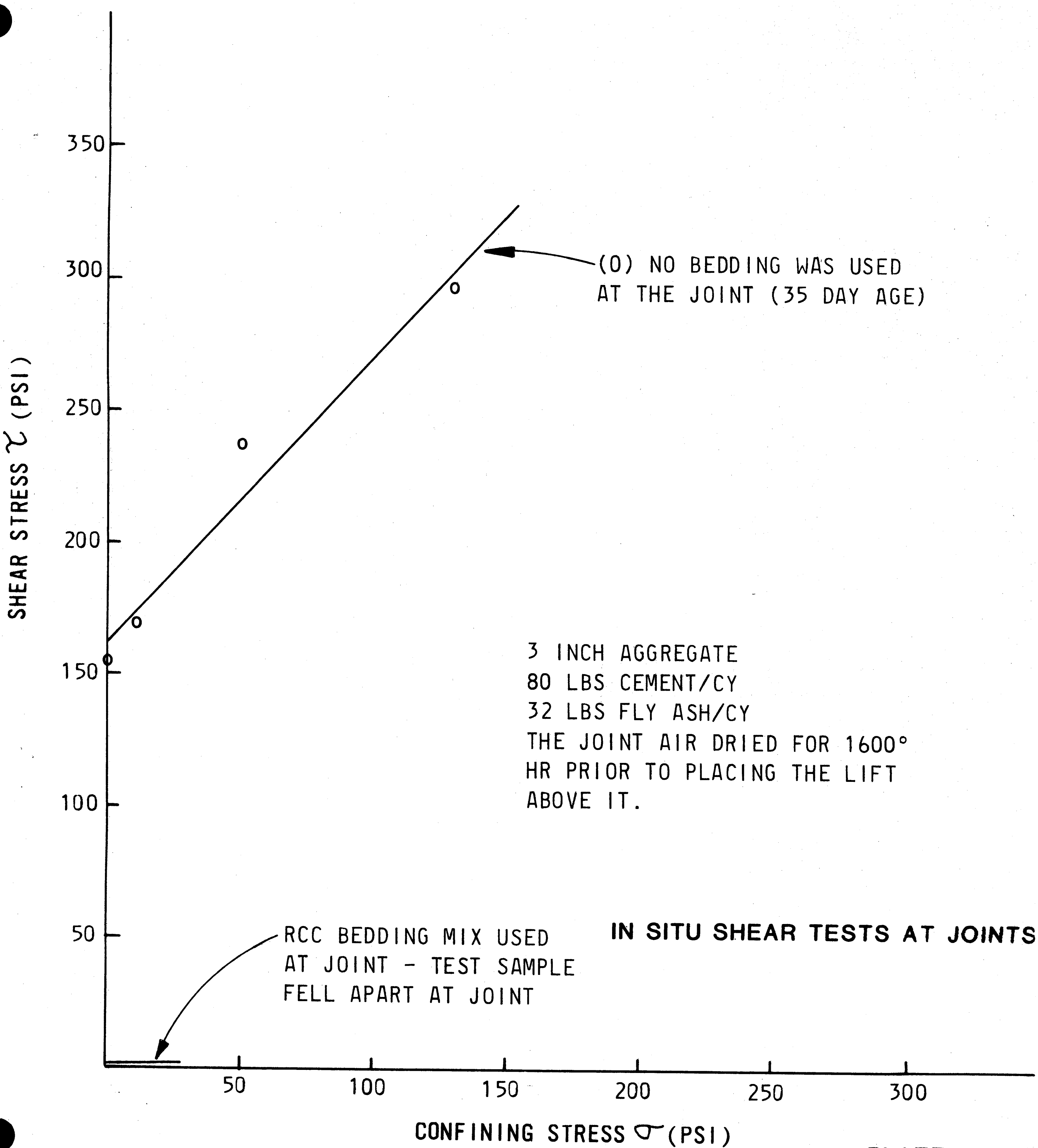
IN SITU SHEAR TESTS AT JOINTS

PLATE 15.14



IN SITU SHEAR TESTS AT JOINTS

PLATE 15.15



IN SITU SHEAR TESTS AT JOINTS

PLATE 15.16

CHAPTER 16

RCC TO FOUNDATION ROCK CONTACT

The geology of the foundation and its discussion will be contained in a separate project foundation report. The interface between the rock and concrete is discussed here. For general information, rock contours of the foundation contact area are shown on Plate 16.1.

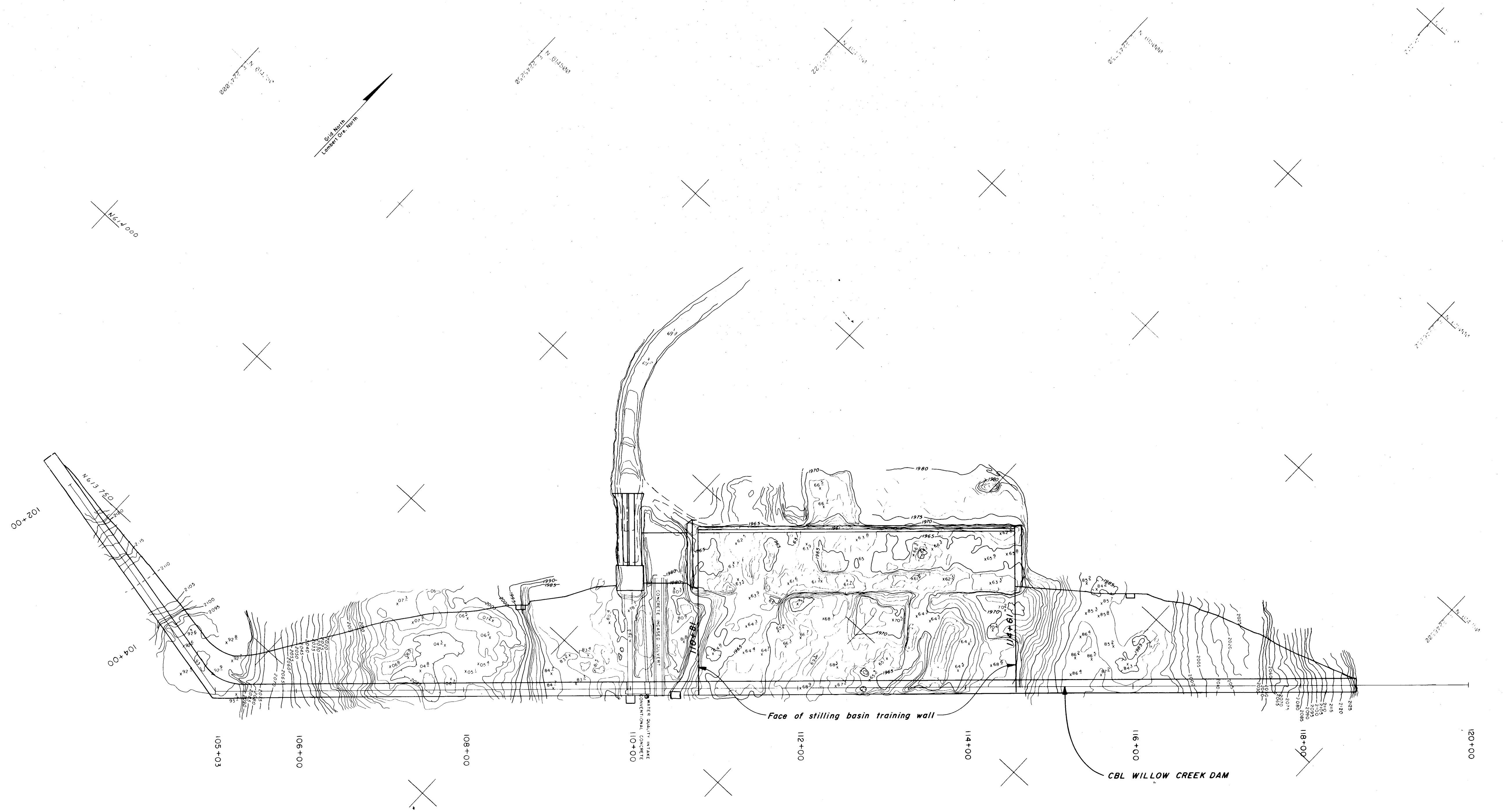
Cleanup operations used were typical for any concrete gravity dam although an effort was made to recognize that "clean" did not mean perfect. There was no technical reason to obtain a better interface between the rock and RCC than between RCC layers above it. Most cleaning was done with water washing and a large vacuum capable of picking up water, sand, debris, and rock up to about 3-inch size. Deep holes in the foundation were filled with enough lean mix 2,500-psi dental concrete to level the area so that RCC could be hauled into the area, dumped, and spread.

A special conventional concrete bedding mix was spread over the foundation rock just prior to placing the RCC. The mix had a high slump (about 5 to 7 inches), high sand content (about 48 percent), and 3/4-inch maximum size aggregate. The strength requirement was for 2,000 psi in 90 days.

The bedding was spread as thin as could be done while still covering all rock areas - generally about a 1-inch average thickness but with variations from about 1/4-inch to several inches. RCC was dumped, spread, and compacted over the bedding before it began to set. Original requirements were to use the mix and place RCC on it within 45 minutes of batching when the temperature was above 85 degrees F, and within 1-1/2 hours of batching when it was cooler. This was quite restrictive and resulted both in wasted concrete and not always having the mix onsite when needed because of concern for scheduling. The problem was solved by including a high dosage of retarder which allowed a full load of bedding to be on standby at the site for up to 4 hours at 100 degrees F. Plate 16.2 shows foundation cleanup and application of the bedding.

A series of 6-inch-diameter cores has been taken through the RCC and into the foundation. In all cases there was excellent contact. Plates 8.2 and 8.5 show photographs of some of these cores. The foundation contact of these cores was tested in direct shear using varying confining pressures. The test procedure was similar to that described in Chapter 15, "Joints and Shear Between RCC Layers." The foundation portion of the core contained jointed pieces of basalt as they existed in situ. They were pieced together for the test if needed and end capped with soft gypsum so that the confining load could be applied. The shear force was applied through an oversized heavy steel collar that allowed the sample to deform and the surface to "override" while sliding or shearing. Plate 16.2 shows one of the samples prepared for test.

Results of the tests are shown in Plates 16.3 through 16.5. They include the three conditions that occurred during construction: (1) RCC to foundation rock with conventional bedding mix at the interface, (2) RCC to dental fill concrete, and (3) dental fill concrete to foundation rock. The bedding to rock bond tested out at about 250 psi. The phi angle (increase in resistance to sliding with increase in confining load) was an astounding 77 to 89 degrees depending on the test specimen. As bond was broken and the samples began to slide, the resistance to continued sliding increased with a resulting increase in the phi angle as shown.



NOTE:
Compiled from U.S.C.E. Stereo mapping (SH 83-9)
Composite of 1982 Flights.
C.I. = 1'

SCALE IN FEET
50 0 50 100

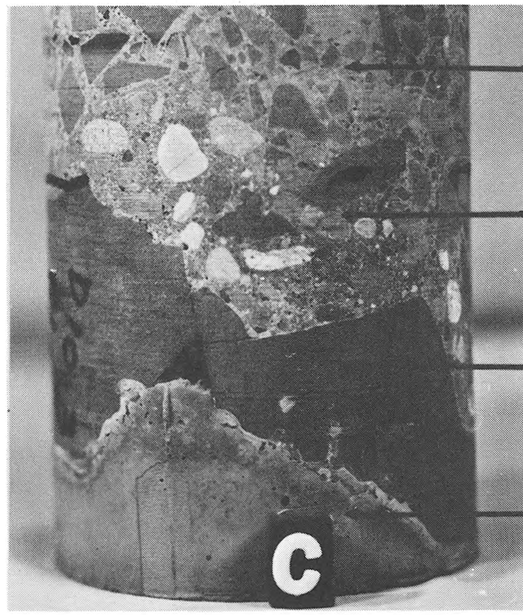
REVISION	DATE	DESCRIPTION	BY
A	83 APR. 15	Added Note	

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA, WASHINGTON

WILLOW CREEK LAKE
HEPPNER, OREGON
DRILLING, GROUTING AND CORE SAMPLING
ROCK - CONCRETE INTERFACE
TOP OF ROCK

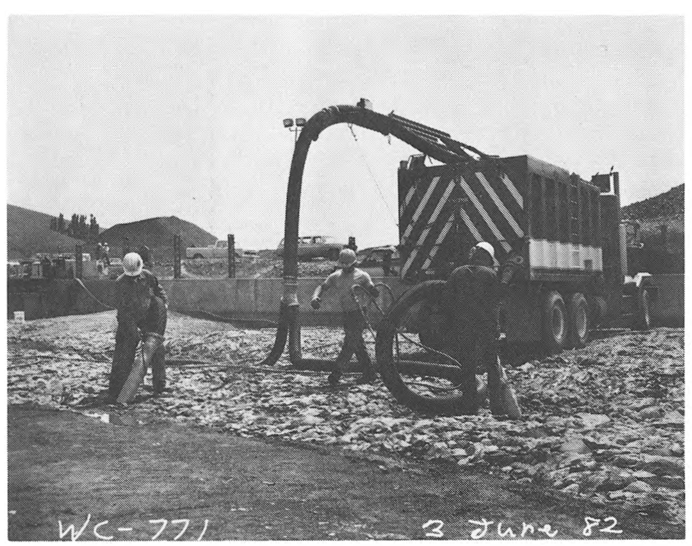
DESIGNED: F. Joscelyn
DRAWN: F. Spaulding
CHECKED: S. Tatro
SUPERVISED: CHIEF, GEO-EXPL. SEC.
SUBMITTED: CHIEF, FOUNDATIONS AND MATERIALS BRANCH

DATE 83 MAR 15
SCALE AS SHOWN
INV. NO. 83-B-37
SHEET 3
FILE NO. WC-1-11/3



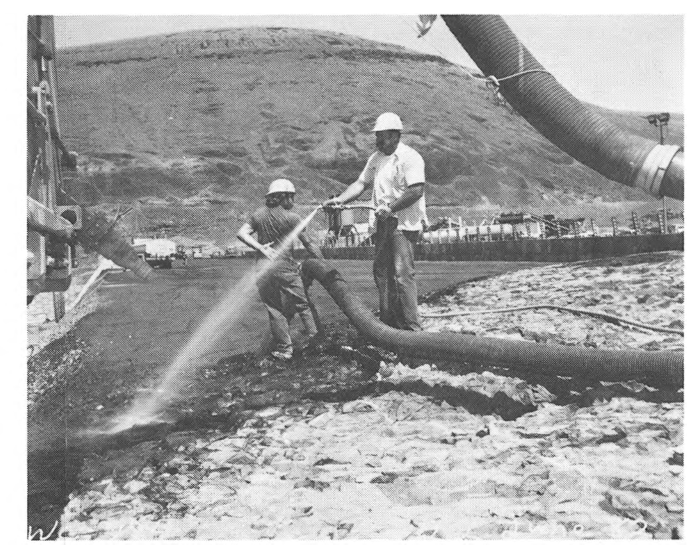
SIX-INCH CORE THROUGH THE RCC AND BEDDING INTO THE FOUNDATION ROCK. SAMPLE PREPARED FOR SHEAR TEST.

PLACING BEDDING ON THE FOUNDATION PRIOR TO ROLLING RCC INTO IT.



VACUUM CLEANUP OF THE FOUNDATION PRIOR TO PLACING THE BEDDING MIX AND RCC ON IT.

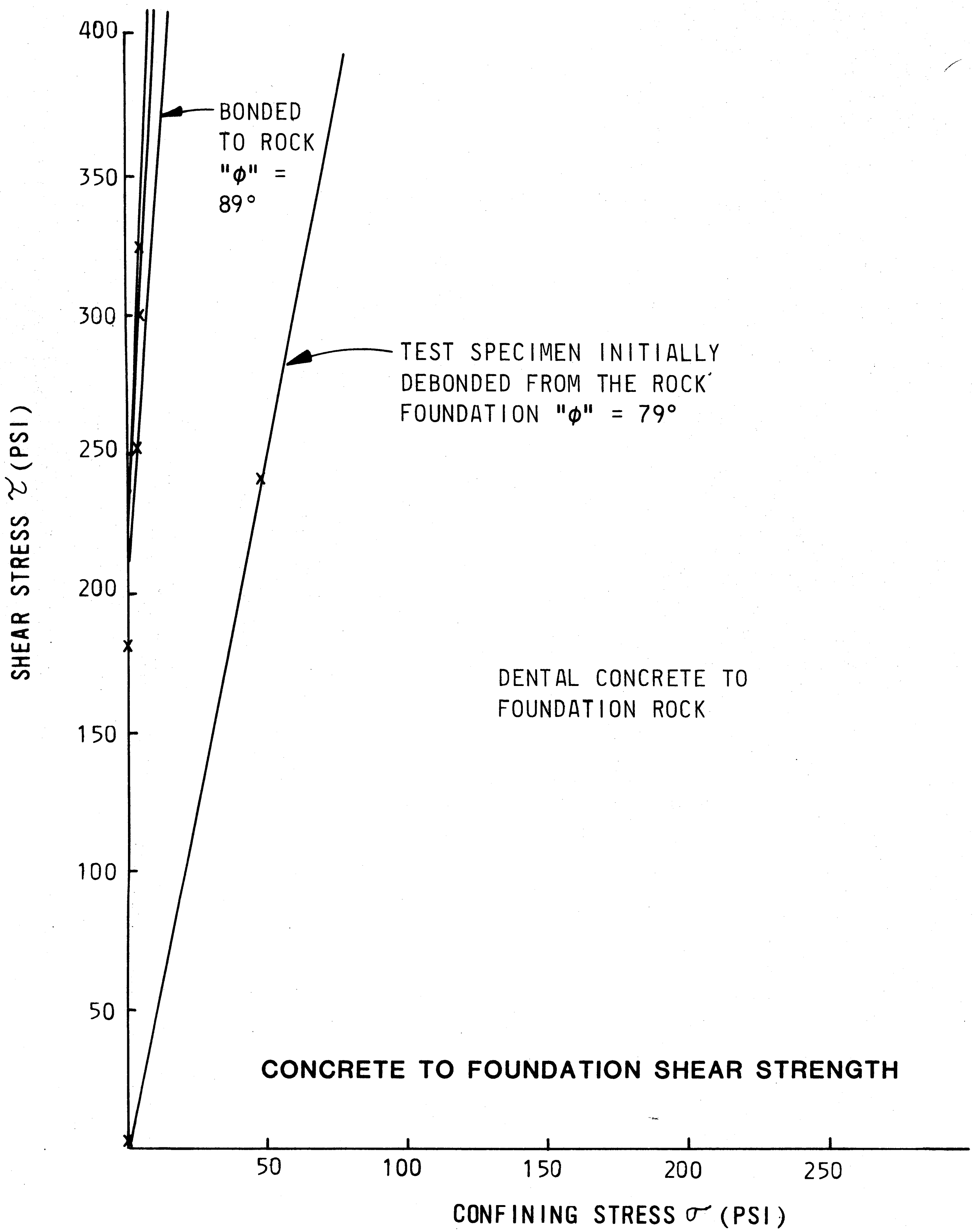
VACUUM CLEANUP OF THE FOUNDATION.



FOUNDATION CLEANUP WITH A STANDARD GARDEN HOSE AND THE VACUUM.

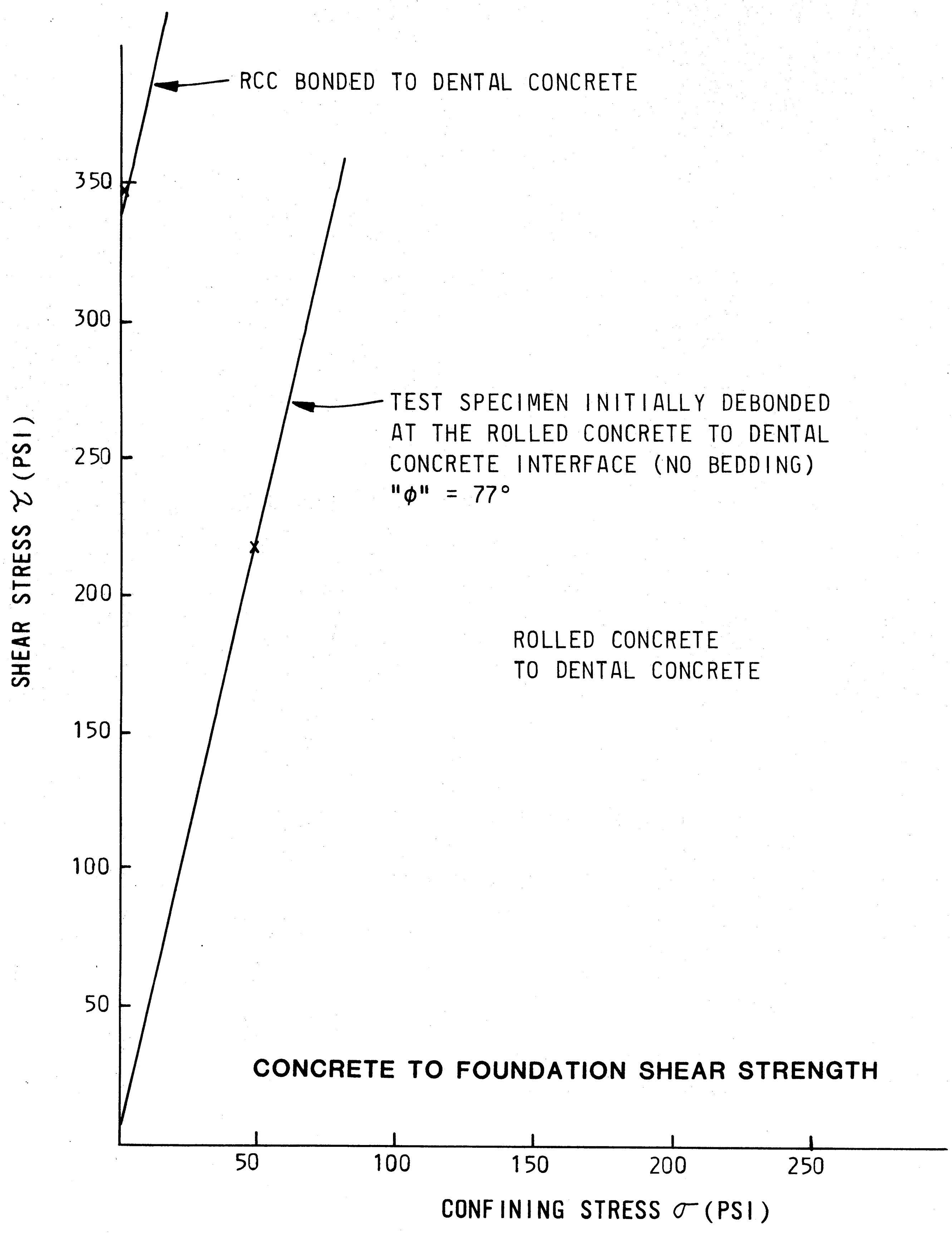
FOUNDATION CLEANUP AND BEDDING

PLATE 16.2



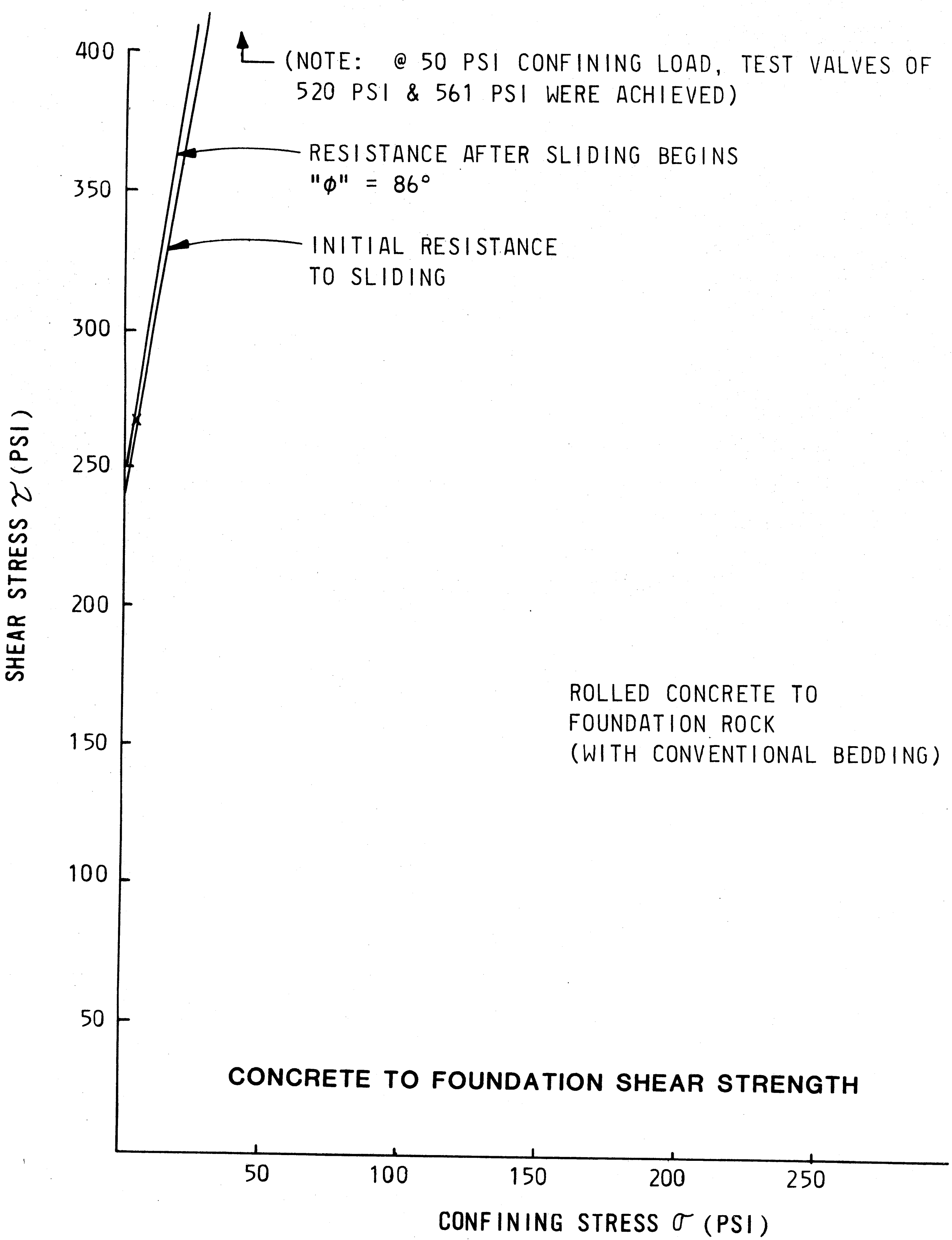
CONCRETE TO FOUNDATION SHEAR STRENGTH

PLATE 16.3



CONCRETE TO FOUNDATION SHEAR STRENGTH

PLATE 16.4



CONCRETE TO FOUNDATION SHEAR STRENGTH

PLATE 16.5

CHAPTER 17

BEDDING MIX, GALLERY, AND REINFORCING STEEL

A special bedding mix of RCC was required between surfaces that were not covered by the subsequent layer within 1,600 degree hours as measured by the time-temperature surface maturity. This bedding was also intended for use around reinforcing steel. The mix was a relatively high cement factor no-slump mix using the 3/4-inch RCC aggregate with 330 pounds of cement and 135 pounds of fly ash per cubic yard.

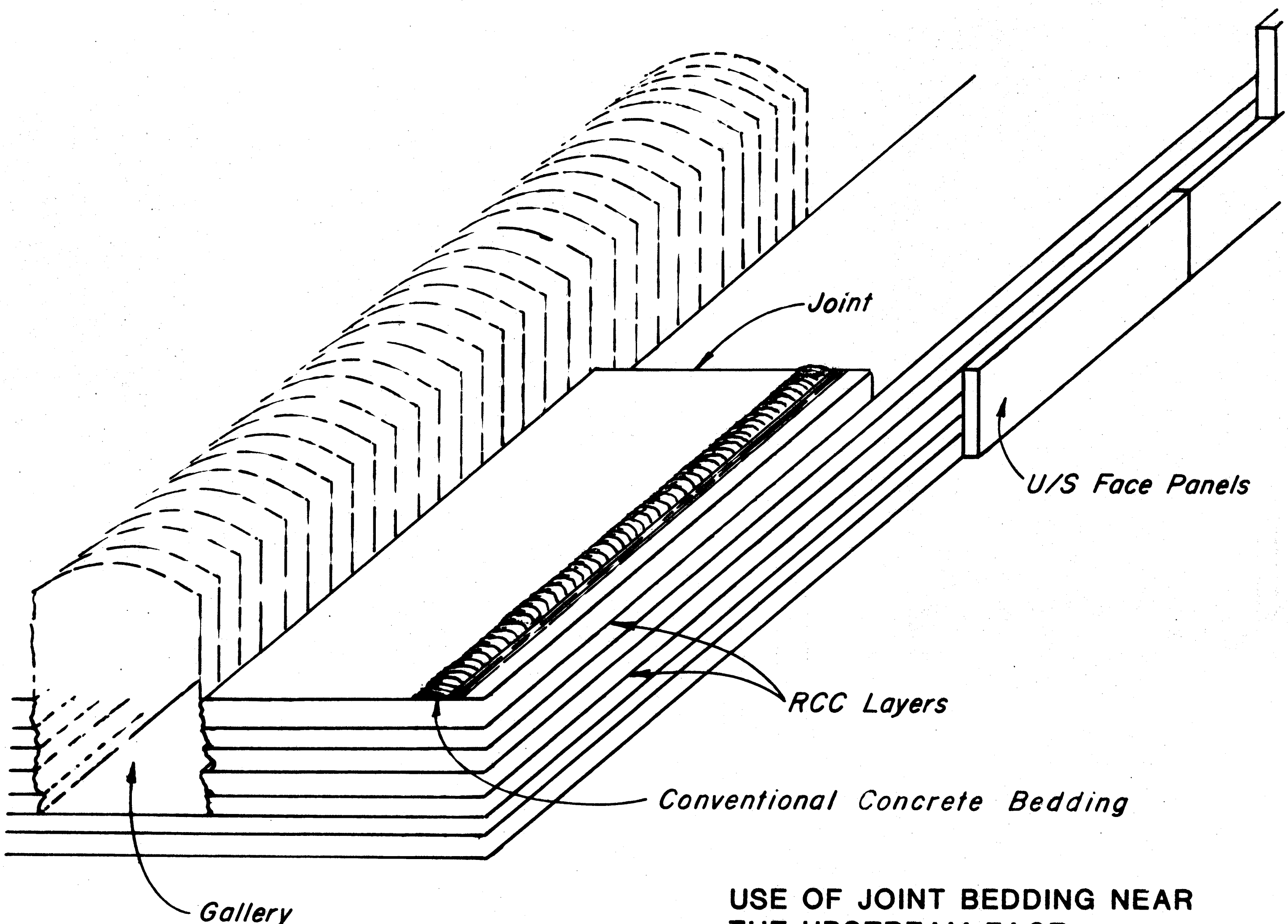
The main purpose of the mix was really to act as a deterrent to the contractor so that he would keep production moving fast enough to prevent cold joints (there was no additional payment for the bedding mix). Mostly because of noise restrictions and community concern, RCC placing was stopped on Sundays. Consequently, a cold joint occurred essentially every Monday morning.

The effect of the mix on the joint strength is discussed in Chapter 15, "Joints and Shear Between RCC Layers." When it became evident that the bedding mix was probably doing more harm than good, that the contractor in fact was not causing unnecessary cold joints, and when results were received on the supplemental shear test, field personnel were advised to relax the original 1,600 degree hour definition of a cold joint and use 2,000 degree hours. Unfortunately, the inspectors did not always do this, apparently not appreciating the undesirability of the RCC bedding.

The bedding also was intended for use around reinforcing steel located throughout the stilling basin floor, above the gallery, and below the gallery. Soon after the difficulty in effectively spreading and handling the bedding was realized, placing at the reinforcing steel with the standard 1-1/2-inch aggregate RCC spillway mix was tried. This worked very well and was followed for the rest of the job. As shown by the cores on Plates 8.1, 8.3, and 8.5, where the RCC bedding was used it broke out in pieces or as a disc separated from the rest of the RCC. Where the 1-1/2-inch RCC mix was used without the bedding, very good embedment of the bar resulted and the joint surface was good.

Above the gallery, the conventional concrete bedding mix used at the foundation to RCC contact was spread in a strip from abutment to abutment and about 1 to 2 feet behind the upstream face panels to provide better joint bonding and watertightness as indicated on Plate 17.1. This is described further in Chapter 23, "Reservoir Raise, Seepage, and Grouting." It appeared to have worked well but has not yet been cored. The bedding was also used over a larger trial area between cold joint layers, as were trial mortar mixes. These areas are scheduled to be cored, inspected, pressure tested, and evaluated during the summer of 1983. The update to this report, scheduled for October 1983, will include results of that investigation.

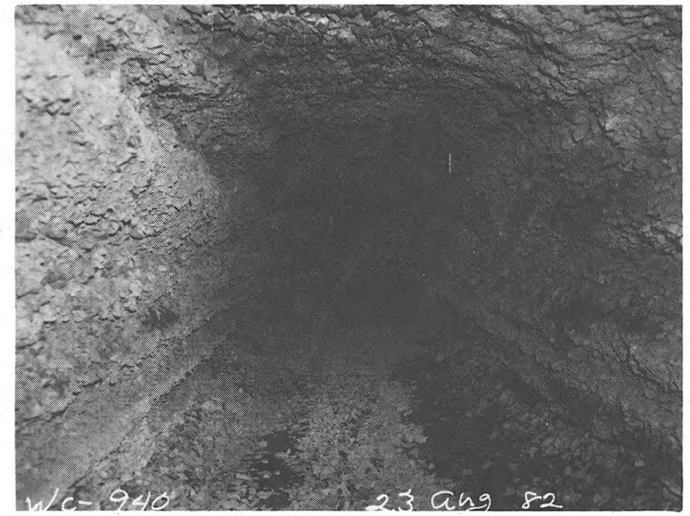
Specifications allowed the gallery to be established by several methods including: (1) forming, (2) precast concrete segments, and (3) by simply filling the gallery area with uncemented aggregate during placement of adjacent RCC and then excavating out the aggregate after the RCC hardened. The fill/excavation method was selected by the contractor as the fastest and least expensive. From an engineering standpoint, it is the most desirable and leaves a natural RCC interior surface for inspection. Plate 17.2 shows the gallery and interior RCC appearance at the gallery wall.



USE OF JOINT BEDDING NEAR THE UPSTREAM FACE

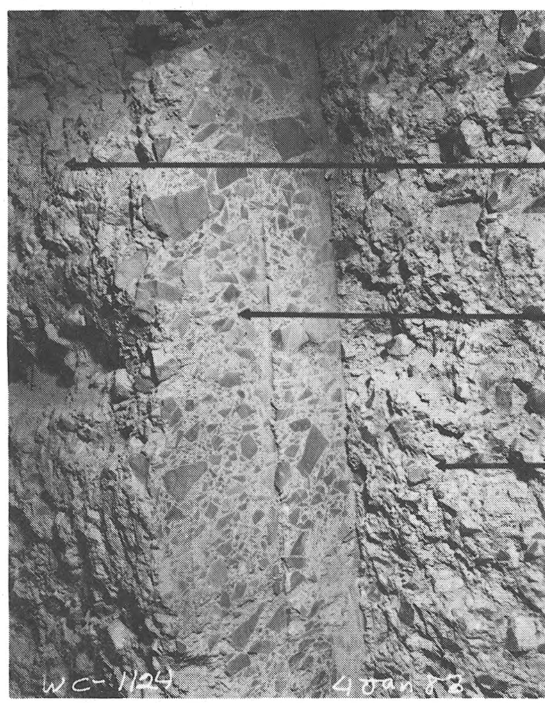
PLATE 17.1

MUCKING OUT AGGREGATE FILL FROM THE GALLERY.

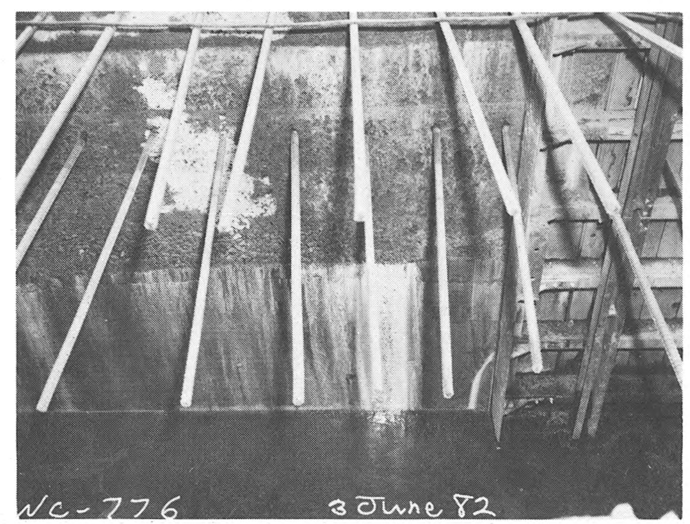


ROUGH MUCKED GALLERY.

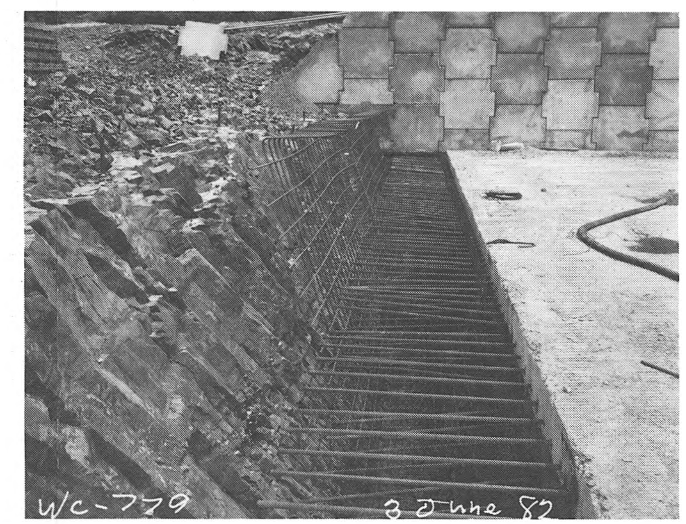
GALLERY AFTER CLEANING.



VERTICAL SAW CUT CROSSING SEVERAL JOINTS BETWEEN RCC LAYERS IN THE LEAN INTERIOR RCC MIX AT THE GALLERY WALL.



REBAR EXTENDING THROUGH THE RCC INTO THE END SILL AREA FROM THE STILLING BASIN.



REBAR FROM THE RCC STILLING BASIN EXTENDING INTO THE END SILL AREA.

GALLERY AND REINFORCING STEEL IN THE RCC

CHAPTER 18

TEMPERATURES AND THERMAL BEHAVIOR

The thermal behavior of the RCC was one of the most important aspects of design. The project design memorandum explains how the thermal studies were done, the results, and their importance. In essence, the thermal study established the construction schedule which was then mandated to the contractor. This required producing at least half of the aggregate during the winter so that it was put into huge stockpiles where it stayed cool for use during the warmer months. It required RCC placing to start by 1 May. It required a plant capacity of at least 400 cubic yards of RCC per hour and placement at a rate of at least one lift for every three shifts but not more than three lifts every two shifts. The thermal study took into account predicted normal warm and cool weather, the effect of the aggregate, the effect of wind and sun, the geometry of the structure (the amount of concrete in each lift), the adiabatic heat rise of each mix, the heat sink of the foundation rock, and the range of allowed placing rates. Through the study, contract placing controls were established so that even with no monolith joints, internal temperatures would not create stresses that would cause undesirable internal loadings or unacceptable cracking. Because of the higher cement factor spillway mix required by hydraulic designers, thermal cracking which was undesirable but structurally tolerable was predicted in it. These cracks were not predicted to extend through the interior leaner mix to the upstream face of the dam. For reasons of geometry influenced by thermal stress, probable but acceptable long-term upstream to downstream cracks were predicted at the spillway training walls and at the bend in the dam axis.

Thermal behavior of the dam and cracking has developed as predicted. At this time the spillway has about five very tight vertical cracks that do not go through the structure. Crack meters indicate that a crack in line with the spillway walls probably has occurred in the lower part of the dam. There is no indication of other cracking except for several thermal shock and/or drying shrinkage cracks in the top lift of the non-overflow sections. These have been instrumented and appear to be stable nonworking cracks. Expected shrinkage/thermal cracks appeared in the high cement factor conventional shotcrete of the spillway cap.

Plates 18.1 through 18.18 show actual thermal contours in the dam for both the spillway and nonoverflow sections on the first of each month since construction began. Also shown on the plates is the fact that actual temperatures throughout the structure were as expected. During construction, approximately 250 resistance thermometers were embedded and monitored. They showed predicted temperatures within a few degrees of the actual temperature at essentially every location in every mix at any time. Almost all of the peak temperatures were within a degree of the predicted peak temperature. Most of the thermometers have been abandoned, but a select group of about 40 will remain in place to permit long-term thermal observations.

Exhibit 18.1 shows examples of the time-temperature behavior of resistance thermometers at different locations in each mix. The datum was input to a computer program as it was collected, and the graphs shown in the plates were machine plotted. As time passes, the plotter adjusts the time scale as can be seen on the plates.

Plates 18.19 through 18.21 show the temperature of the RCC mix as it was batched and placed, the temperature of the aggregates as they went to the mixer from stockpile, and the ambient conditions. The only cooling was the benefit of having made a large portion of the aggregate during the cool months. The contractor had no temperature requirements to meet.

Plate 18.22 shows the adiabatic temperature rise for the mixes. Because of its importance to thermal stress and cracking, typical creep curves for the Willow Creek RCC mixes, other RCC mixes (Zintel), and conventional mass concrete (Dworshak) are shown on Plate 18.23.

Potential damage from thermal shock was also thoroughly studied during design and is discussed in the design memorandum. At Willow Creek the condition can occur in the fall when concrete at early age and with little strength or strain capacity is subjected to a rapid drop in surface temperature. The surface then tries to contract, but is restrained by the warmer interior material. If the temperature differential between the surface and interior is too great, cracking can develop. General controls which would allow for the use of insulation at Willow Creek if and when needed during a normal climatic year to control thermal shock cracking were given in the contract as follows:

> "For RCC placed after August 20, the following specified insulation shall be installed on the unformed downstream sloping face (the downstream dam face, spillway surface, and back of the stilling basin training walls) and on the final top surface of the dam crest. The requirements also apply to the surface of conventional concrete used to cap the spillway crest.
>
> (1) RCC placed between August 20 and September 15 shall be covered with insulation not sooner than 5 days nor later

than 15 days from the time of placement. The insulation shall be removed not sooner than the following April 30 nor later than the following May 30.

(2) RCC placed after September 15 shall be covered with insulation within 5 days of the time that it is placed. The insulation shall be removed not sooner than the following April 30 nor later than the following May 30.

The insulation shall consist of mats or blankets designed for this purpose. It shall have a conductivity of not less than 0.30 BTU/hr.-sq. ft.-degree F nor more than 0.40 BTU/hr.-sq. ft.-degree F. The mats or blankets shall be tightly laced together at the seams or shall be overlapped by at least 2-1/2 feet at the seams and weighted or pinned to the RCC so that no RCC surface becomes exposed regardless of wind, rain, and other conditions. Steel or other acceptable straps or anchors to hold the mats in place may be embedded between RCC layers during construction and later cut off flush with the downstream face."

As the cool nights approached, resistance thermometers were used to monitor the temperature at the surface, 3 inches inside the surface, and 1 foot inside the surface. The thermal differential and resulting strains were checked at various intervals of time each night until they reached about 90 percent of the calculated strain capacity of the RCC before cracking. At that time (7 September) insulation of the surface began.

To help accurately predict the stress and strain capacity of the RCC mixes and the resulting permissible thermal shock, large blocks of RCC were cut from the dam and tested as described in Chapter 14, "Direct Tension Tests." Based on this data, the graph shown on Plate 18.24 was developed which shows the tolerable surface temperature differential in the two exposed mixes at different ages. Calculations were made based on both stress and strain capacities and agreed well with each other. Tests were not made for the lean interior 80+32 mix because it was continually being covered with fresh mix. Tests were not needed for the 175+00 upstream zone mix because it was protected by the precast panels which were, in effect, acting as insulation.

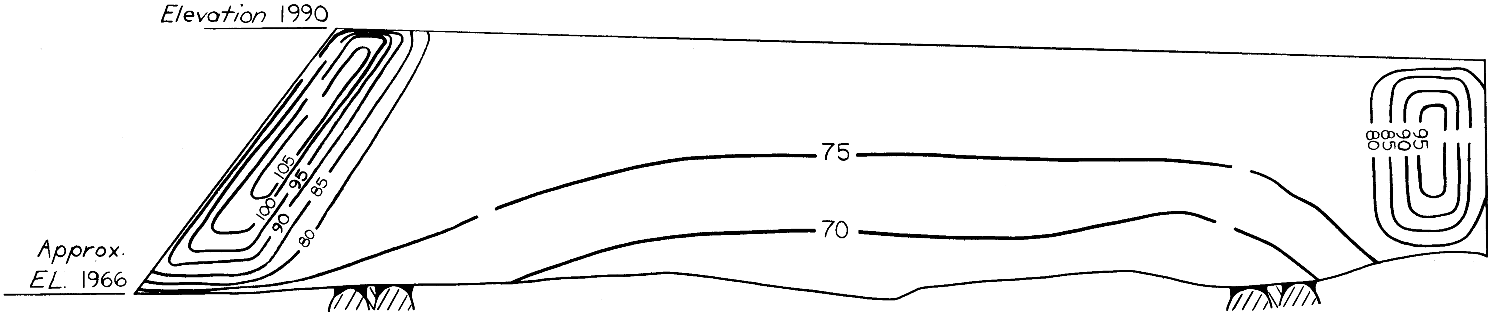
Continued monitoring of resistance thermometers embedded in the RCC mixes as placing progressed and the insulation was used showed that it was working as designed to prevent thermal shock while still gradually allowing the temperature to drop. Unfortunately, it was not tightly secured or properly embedded at the start. Exhibit 18.2 discusses the conditions that developed and how they were corrected. It also provides specifics about the temperature conditions and the stresses and strains that were calculated. Computations showed that thermal stresses near the maximum permissible value occurred and that minimal surface cracking could have been initiated. Inspection in the spring after removal of the insulation showed several very tight surface cracks that probably were caused from the shock, but which have apparently not grown or developed into a condition of concern.

WILLOW CREEK DAM
HEPPNER, OREGON

SPILLWAY THERMAL CONTOURS
1 MAY 1982

DWN BY KAROL TALBOTT

PLATE 18.1



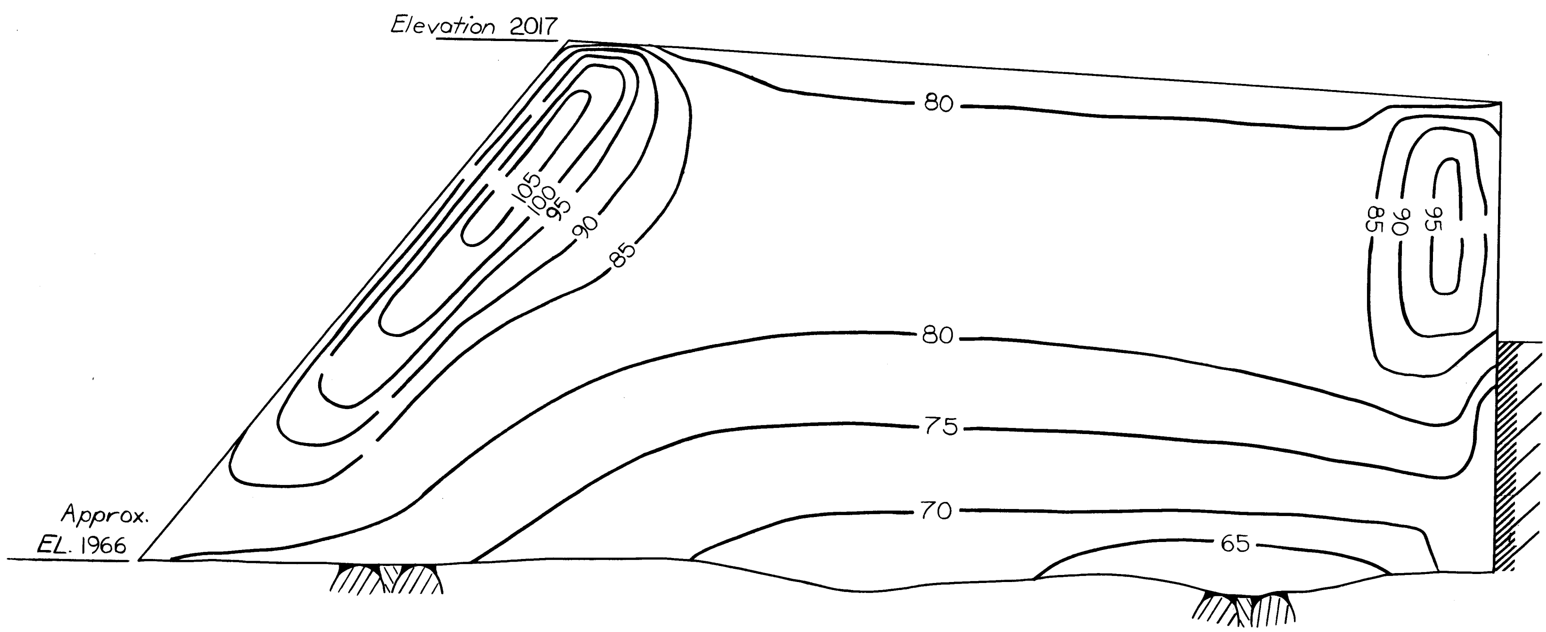
WILLOW CREEK DAM
HEPPNER, OREGON

SPILLWAY THERMAL CONTOURS

1 JUNE 1982

DWN BY KAROL TALBOTT

PLATE 18.2

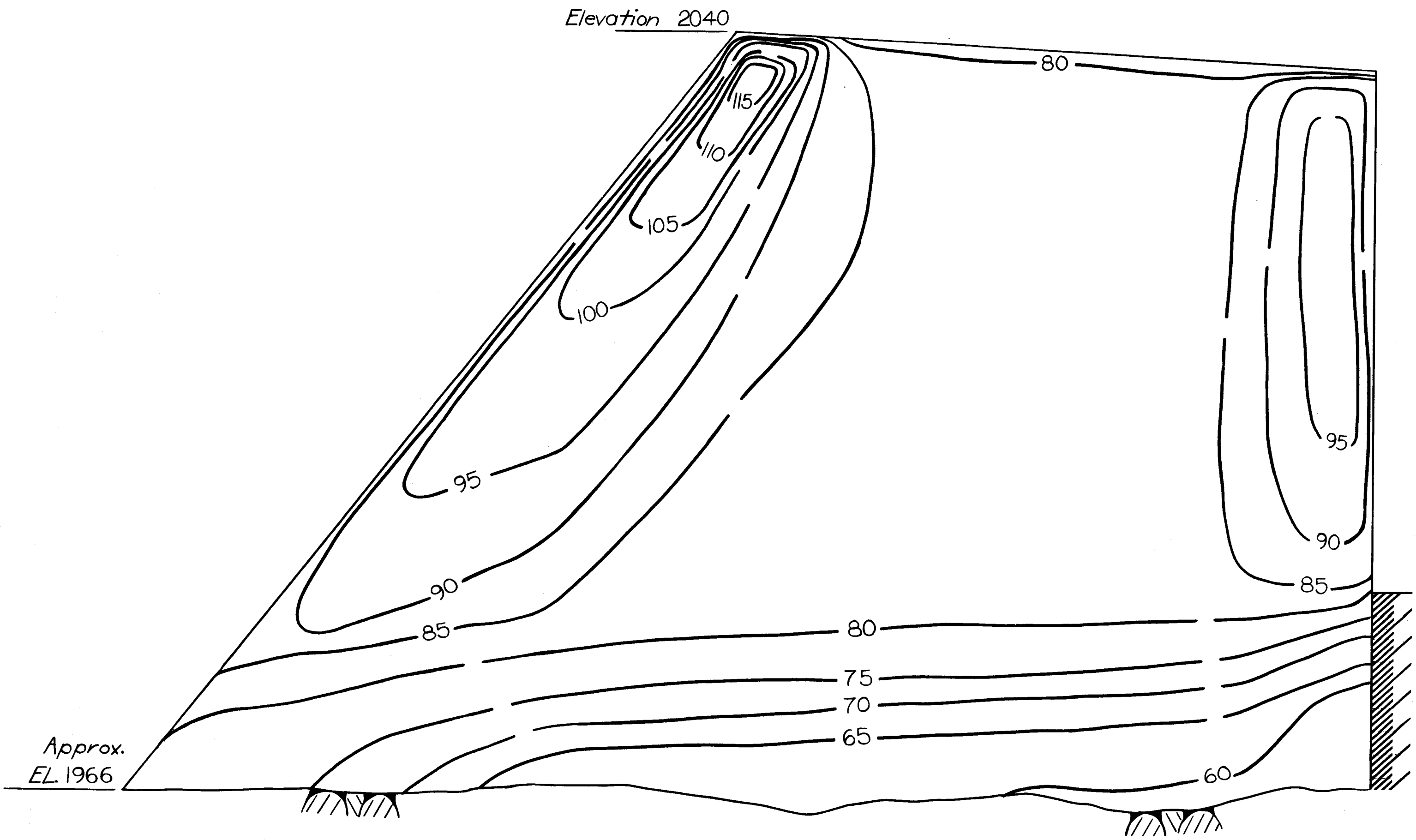


WILLOW CREEK DAM
HEPPNER, OREGON

SPILLWAY THERMAL CONTOURS
1 JULY 1982

DWN BY KAROL TALBOTT

PLATE 18.3



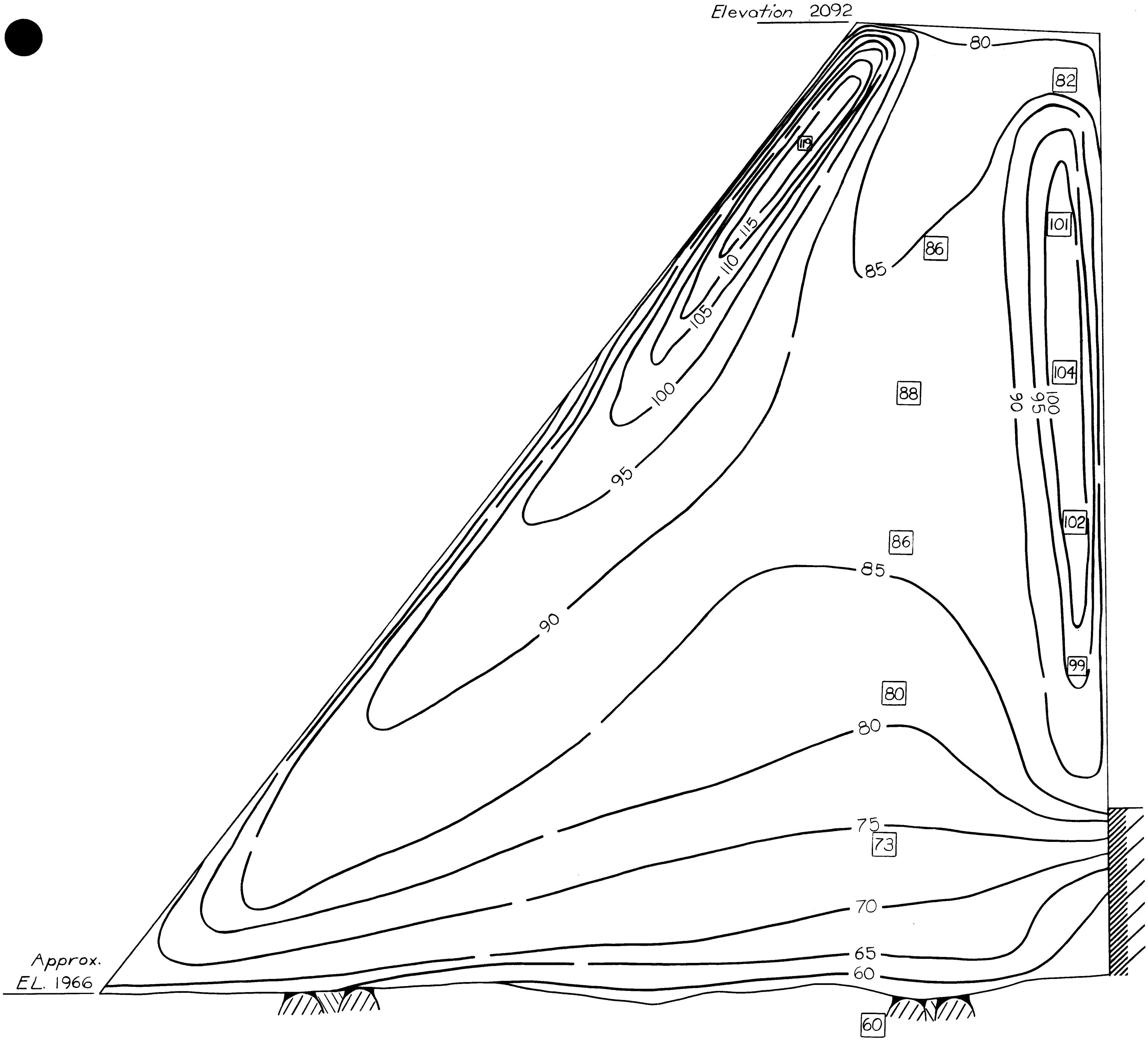
WILLOW CREEK DAM
HEPPNER, OREGON

SPILLWAY THERMAL CONTOURS

1 AUGUST 1982

DWN BY KAROL TALBOTT

PLATE 18.4



LEGEND

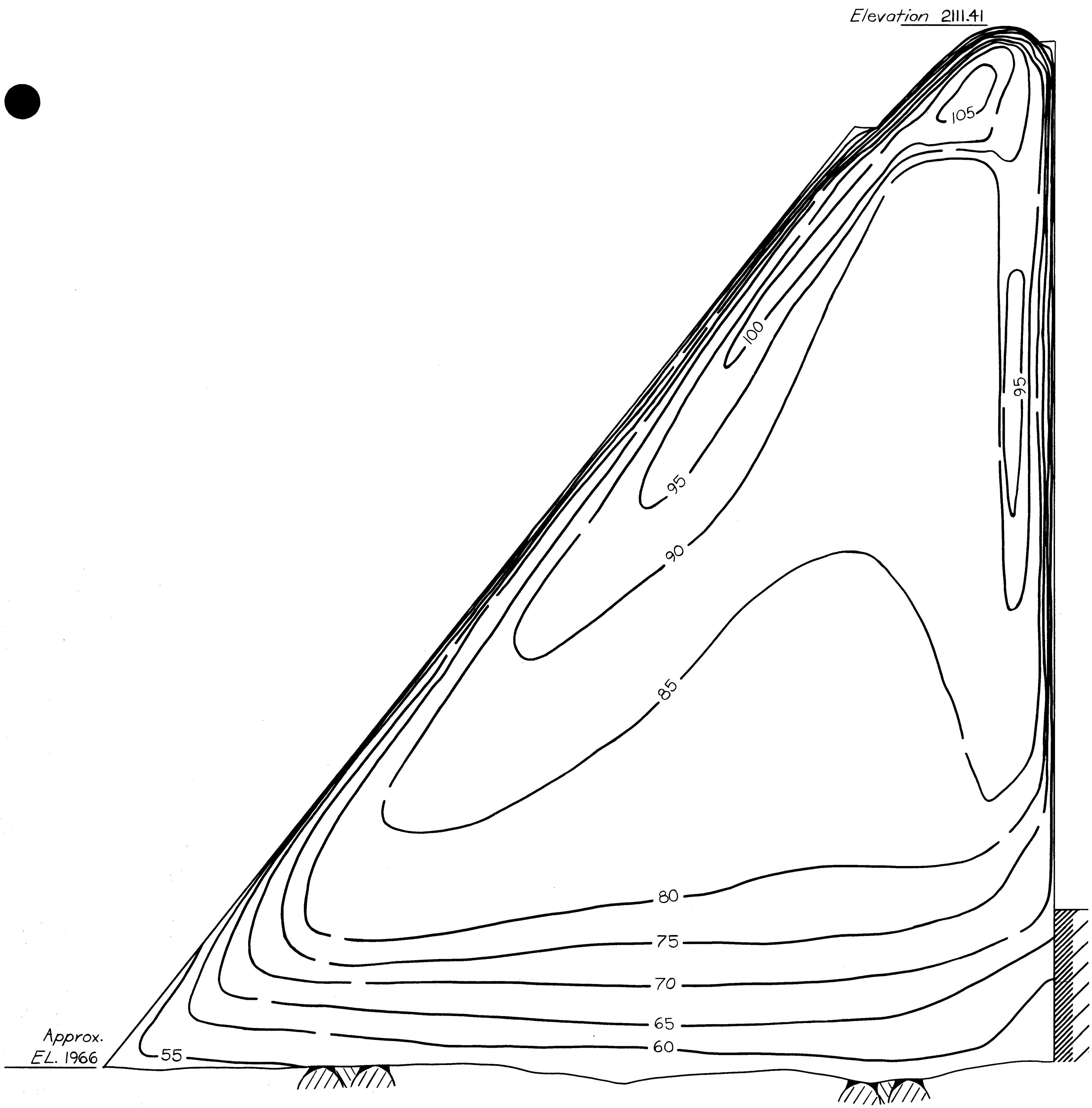
[99] INDICATES TEMPERATURE PREDICTED BY DESIGN COMPUTATIONS FOR THIS MIX, LOCATION, AND TIME.

WILLOW CREEK DAM
HEPPNER, OREGON

SPILLWAY THERMAL CONTOURS
1 SEPTEMBER 1982

DWN BY KAROL TALBOTT

PLATE 18.5

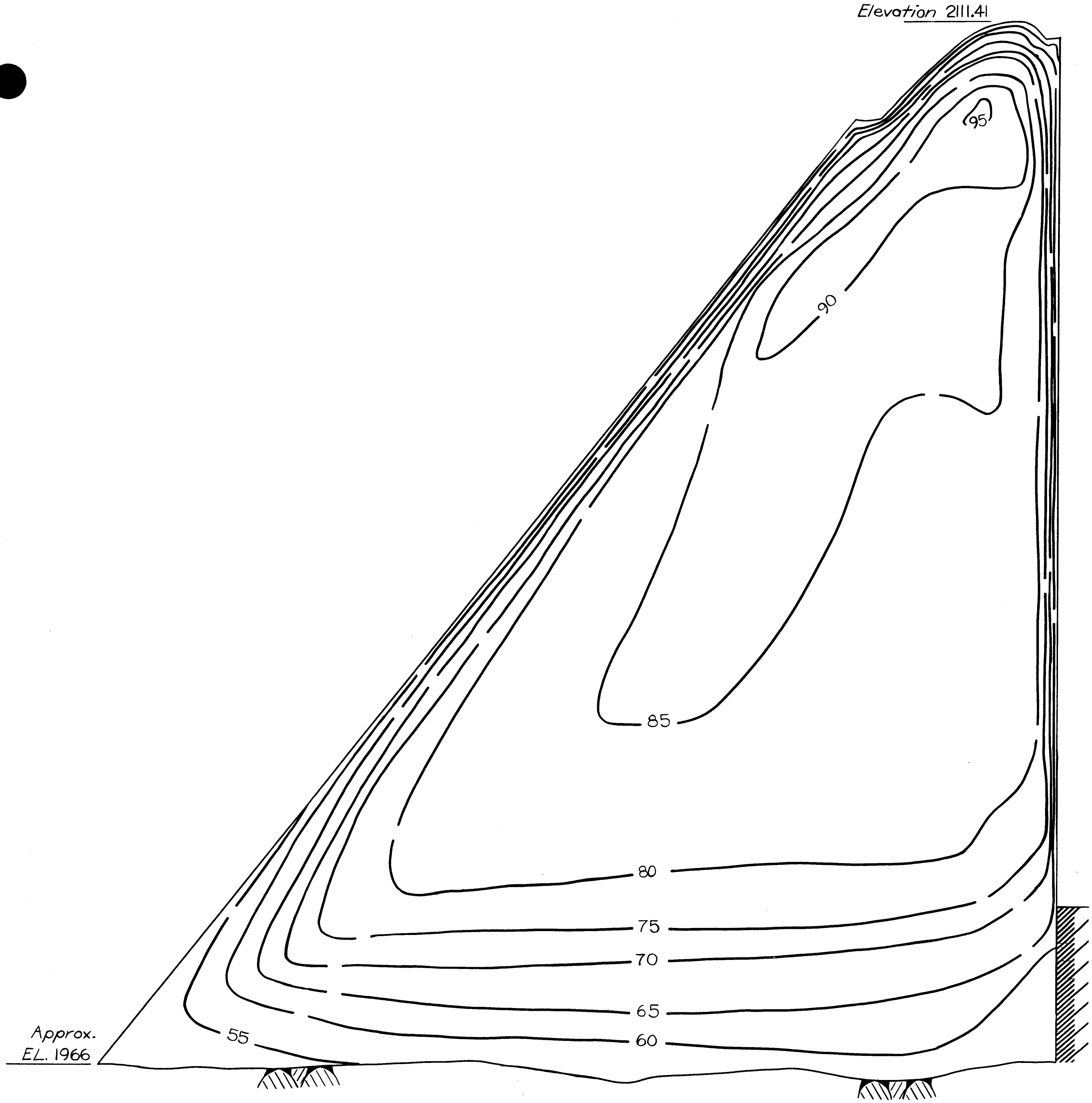


WILLOW CREEK DAM
HEPPNER, OREGON

SPILLWAY THERMAL CONTOURS
1 OCTOBER 1982

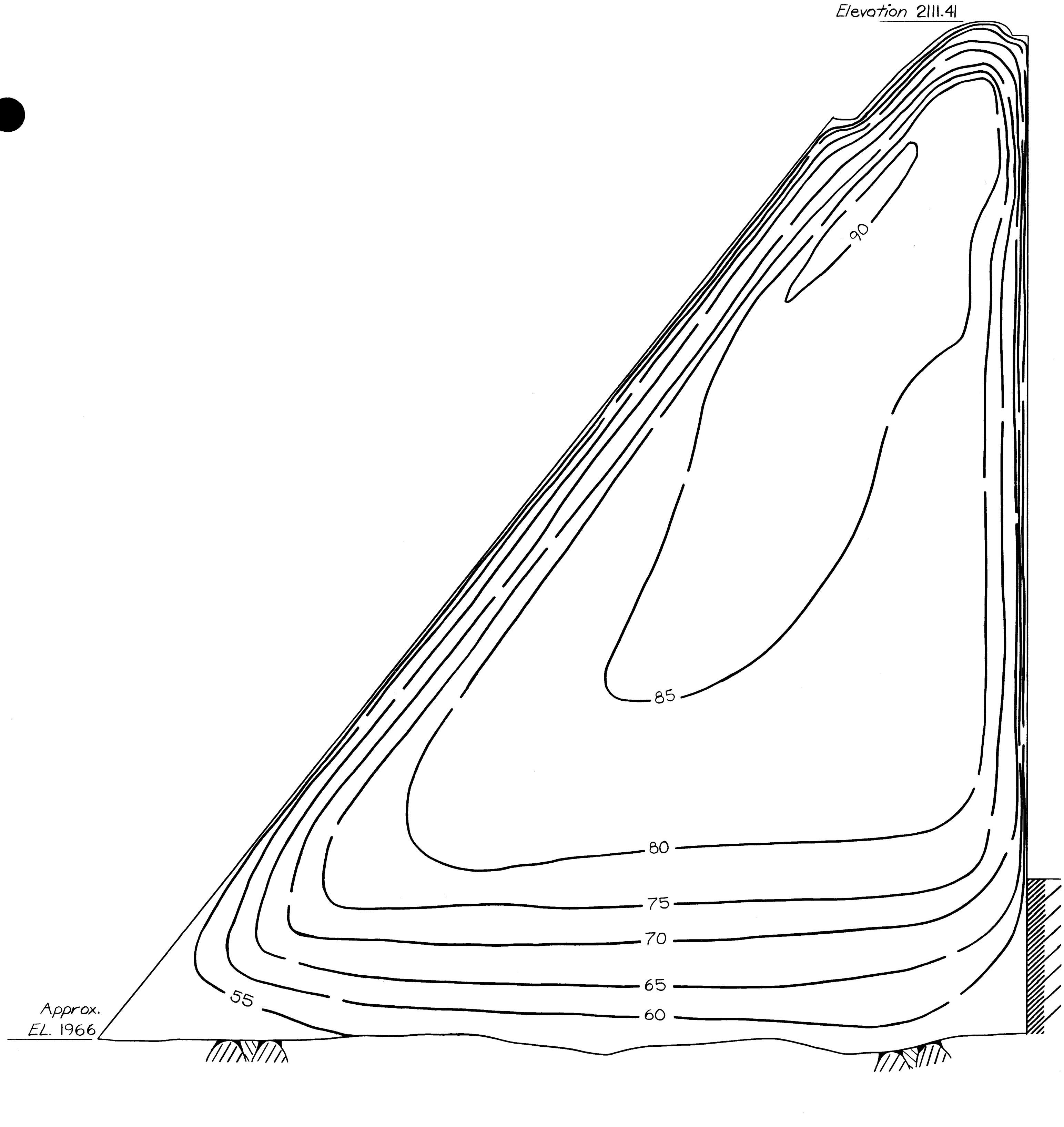
DWN BY KAROL TALBOTT

PLATE 18.6



WILLOW CREEK DAM
HEPPNER, OREGON
SPILLWAY THERMAL CONTOURS
1 NOVEMBER 1982

DWN BY KAROL TALBOTT

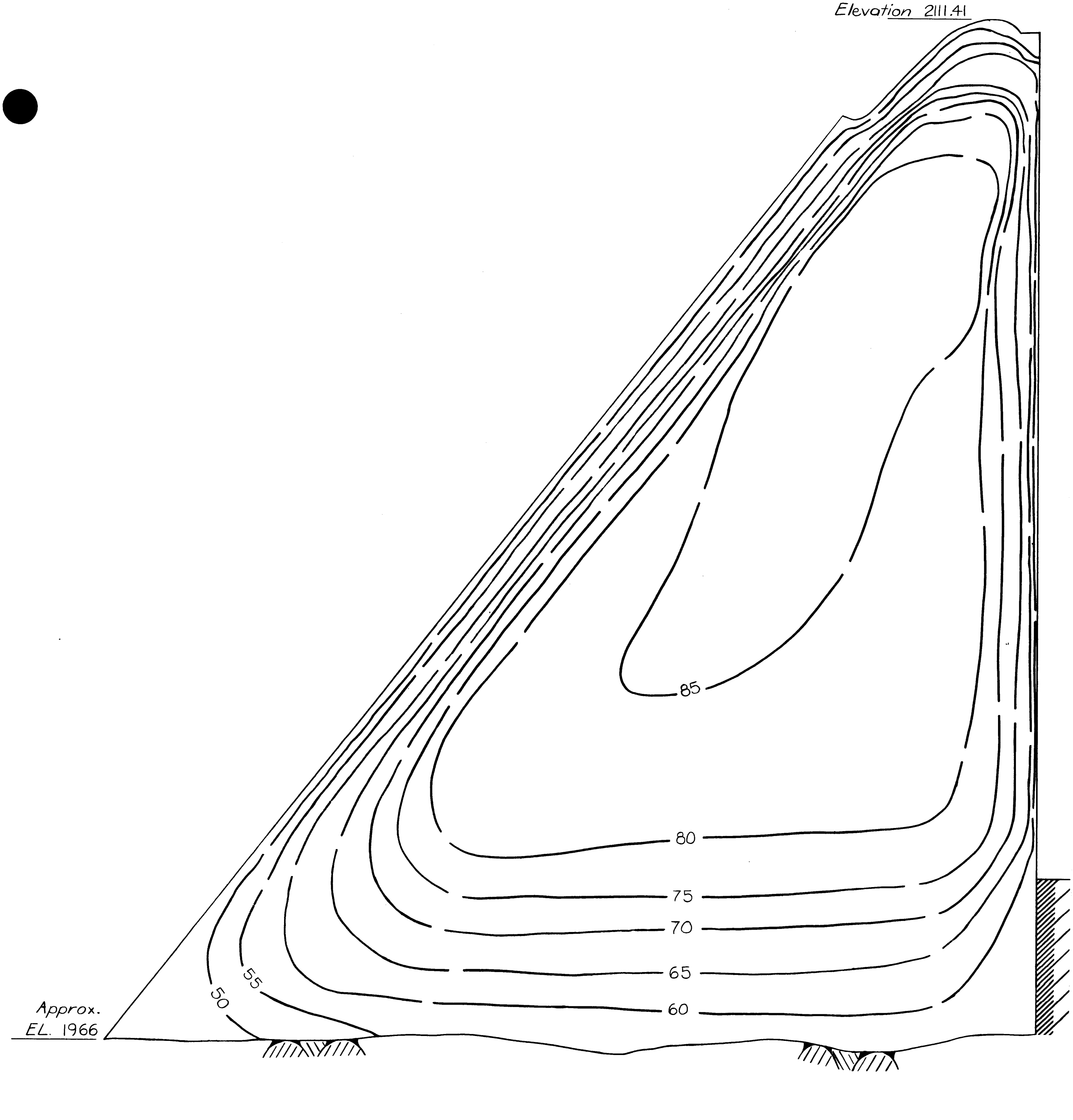


WILLOW CREEK DAM
HEPPNER, OREGON

SPILLWAY THERMAL CONTOURS
1 DECEMBER 1982

DWN BY KAROL TALBOTT

PLATE 18.8



WILLOW CREEK DAM
HEPPNER, OREGON

SPILLWAY THERMAL CONTOURS
1 JANUARY 1983

DWN BY KAROL TALBOTT

PLATE 18.9

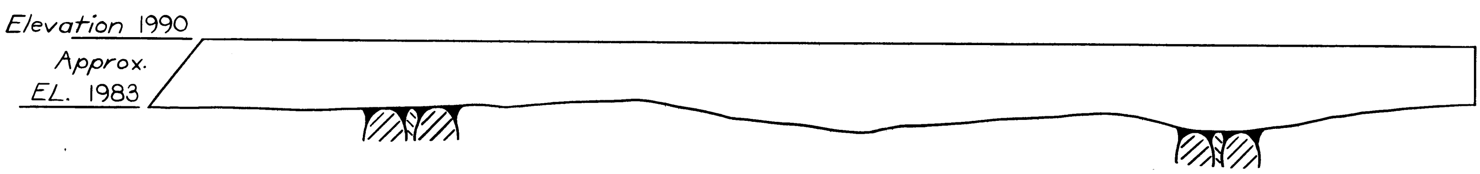
WILLOW CREEK DAM
HEPPNER, OREGON

NON-OVERFLOW THERMAL CONTOURS

1 MAY 1982

DWN BY KAROL TALBOTT

PLATE 18.10



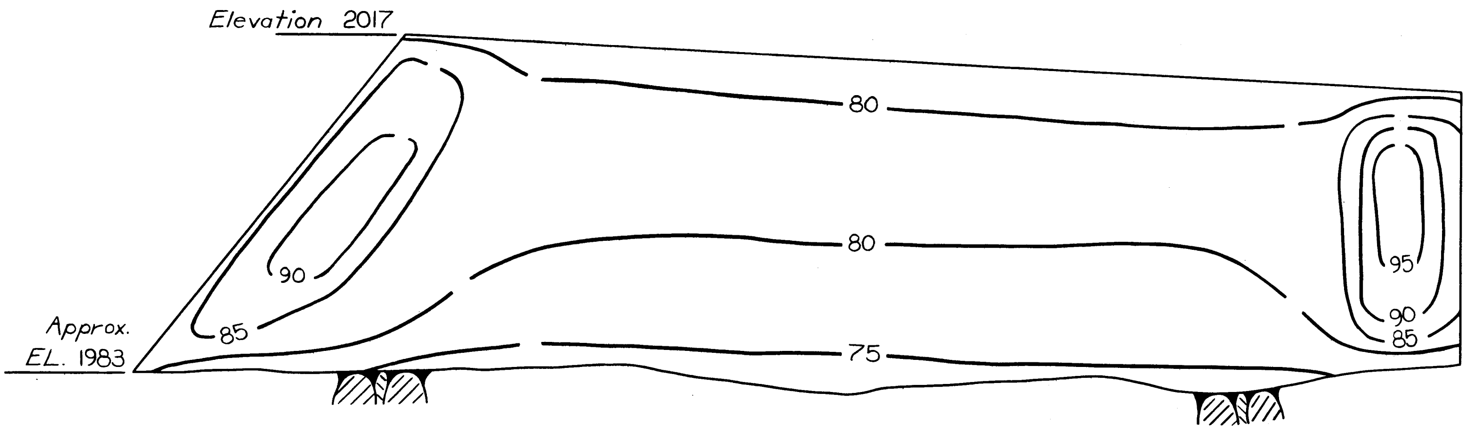
WILLOW CREEK DAM
HEPPNER, OREGON

NON-OVERFLOW THERMAL CONTOURS

1 JUNE 1982

DWN BY KAROL TALBOTT

PLATE 18.11

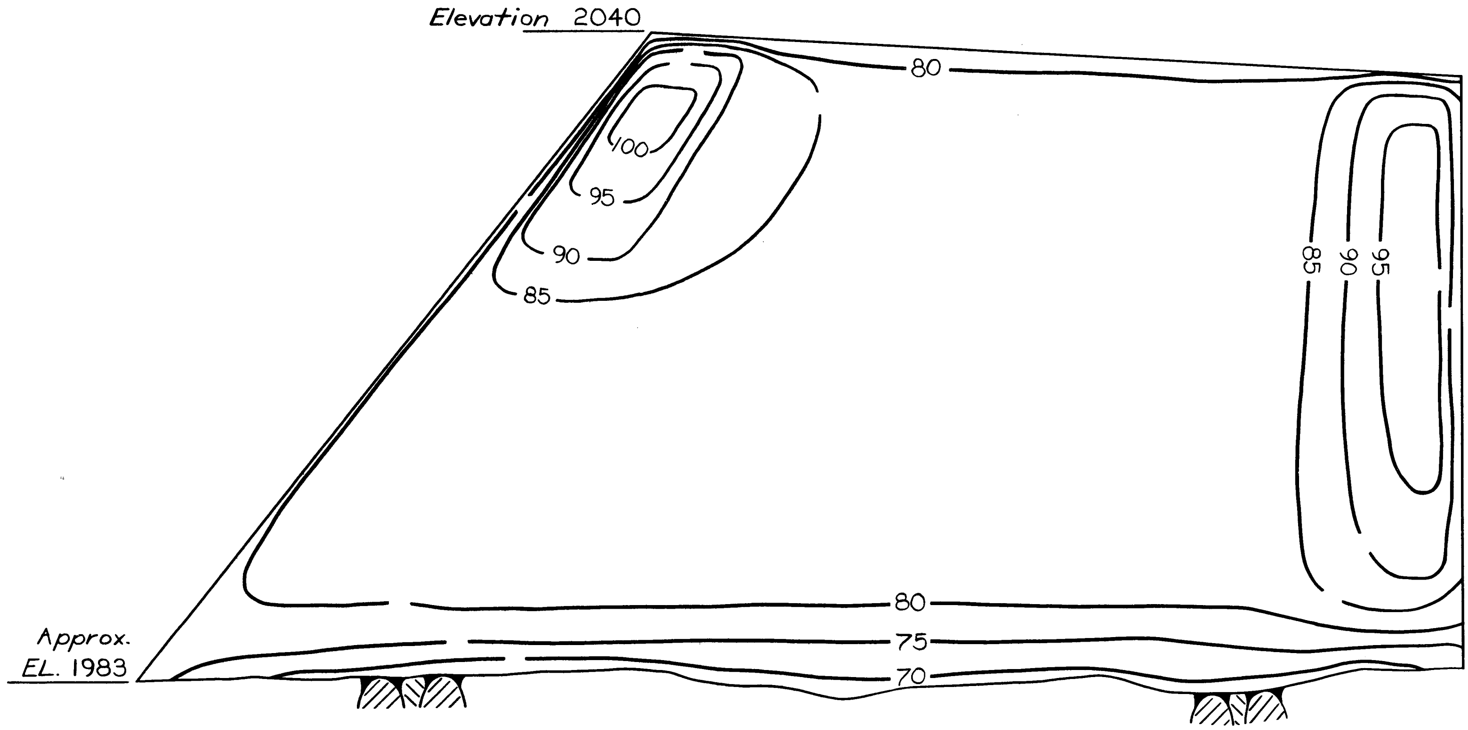


WILLOW CREEK DAM
HEPPNER, OREGON

NON-OVERFLOW THERMAL CONTOURS
1 JULY 1982

DWN BY KAROL TALBOTT

PLATE 18.12

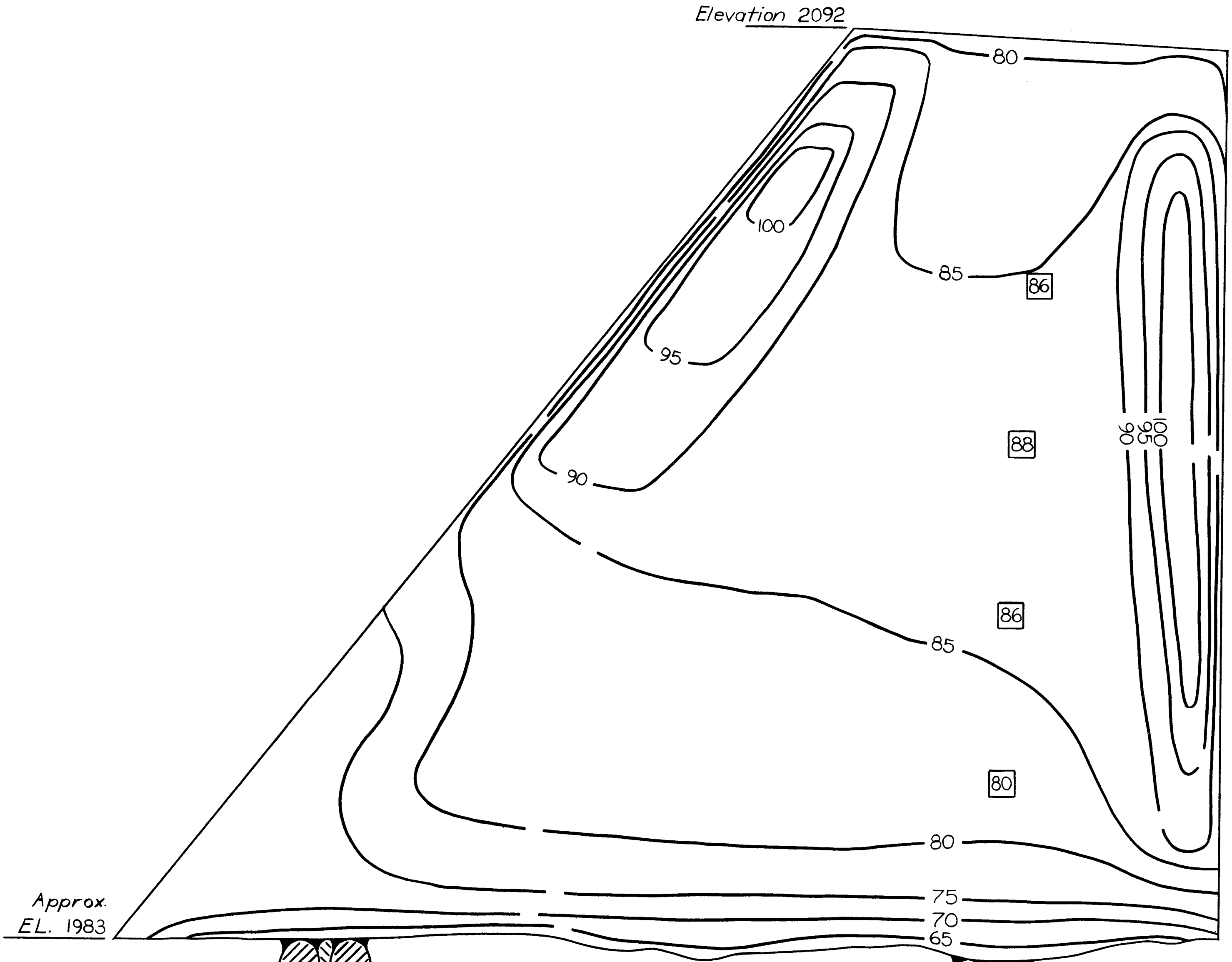


WILLOW CREEK DAM
HEPPNER, OREGON

NON-OVERFLOW THERMAL CONTOURS
1 AUGUST 1982

DWN BY KAROL TALBOTT

PLATE 18.13



LEGEND

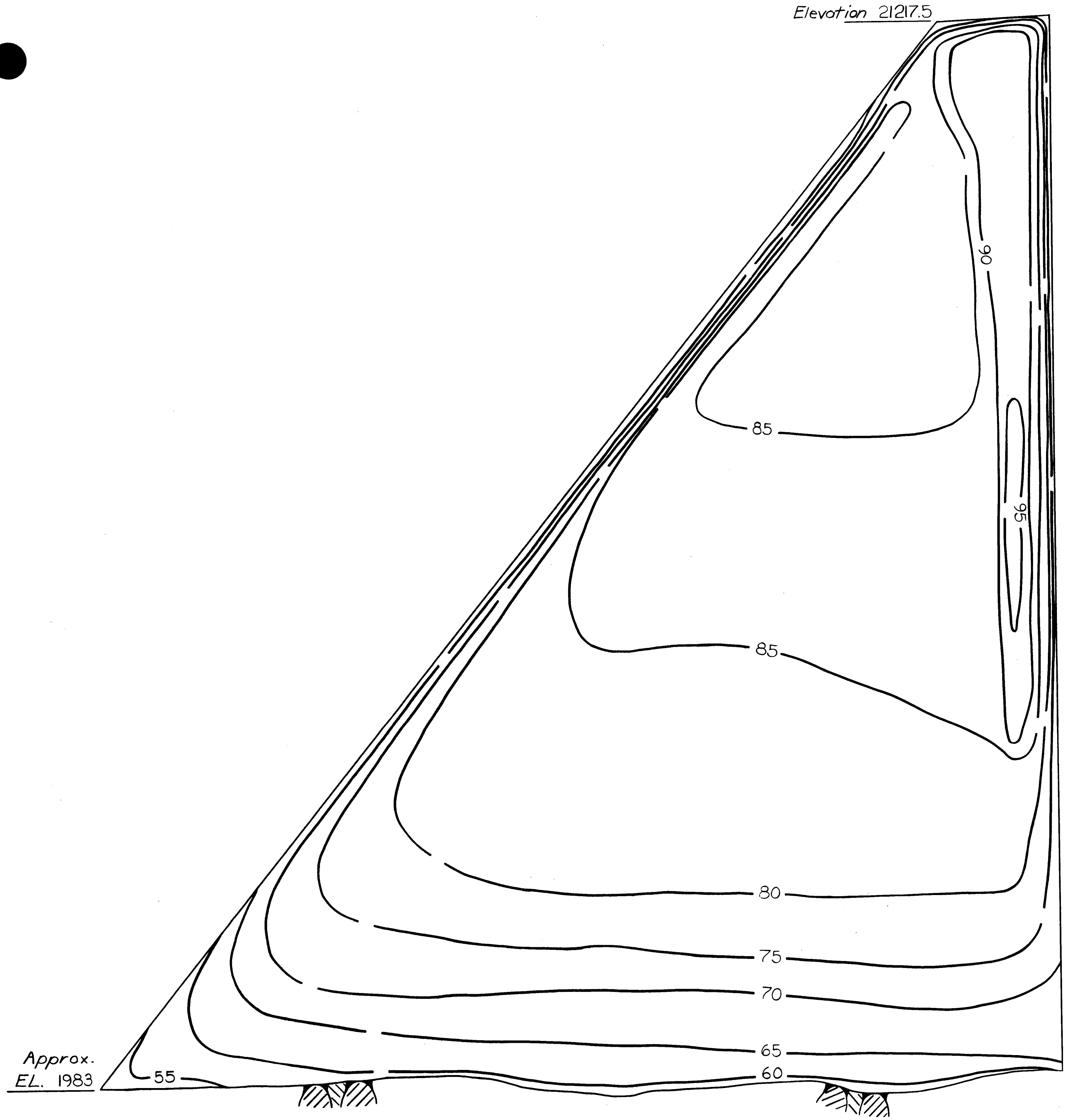
86 INDICATES TEMPERATURE PREDICTED BY DESIGN COMPUTATIONS FOR THIS MIX, LOCATION, AND TIME.

WILLOW CREEK DAM
HEPPNER, OREGON

NON-OVERFLOW THERMAL CONTOURS
1 SEPTEMBER 1982

DWN BY KAROL TALBOTT

PLATE 18.14



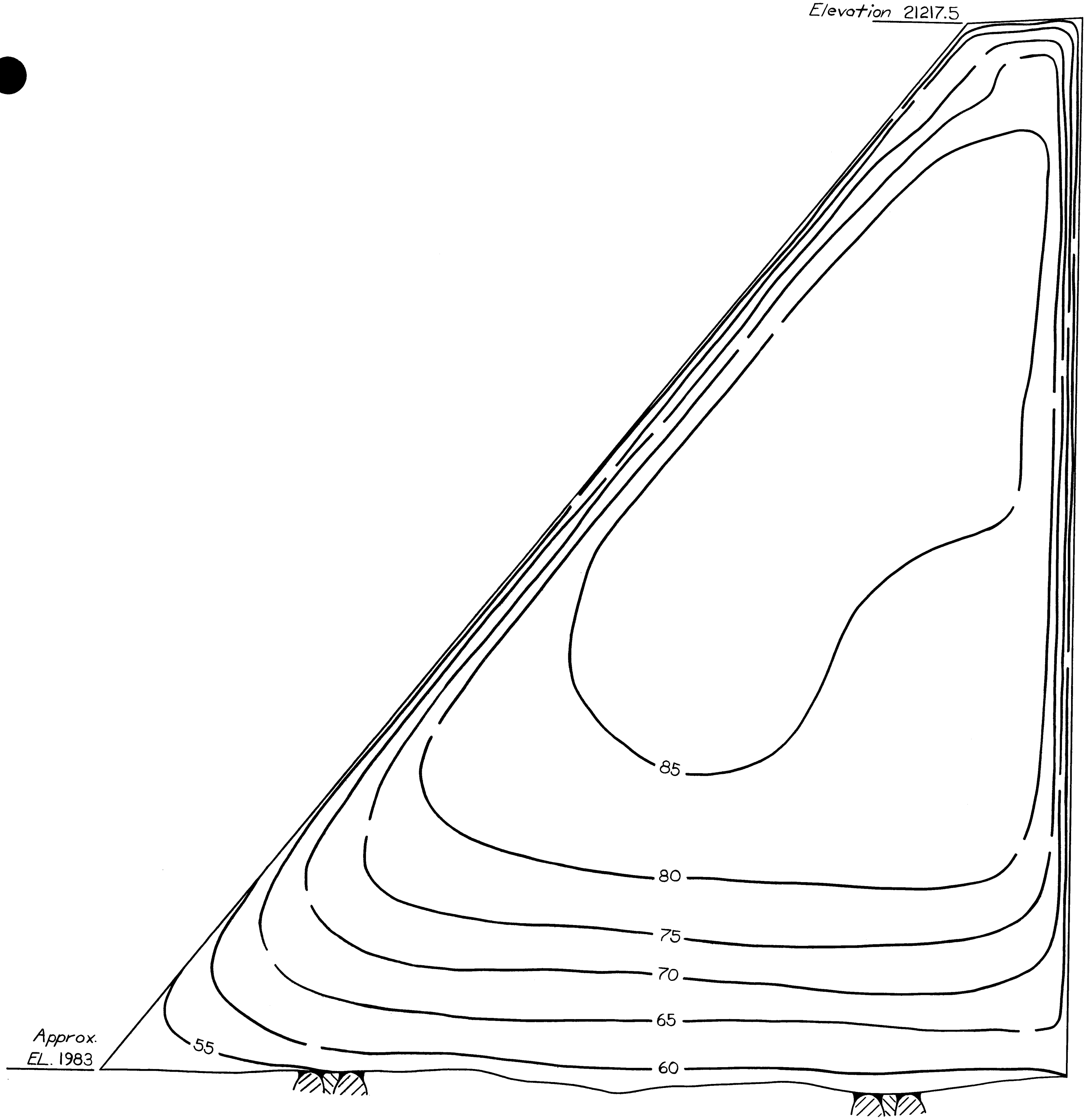
WILLOW CREEK DAM
HEPPNER, OREGON

NON-OVERFLOW THERMAL CONTOURS

1 OCTOBER 1982

DWN BY KAROL TALBOTT

PLATE 18.15

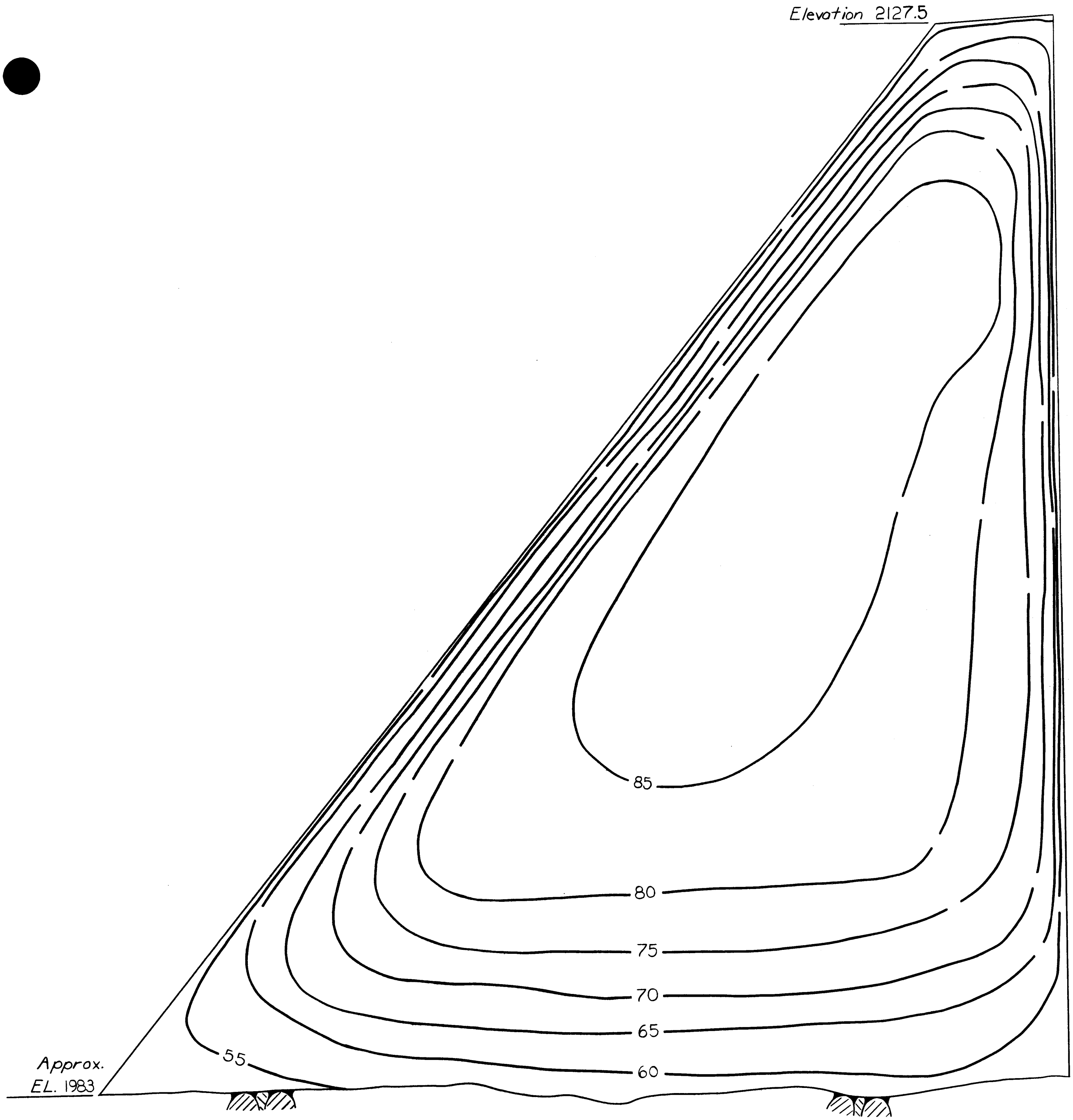


WILLOW CREEK DAM
HEPPNER, OREGON

NON-OVERFLOW THERMAL CONTOURS
1 NOVEMBER 1982

DWN BY KAROL TALBOTT

PLATE 18.16

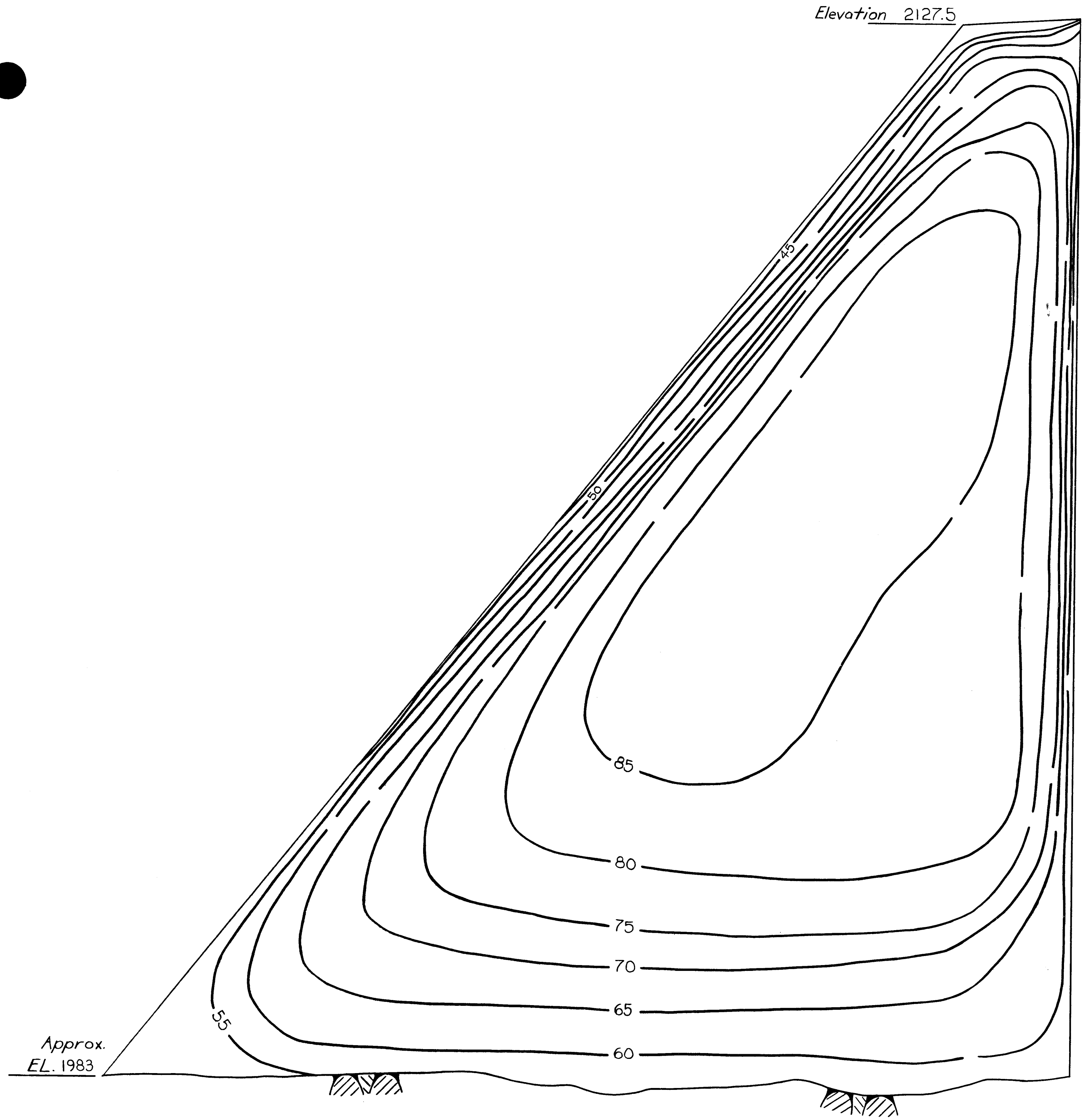


WILLOW CREEK DAM
HEPPNER, OREGON

NON-OVERFLOW THERMAL CONTOURS
1 DECEMBER 1982

DWN BY KAROL TALBOTT

PLATE 18.17

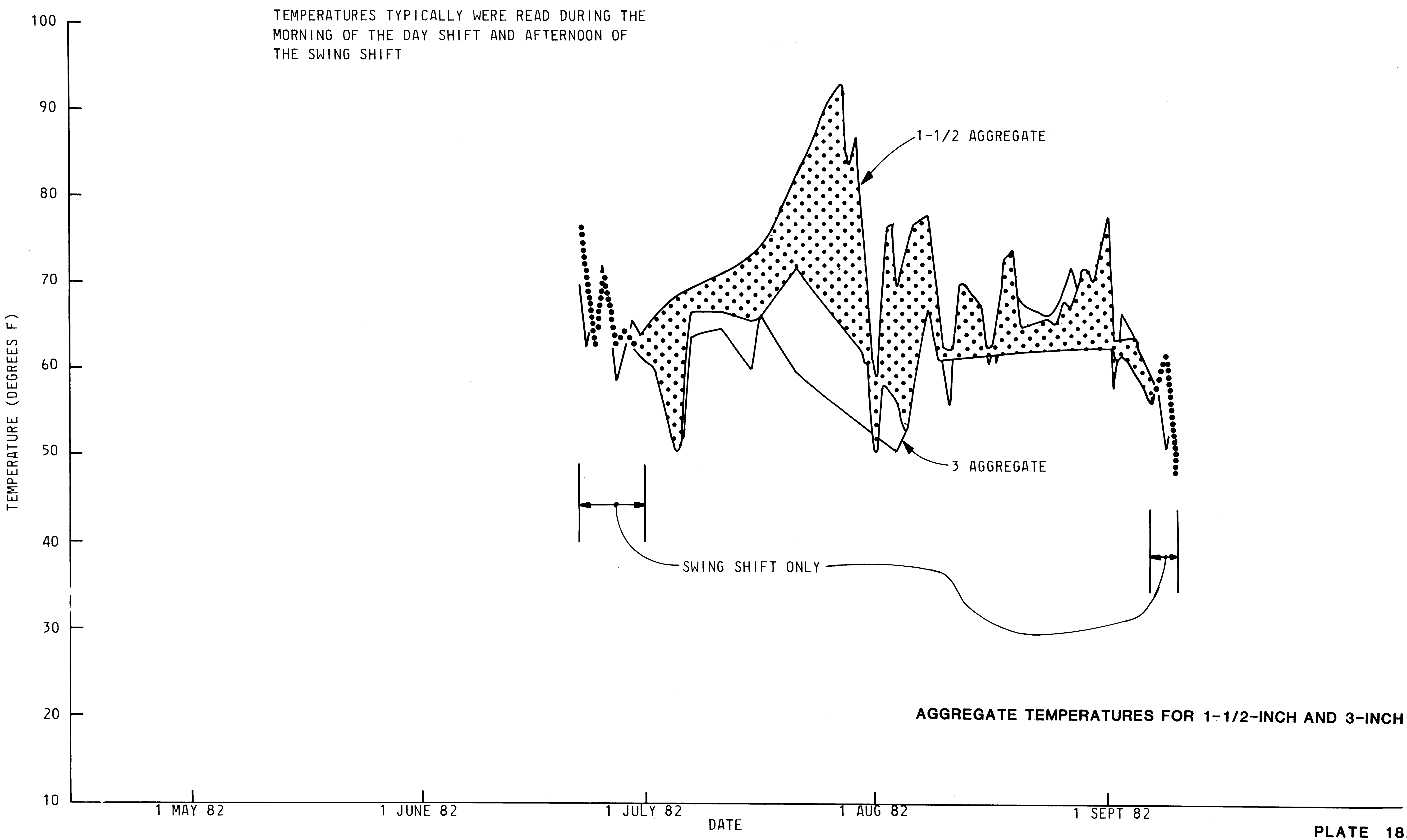


WILLOW CREEK DAM
HEPPNER, OREGON

NON-OVERFLOW THERMAL CONTOURS
1 JANUARY 1983

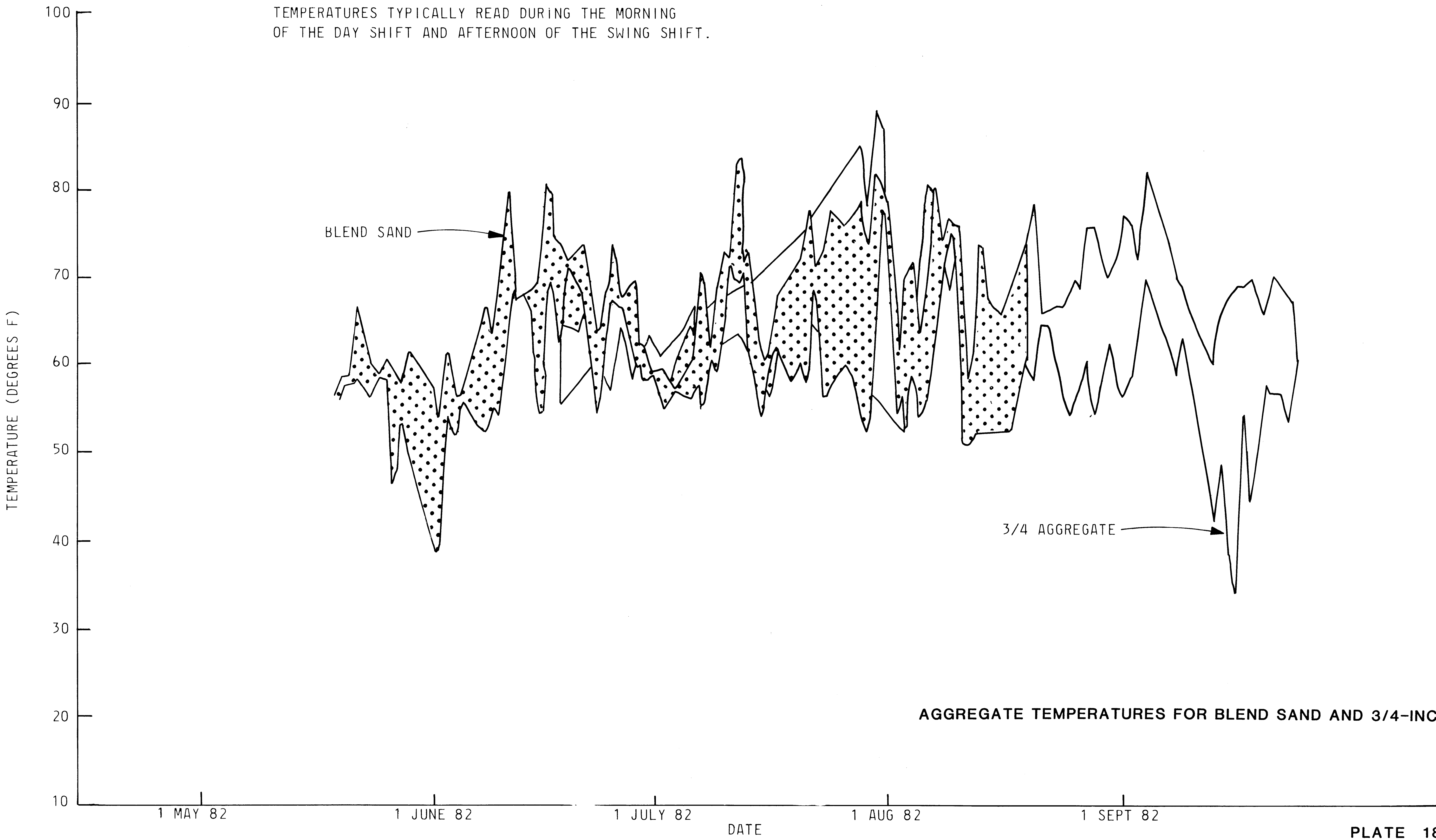
DWN BY KAROL TALBOTT

PLATE 18.18



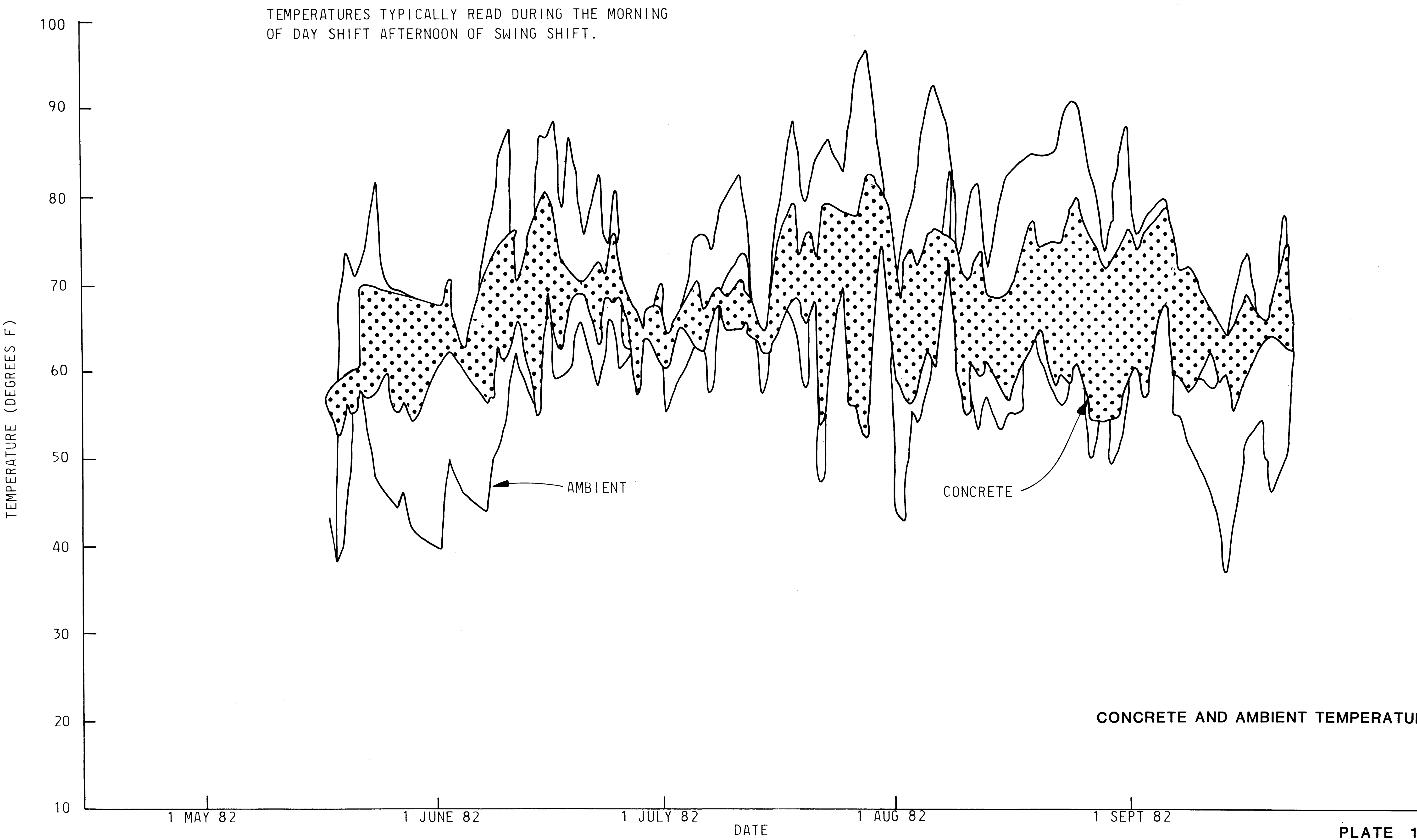
AGGREGATE TEMPERATURES FOR 1-1/2-INCH AND 3-INCH

PLATE 18.19

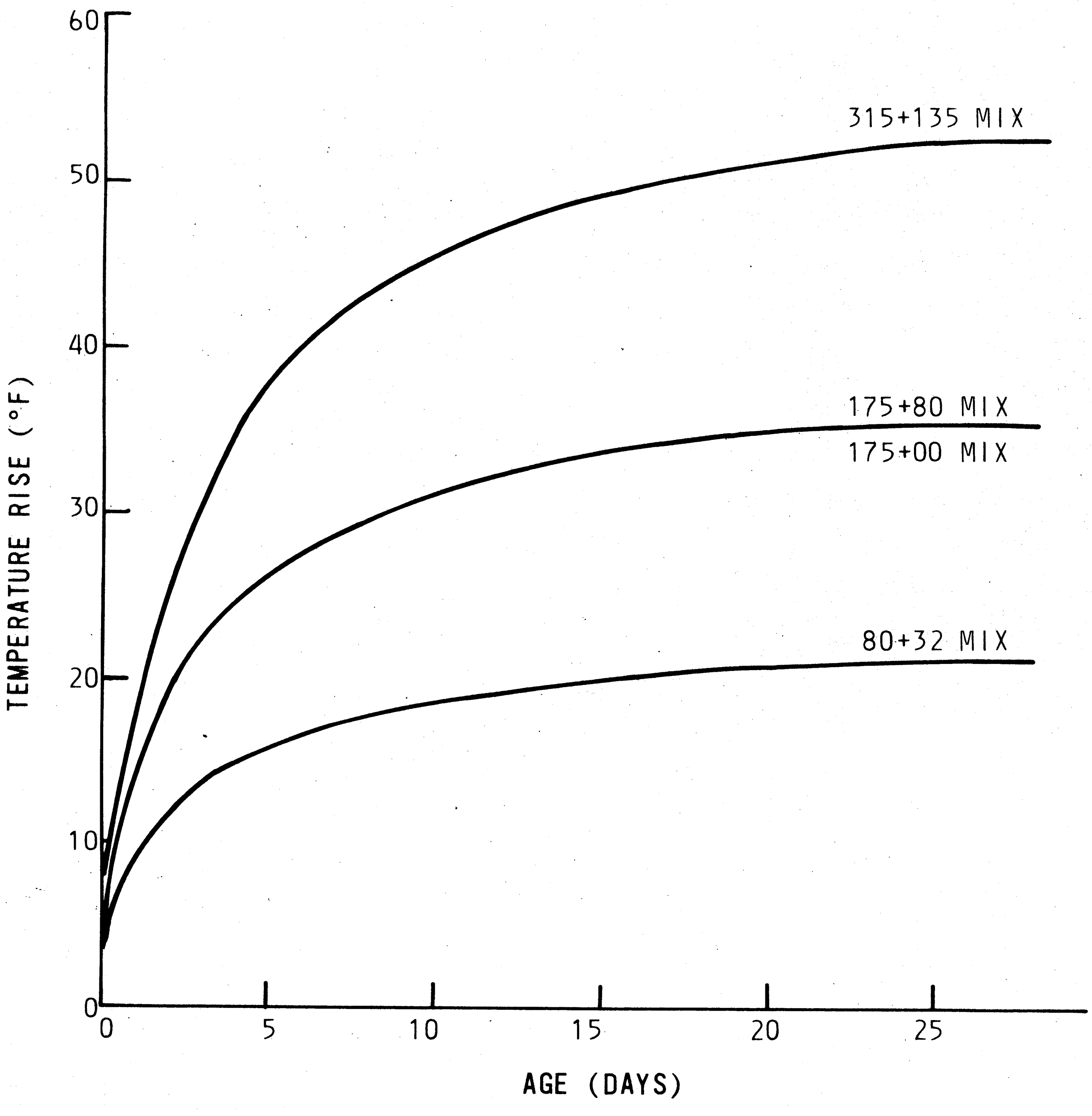


AGGREGATE TEMPERATURES FOR BLEND SAND AND 3/4-INCH

PLATE 18.20



CONCRETE AND AMBIENT TEMPERATURES



WILLOW CREEK DAM RCC MIXES

ADIABATIC TEMPERATURE RISE

PLATE 18.22

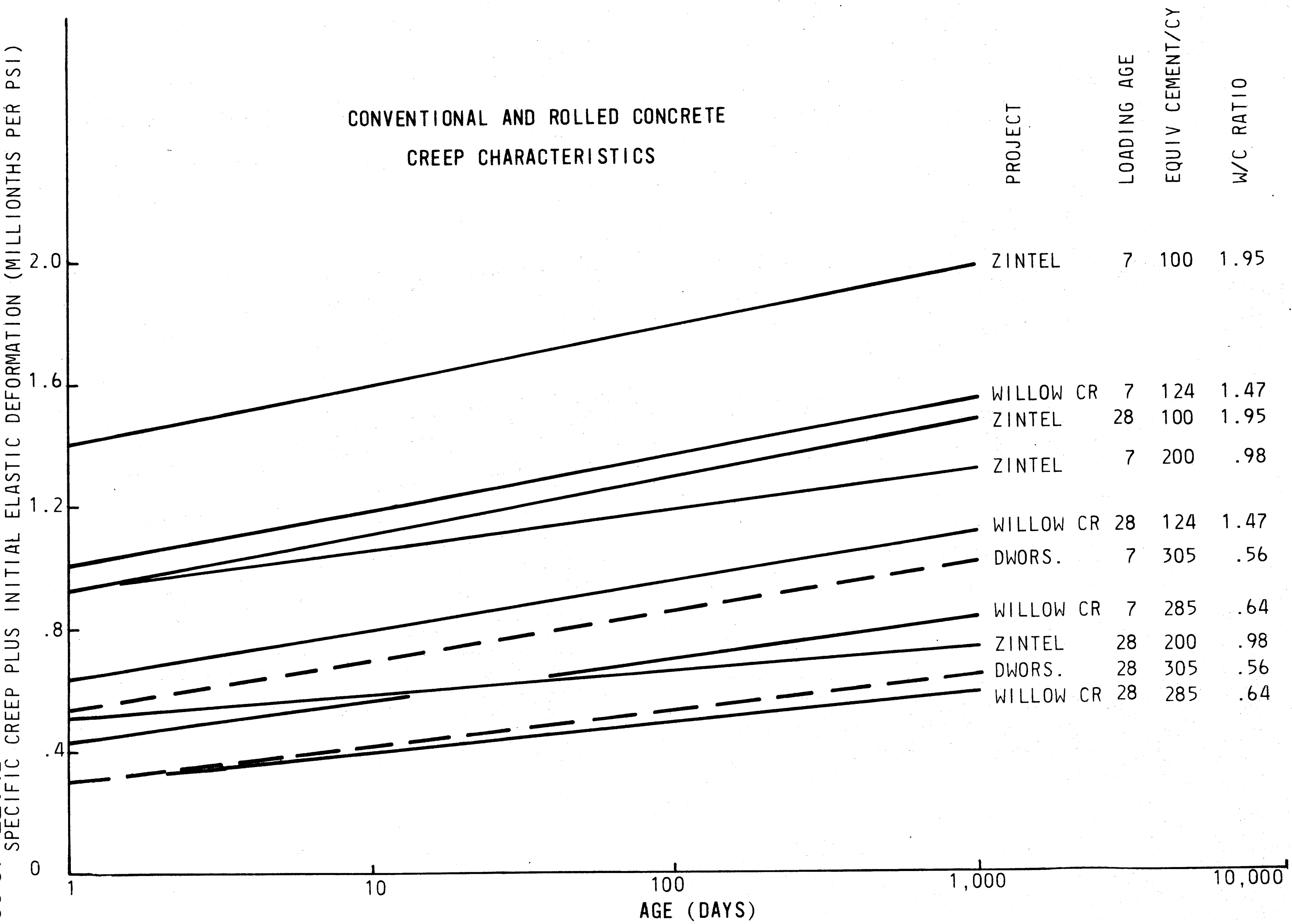
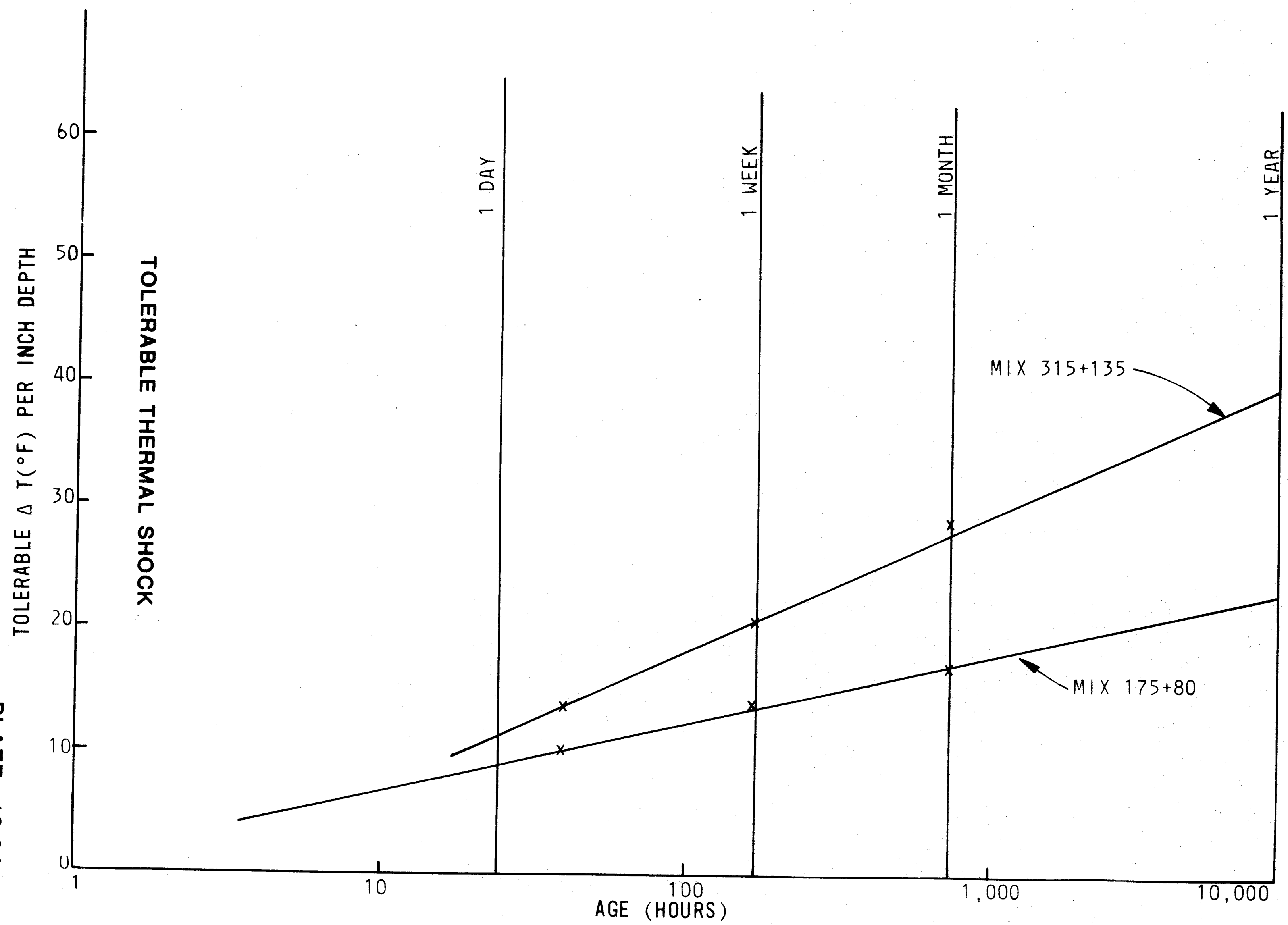

CONVENTIONAL AND ROLLED CONCRETE
CREEP CHARACTERISTICS
SPECIFIC CREEP PLUS INITIAL ELASTIC DEFORMATION (MILLIONTHS PER PSI)
0
.4
.8
1.2
1.6
2.0
1
10
100
1,000
10,000
AGE (DAYS)
PROJECT
LOADING AGE
EQUIV CEMENT/CY
W/C RATIO
ZINTEL 7 100 1.95
WILLOW CR 7 124 1.47
ZINTEL 28 100 1.95
ZINTEL 7 200 .98
WILLOW CR 28 124 1.47
DWORS. 7 305 .56
WILLOW CR 7 285 .64
ZINTEL 28 200 .98
DWORS. 28 305 .56
WILLOW CR 28 285 .64

PLATE 18.23



TOLERABLE THERMAL SHOCK

PLATE 18.24

EXHIBIT 18.1

TYPICAL PLOTTED TEMPERATURES
FOR VARIOUS LOCATIONS AND MIXES

NOTE: The graphs are a sample. Space limitations do not allow inclusion of all of them. They follow sequentially by mix design starting with the lean interior mix (80+32), then the upstream face mix (175+00), then the downstream face mix (175+80), and lastly the spillway face mix (315+135). Within each mix they are organized starting with the lower elevation and progessing to higher elevation. An "offset" location of "50.00 D/S" indicates 50 feet downstream of the upstream face, "0.83 U/S" indicates 0.83 feet (10 inches) upstream of the downstream face, etc.

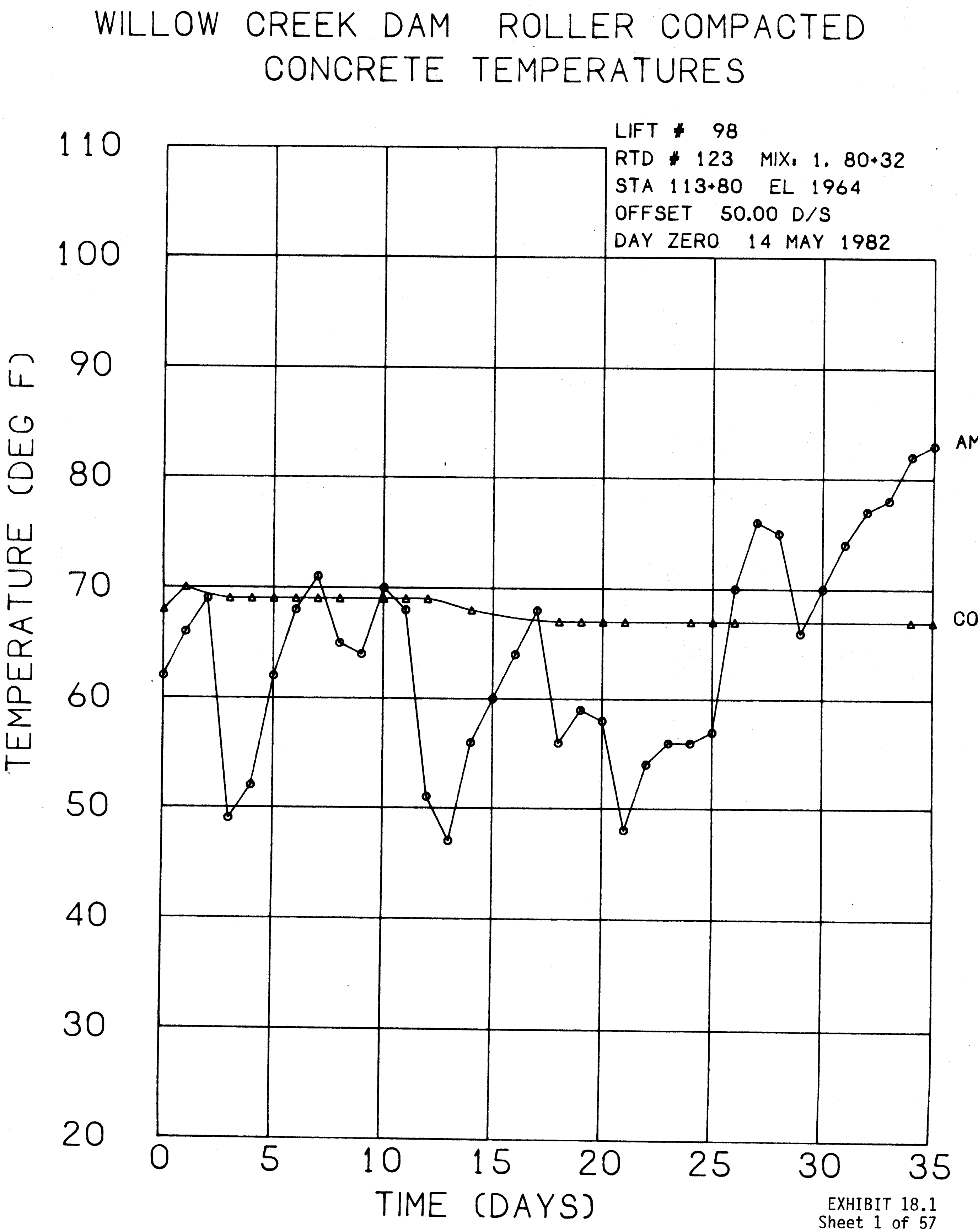


EXHIBIT 18.1
Sheet 1 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

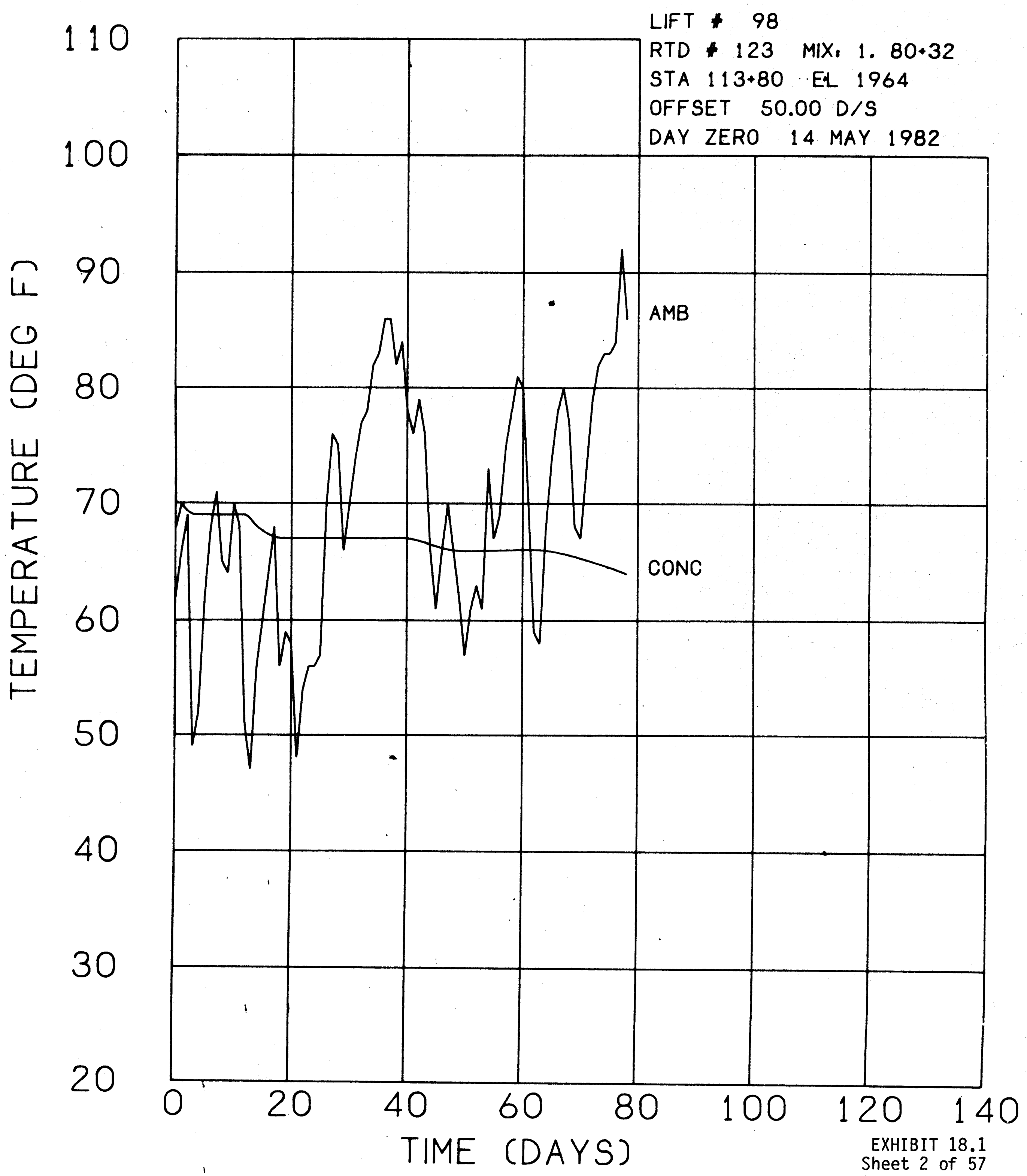


EXHIBIT 18.1
Sheet 2 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

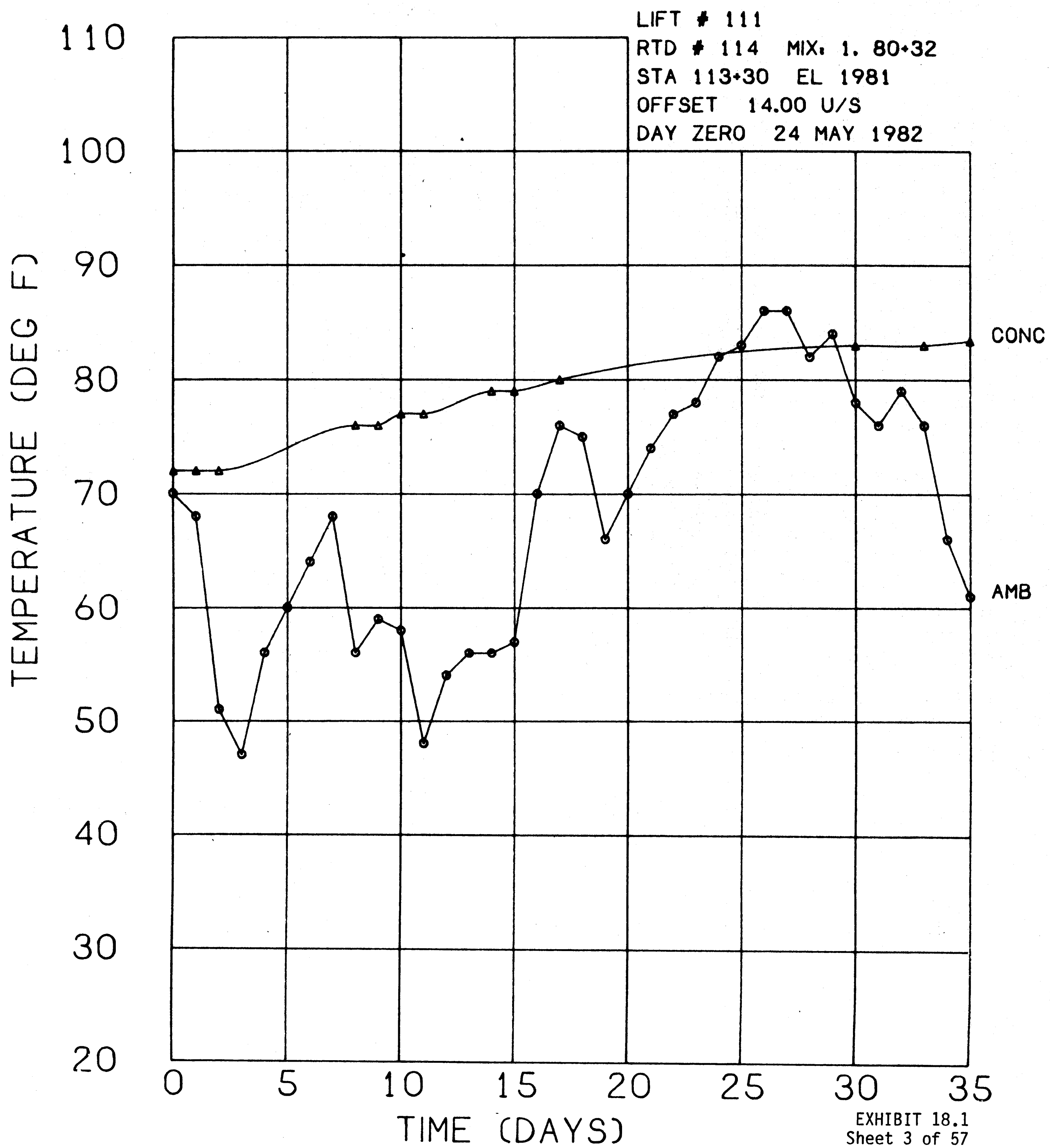


EXHIBIT 18.1
Sheet 3 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

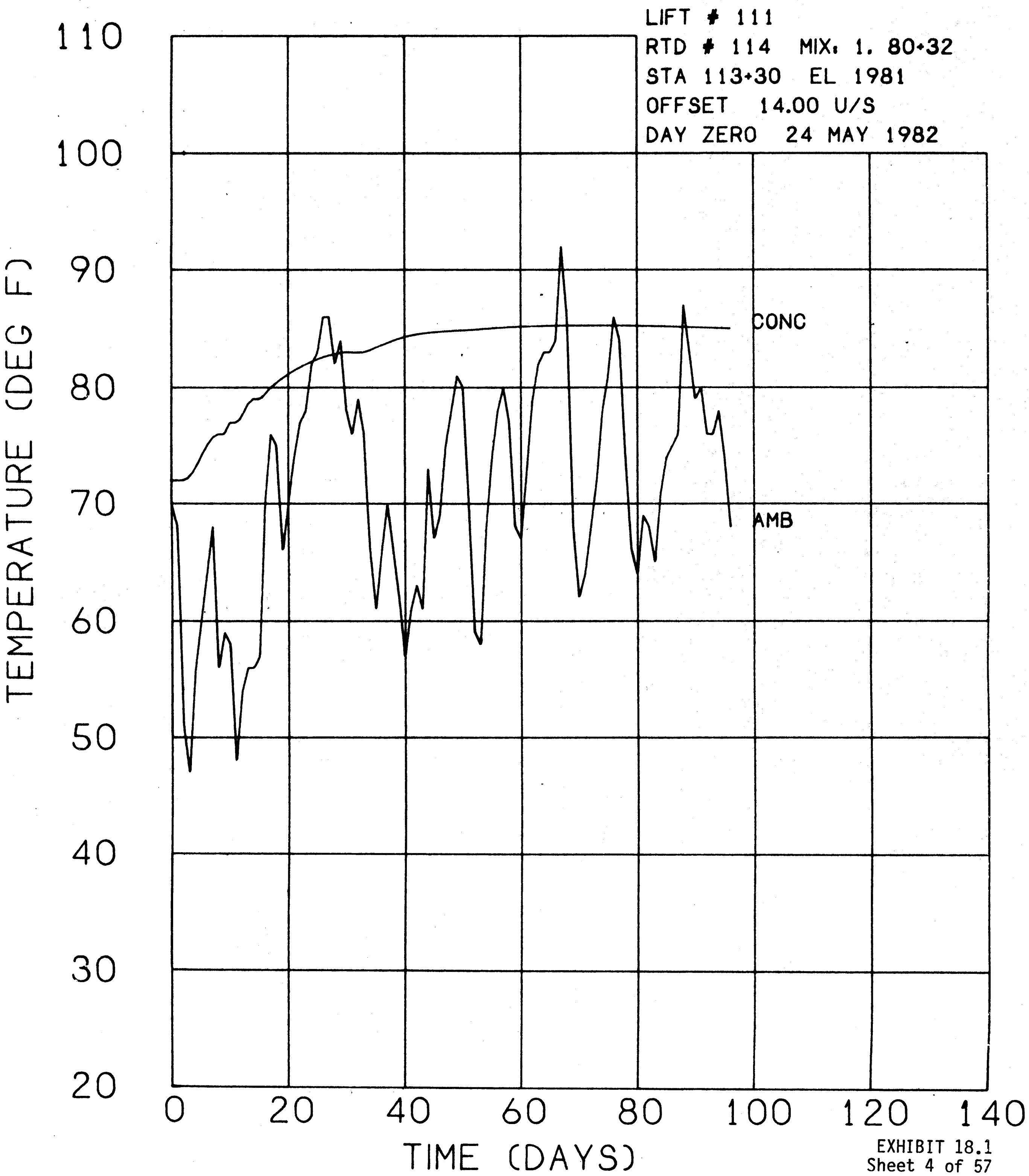


EXHIBIT 18.1
Sheet 4 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

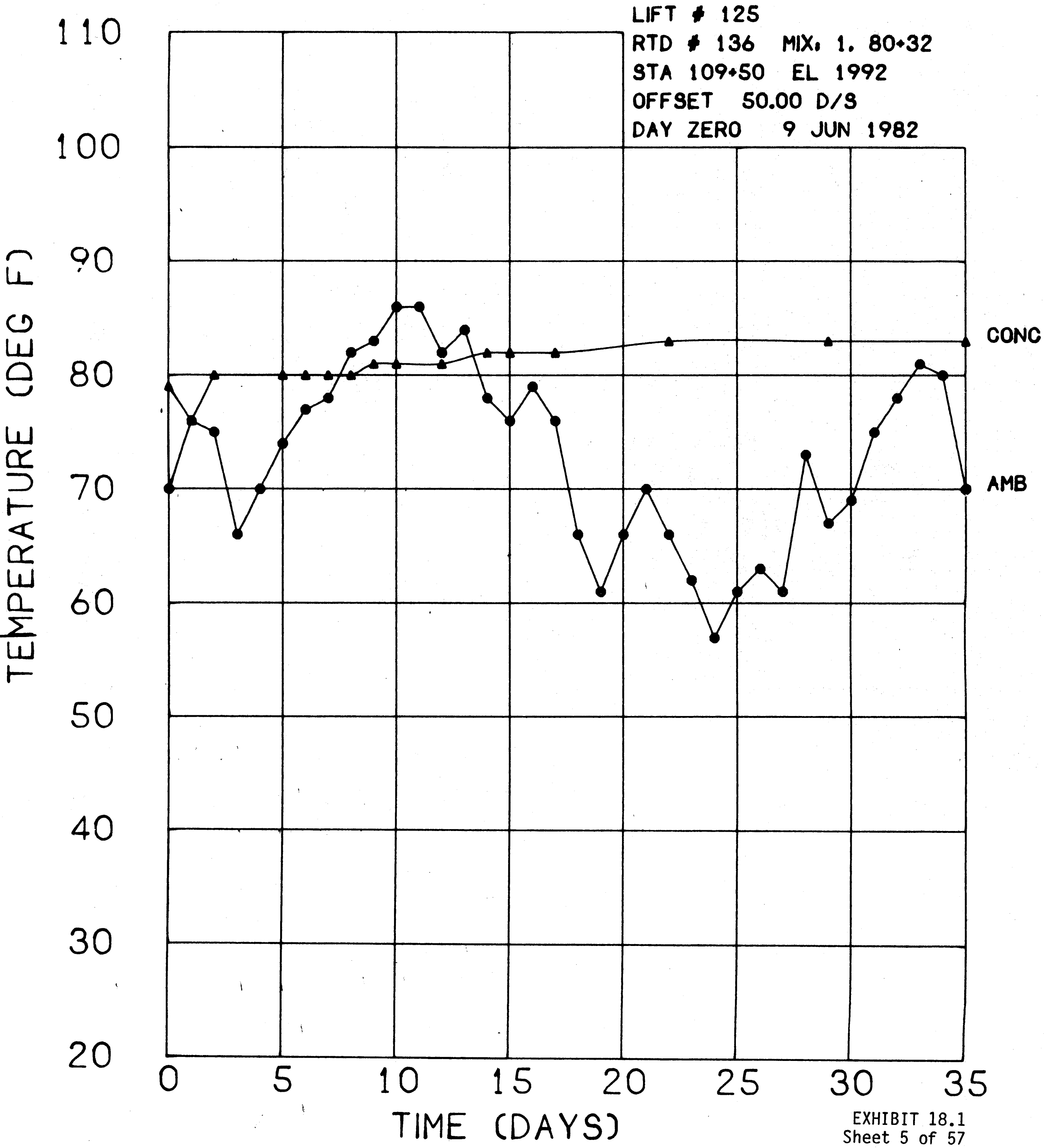


EXHIBIT 18.1
Sheet 5 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

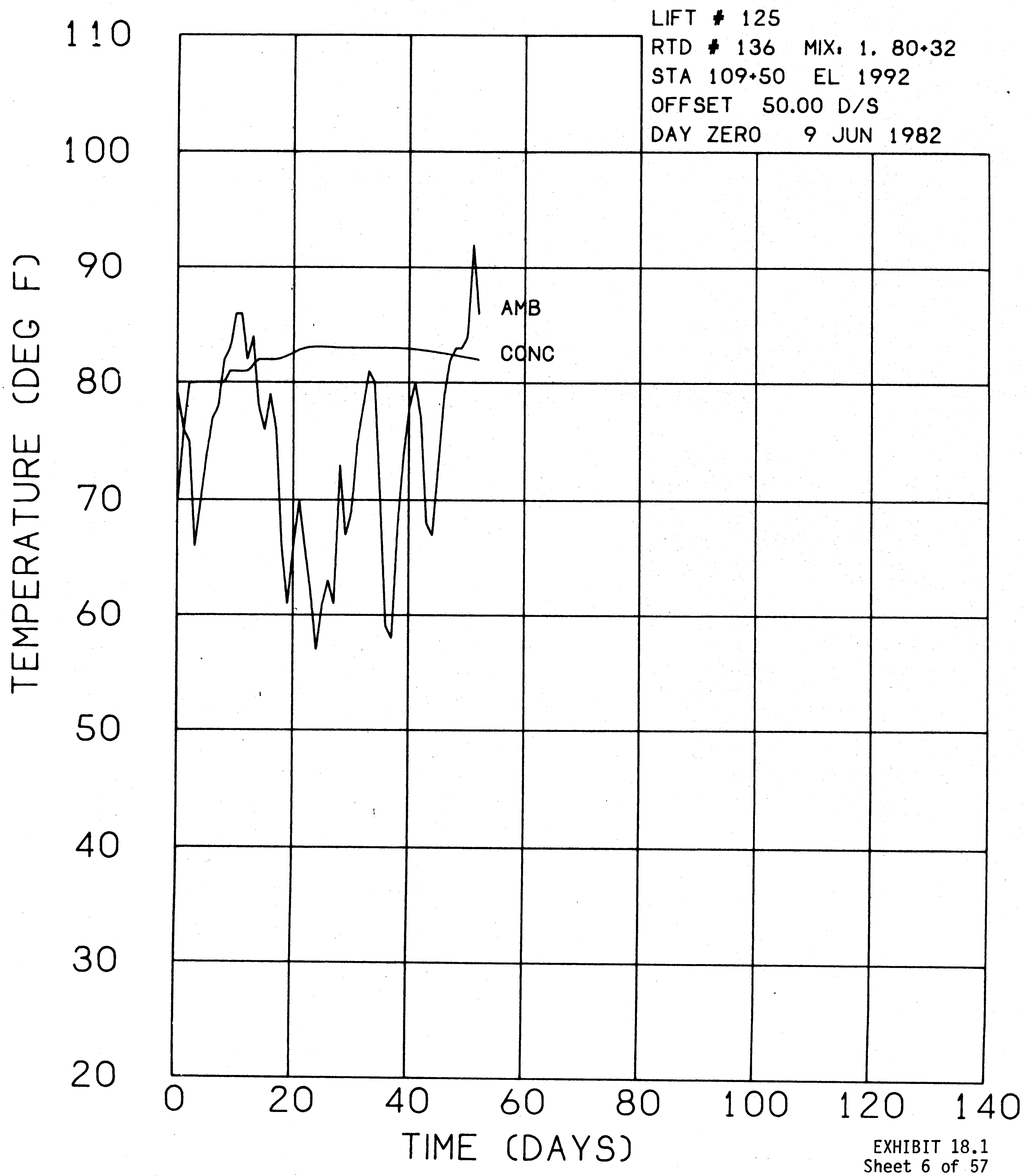
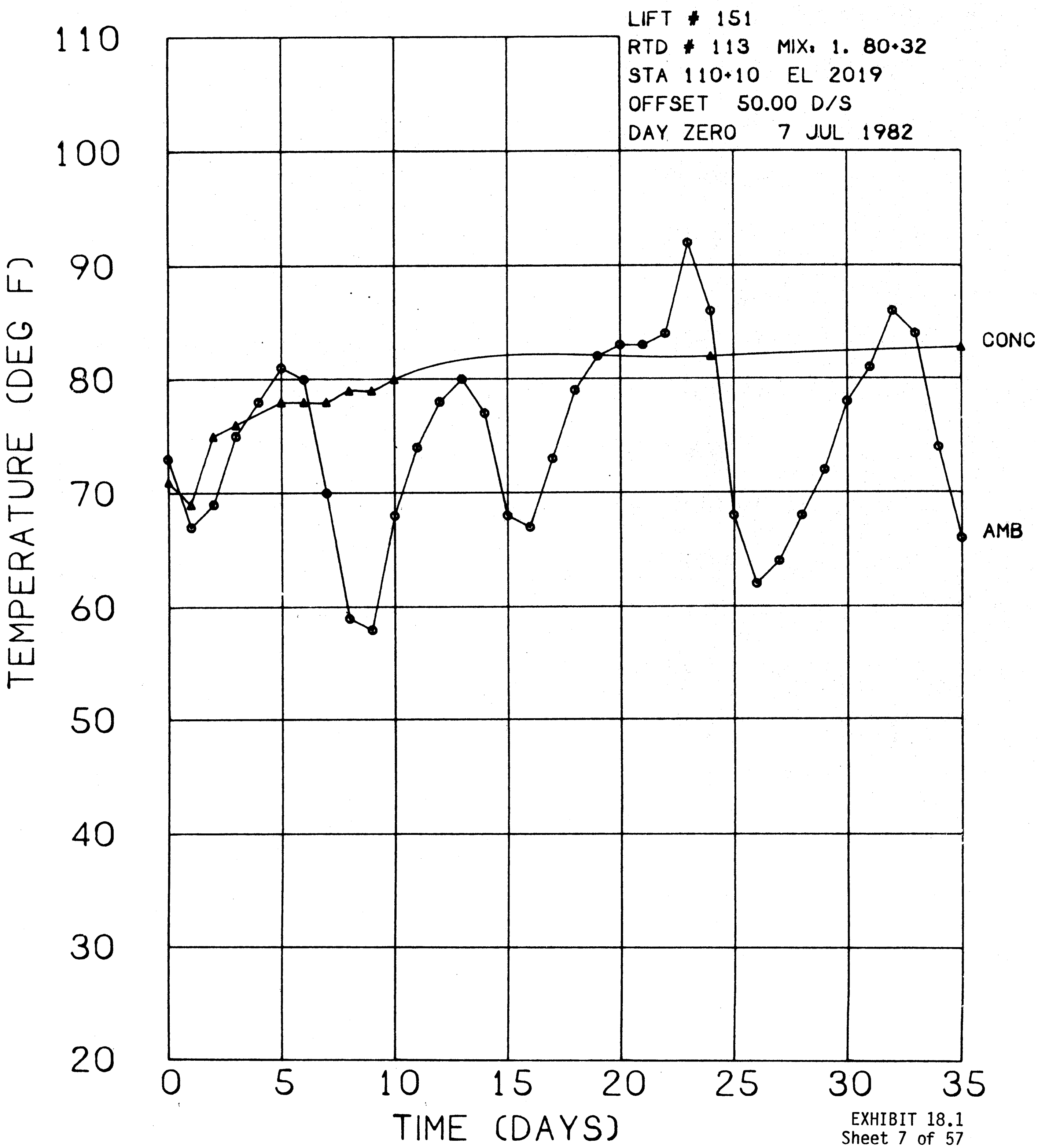


EXHIBIT 18.1
Sheet 6 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES



WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

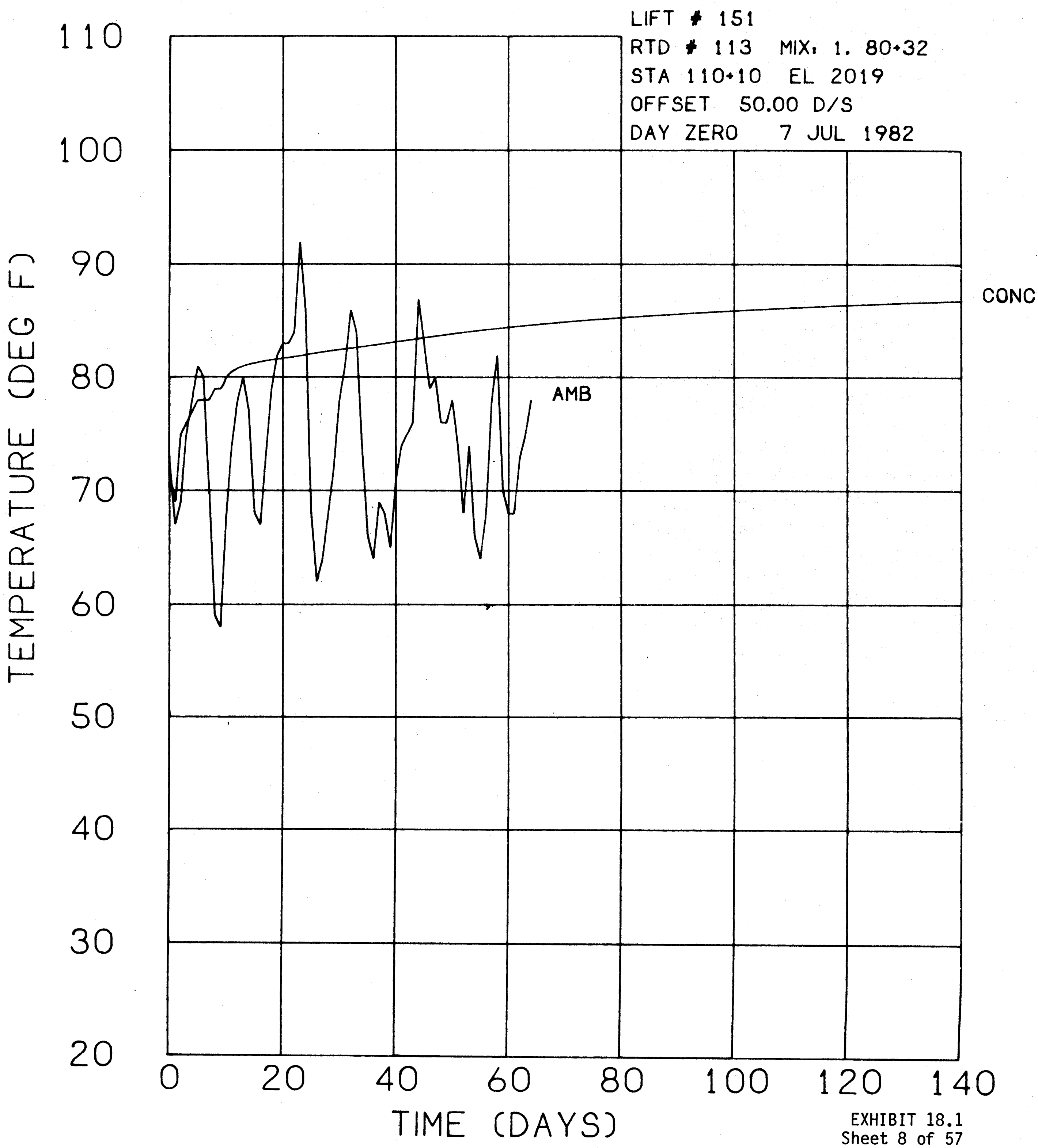


EXHIBIT 18.1
Sheet 8 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

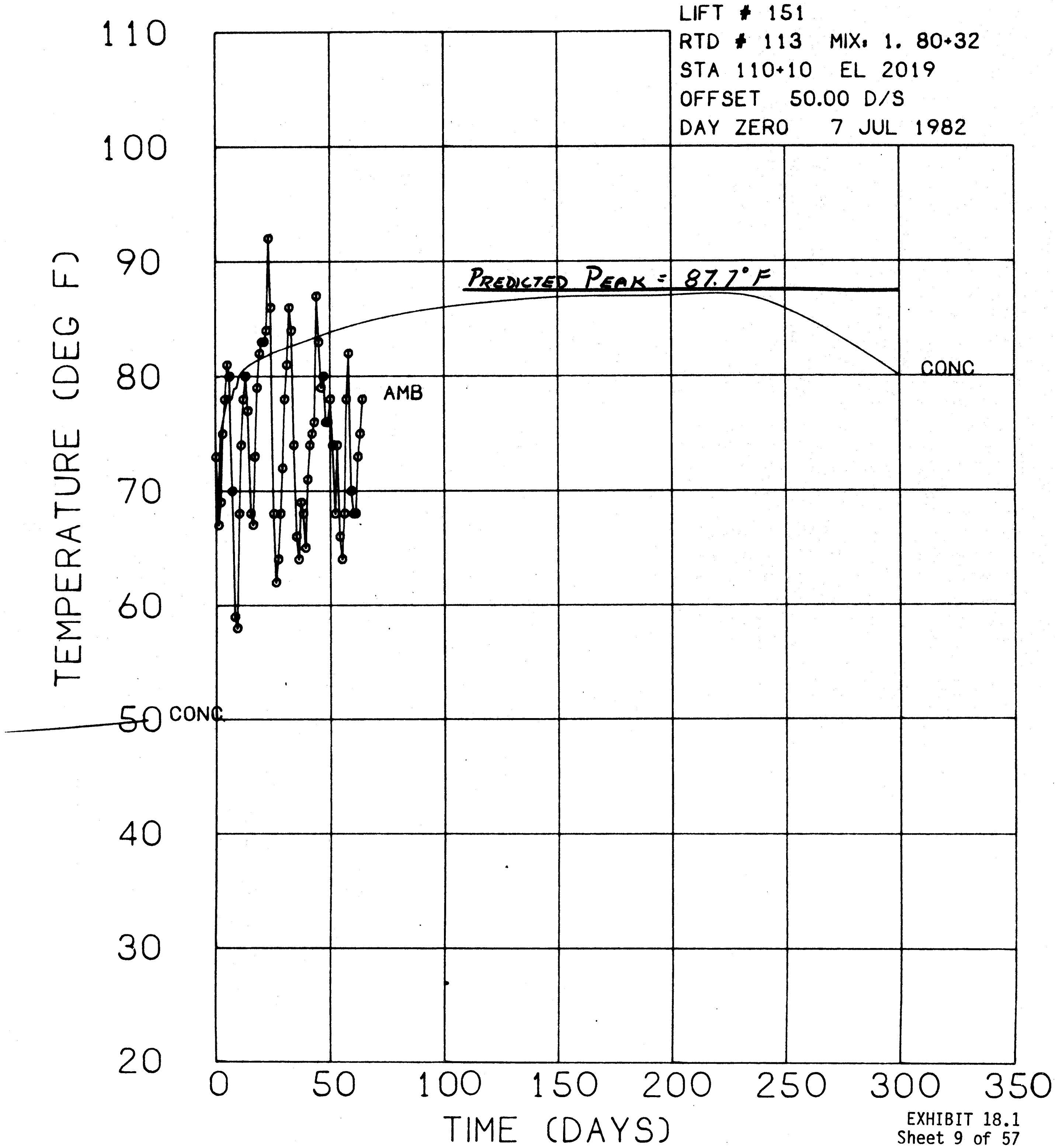


EXHIBIT 18.1
Sheet 9 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

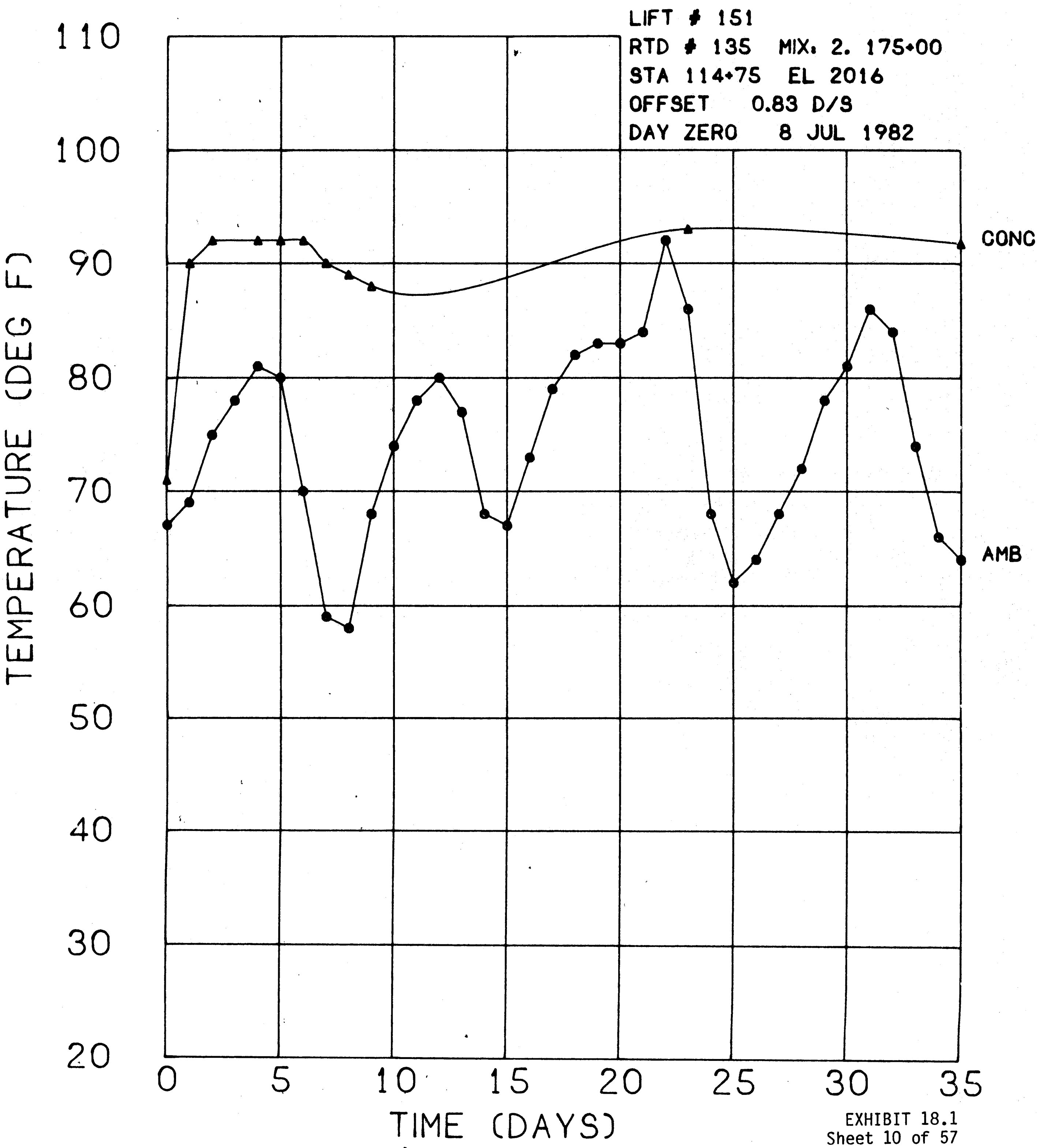


EXHIBIT 18.1
Sheet 10 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

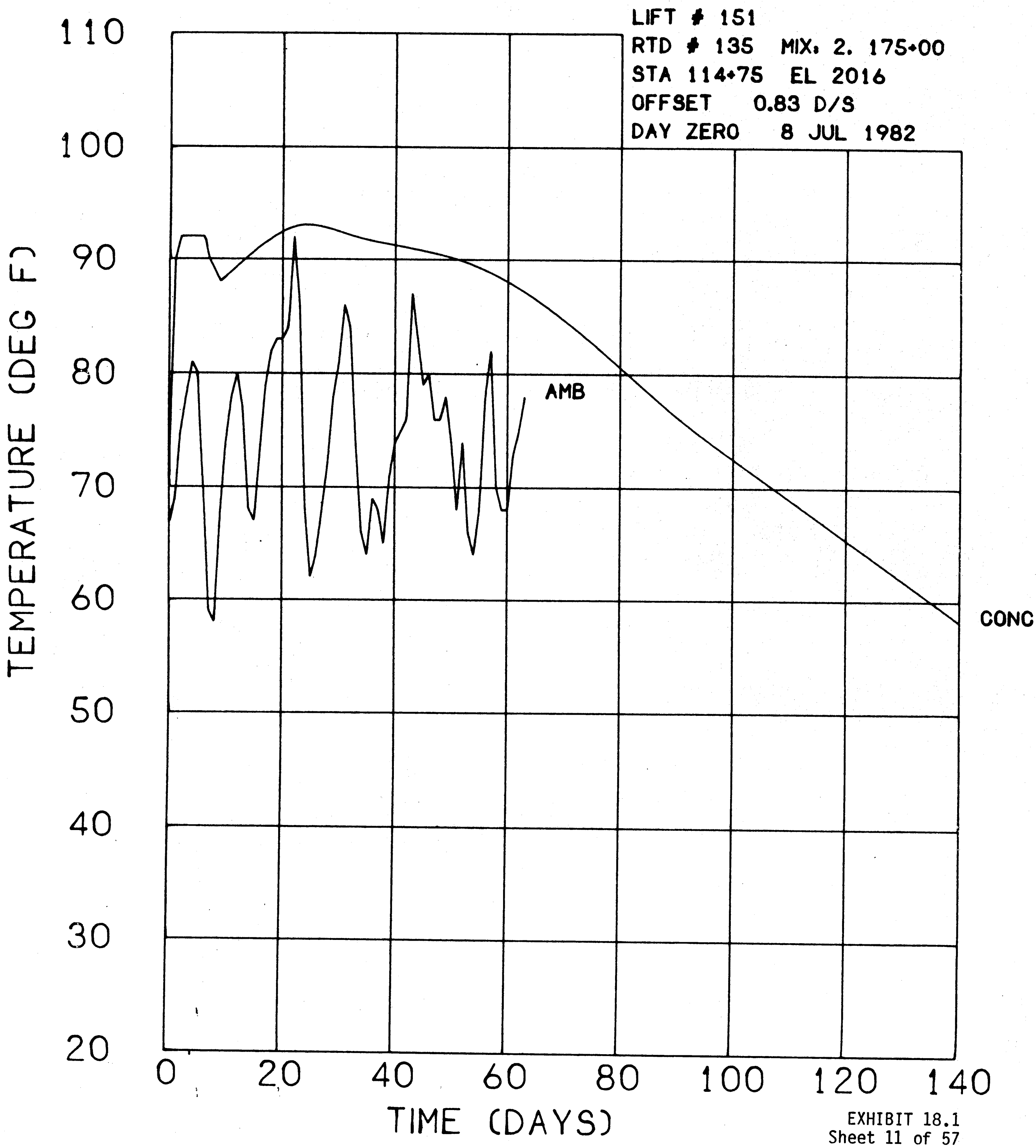
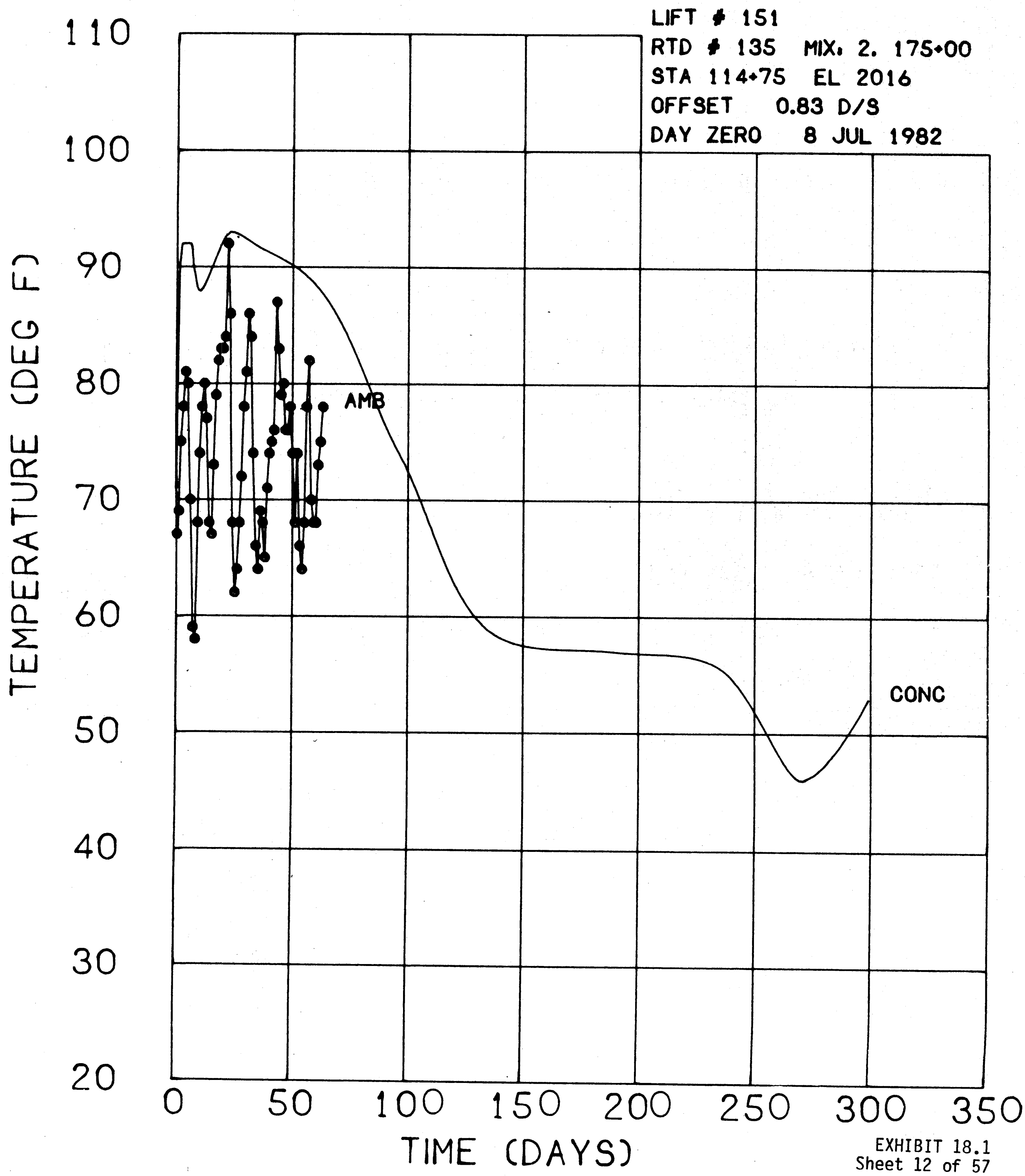


EXHIBIT 18.1
Sheet 11 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES



WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

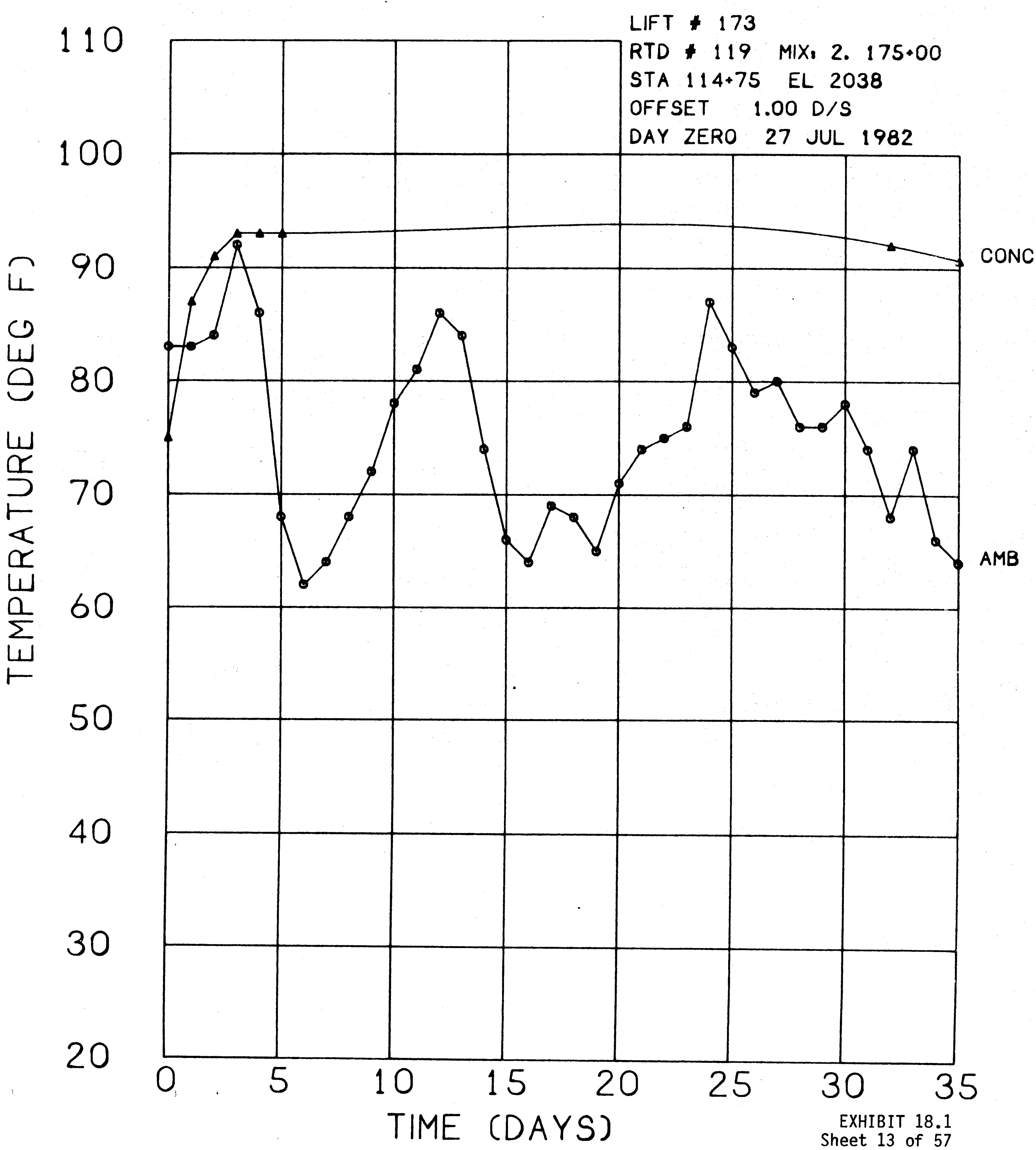
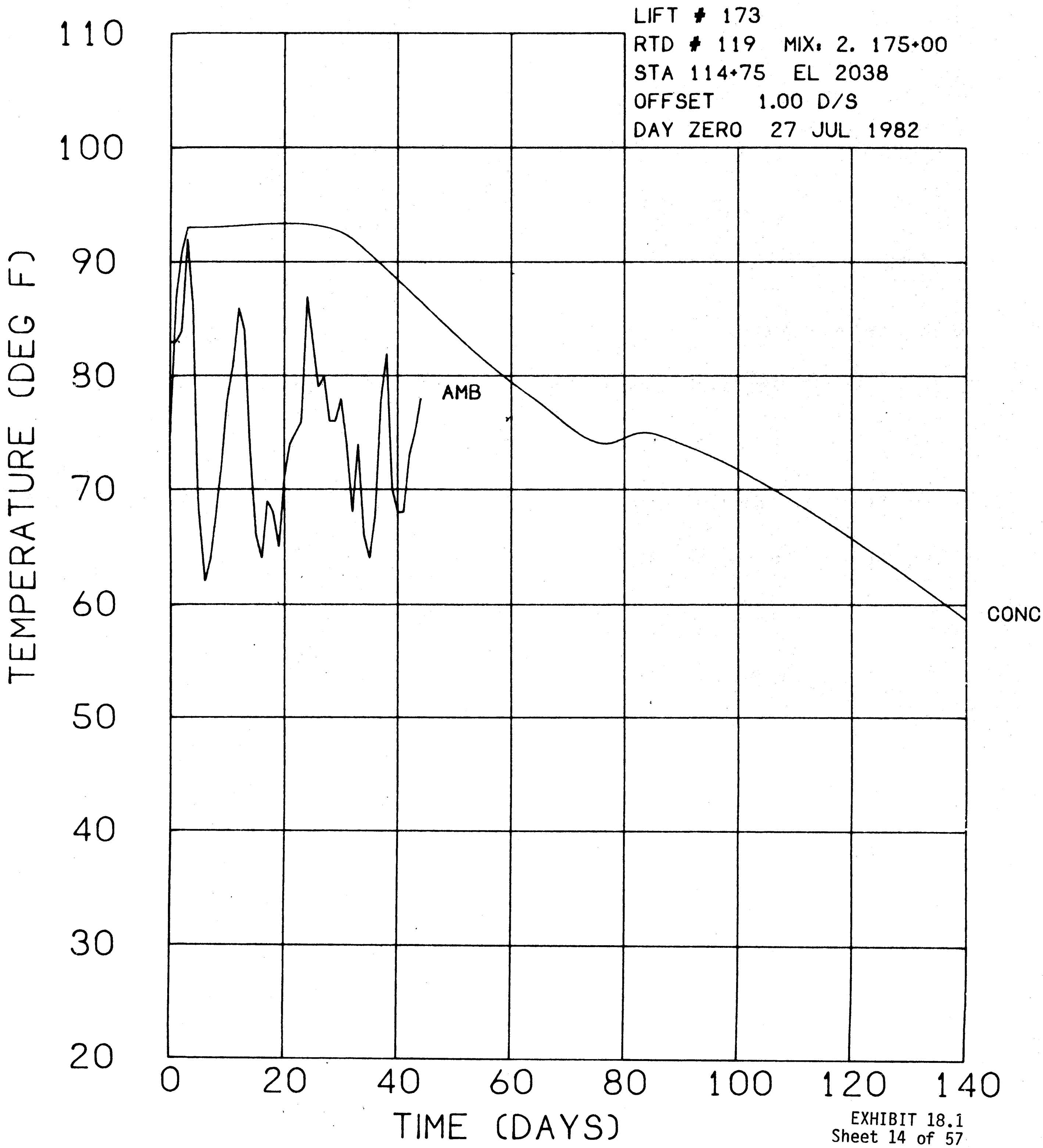


EXHIBIT 18.1
Sheet 13 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES



WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

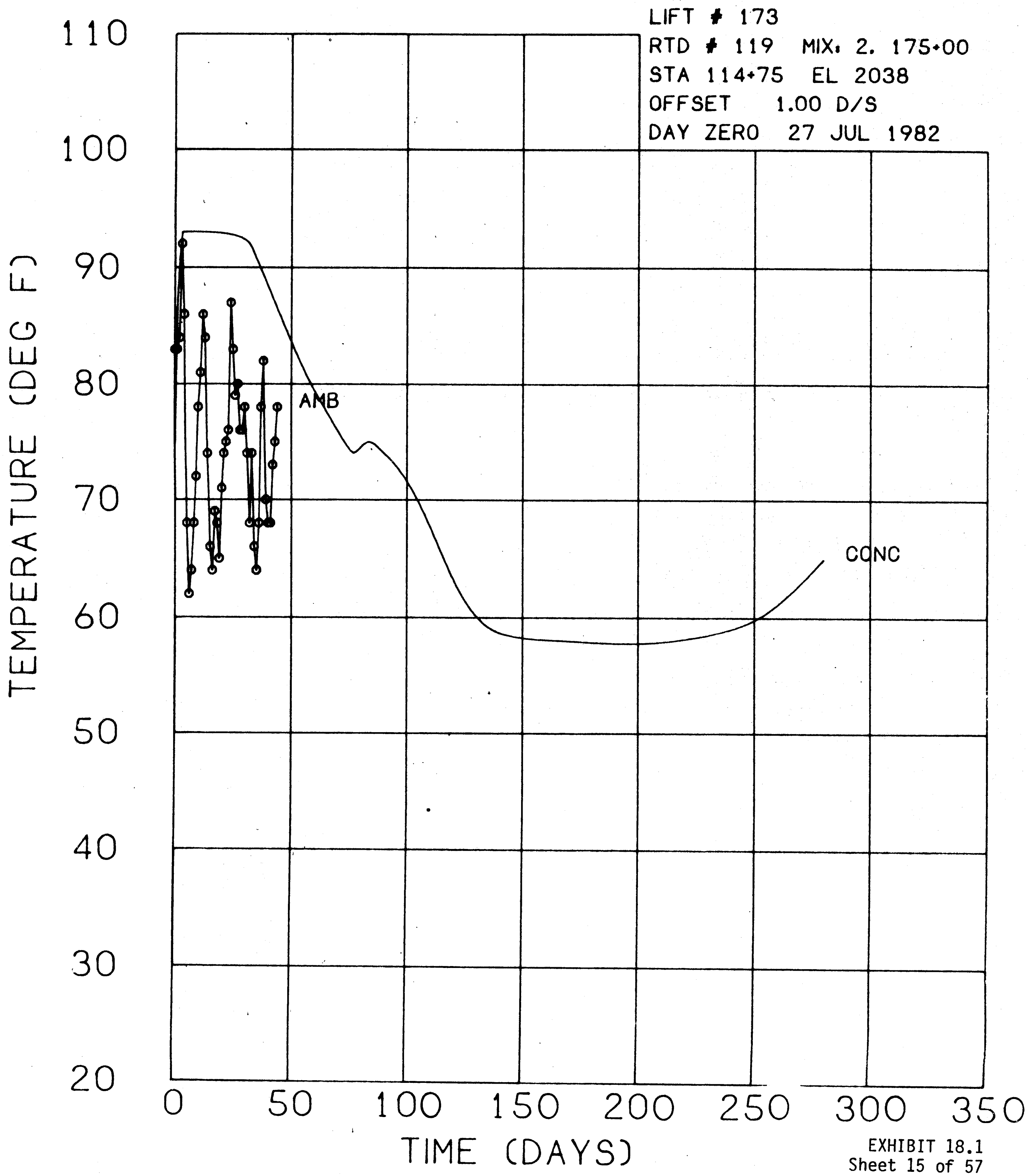


EXHIBIT 18.1
Sheet 15 of 57

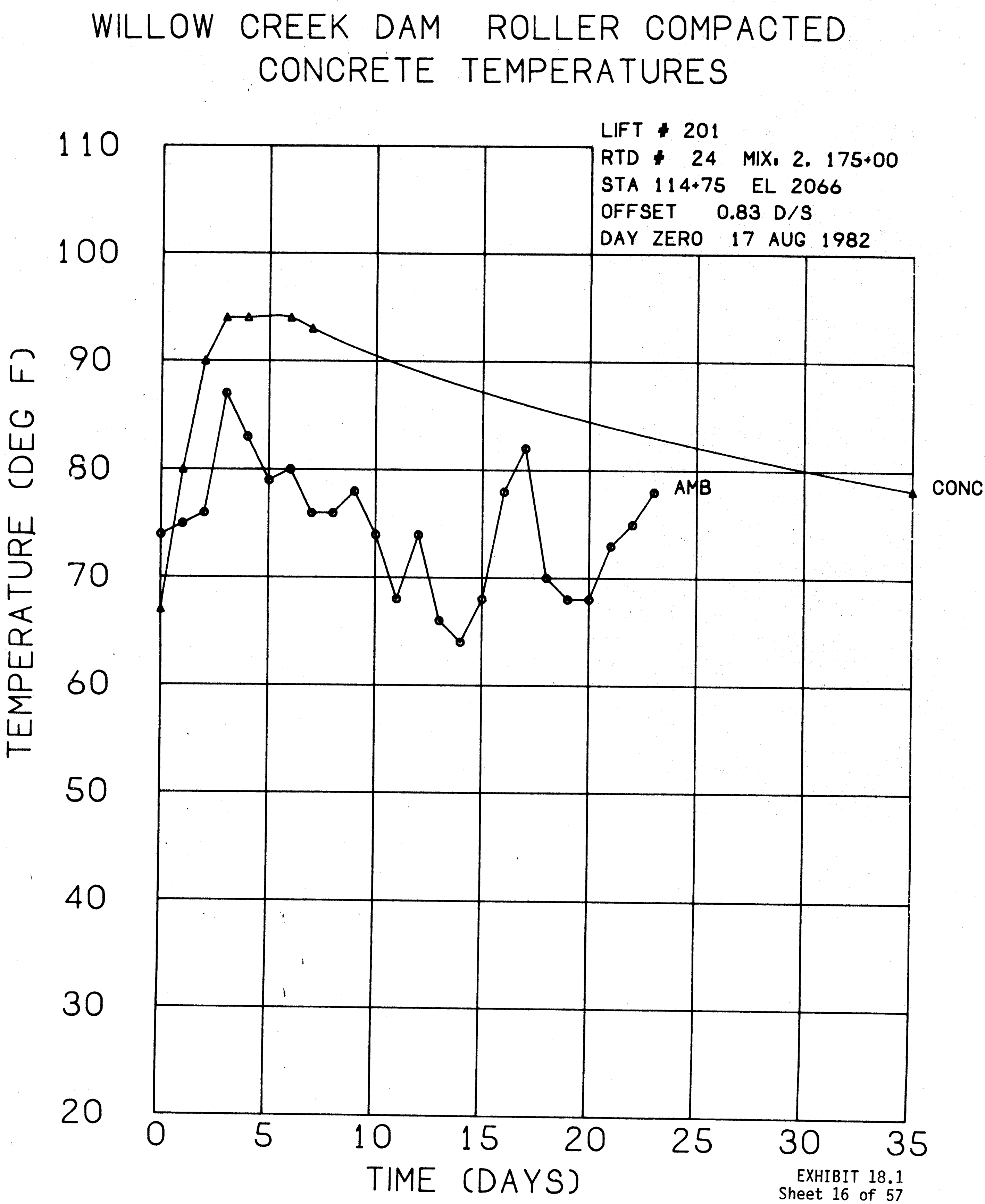


EXHIBIT 18.1
Sheet 16 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

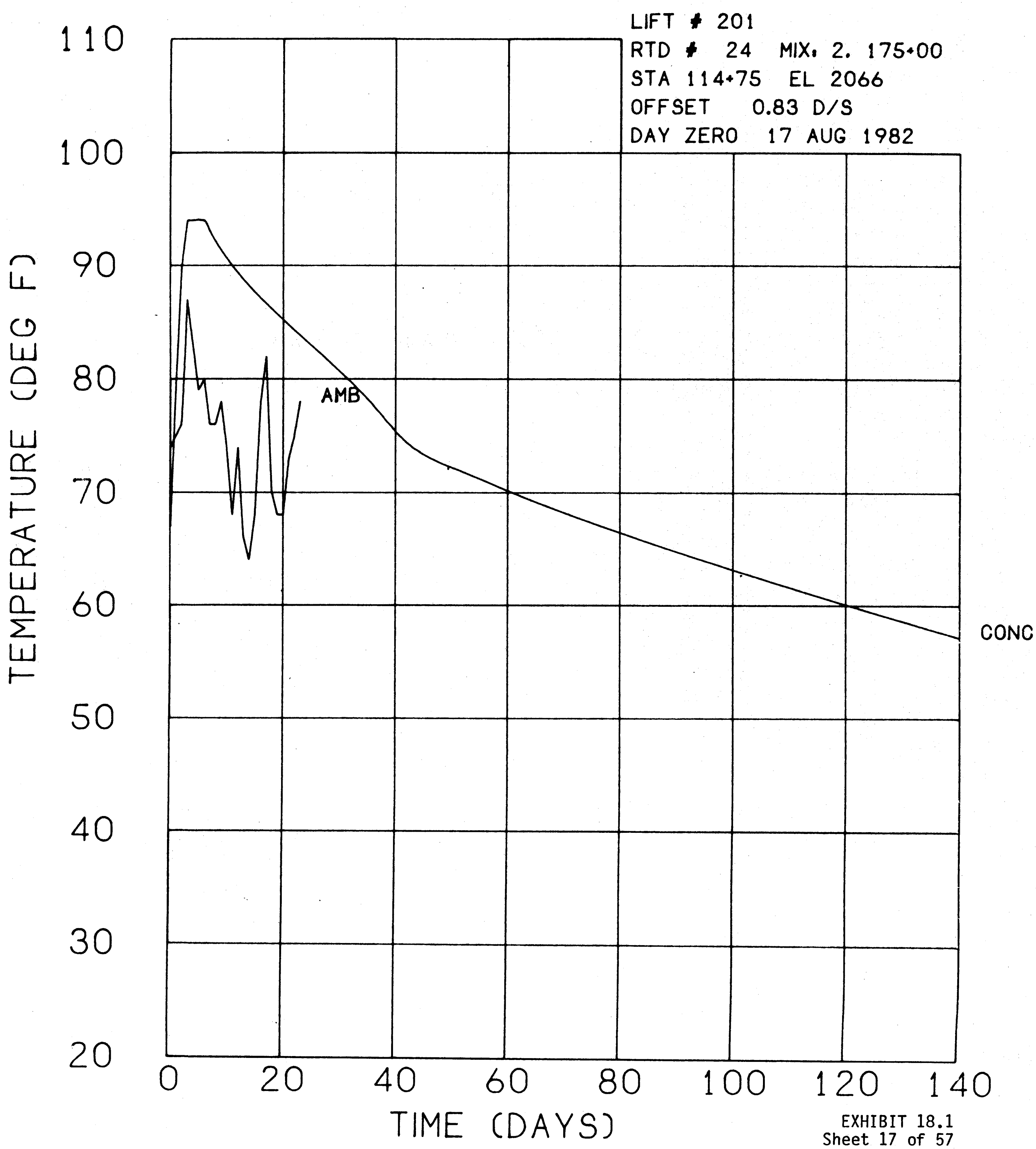


EXHIBIT 18.1
Sheet 17 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

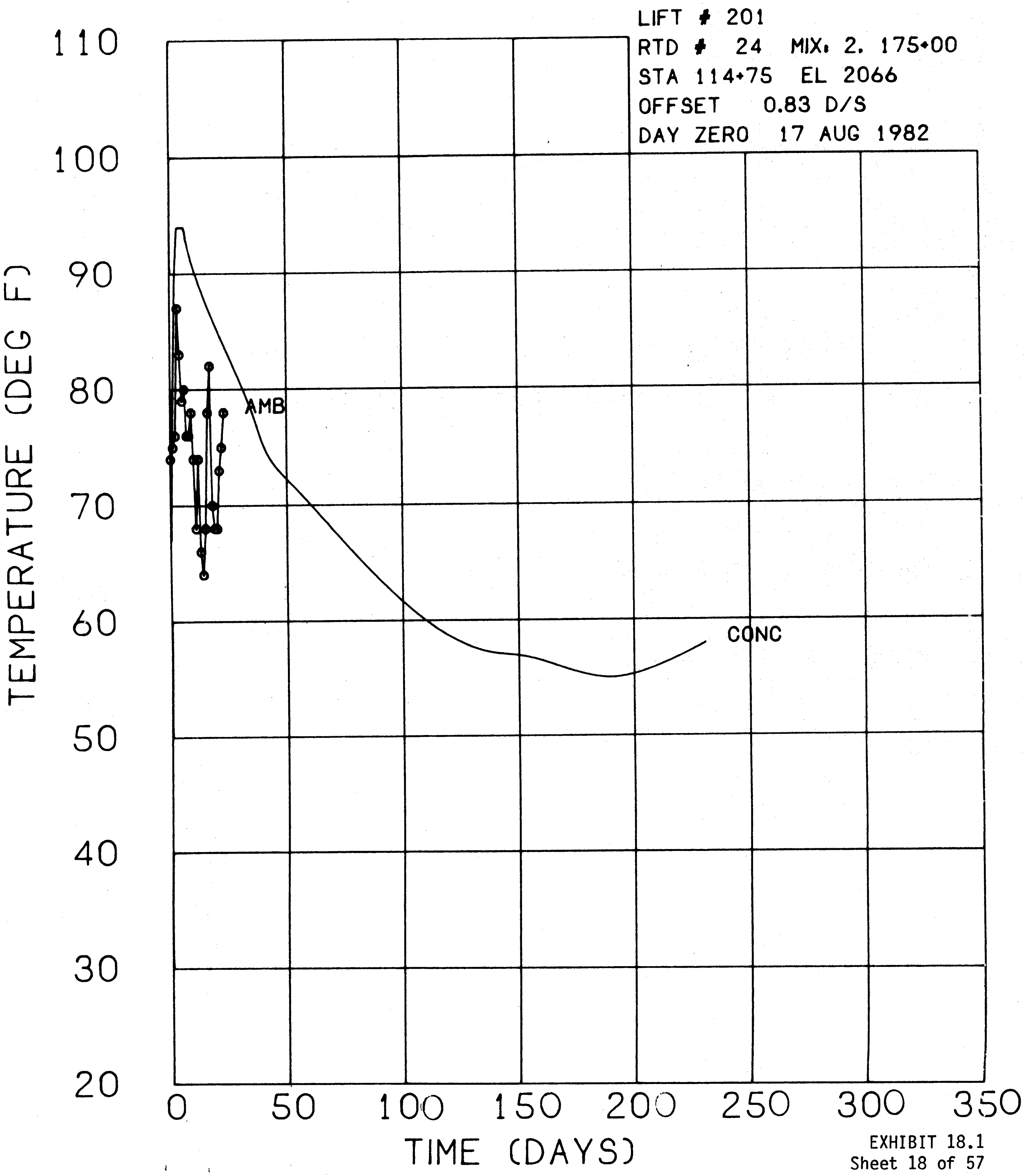
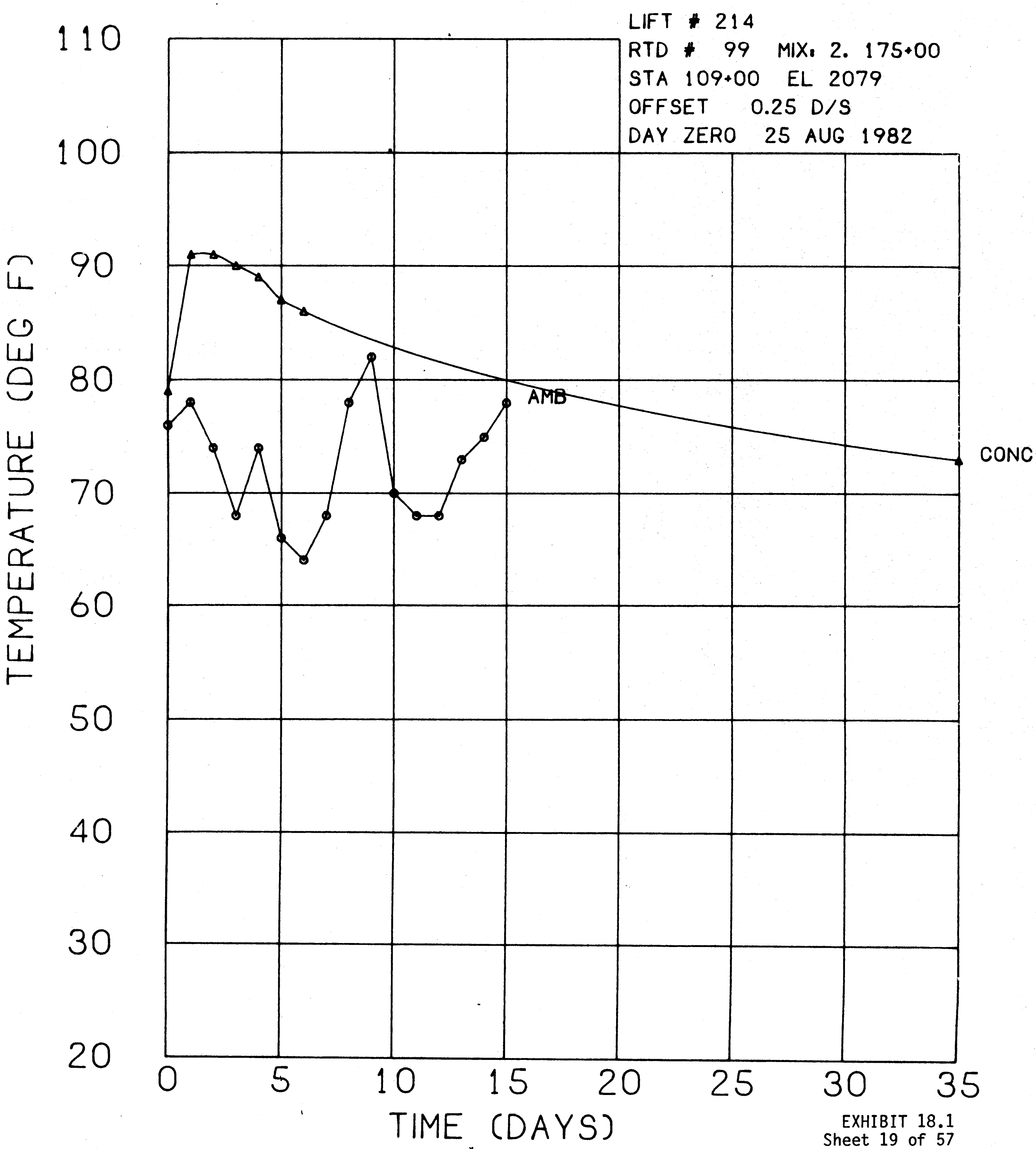


EXHIBIT 18.1
Sheet 18 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES



WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

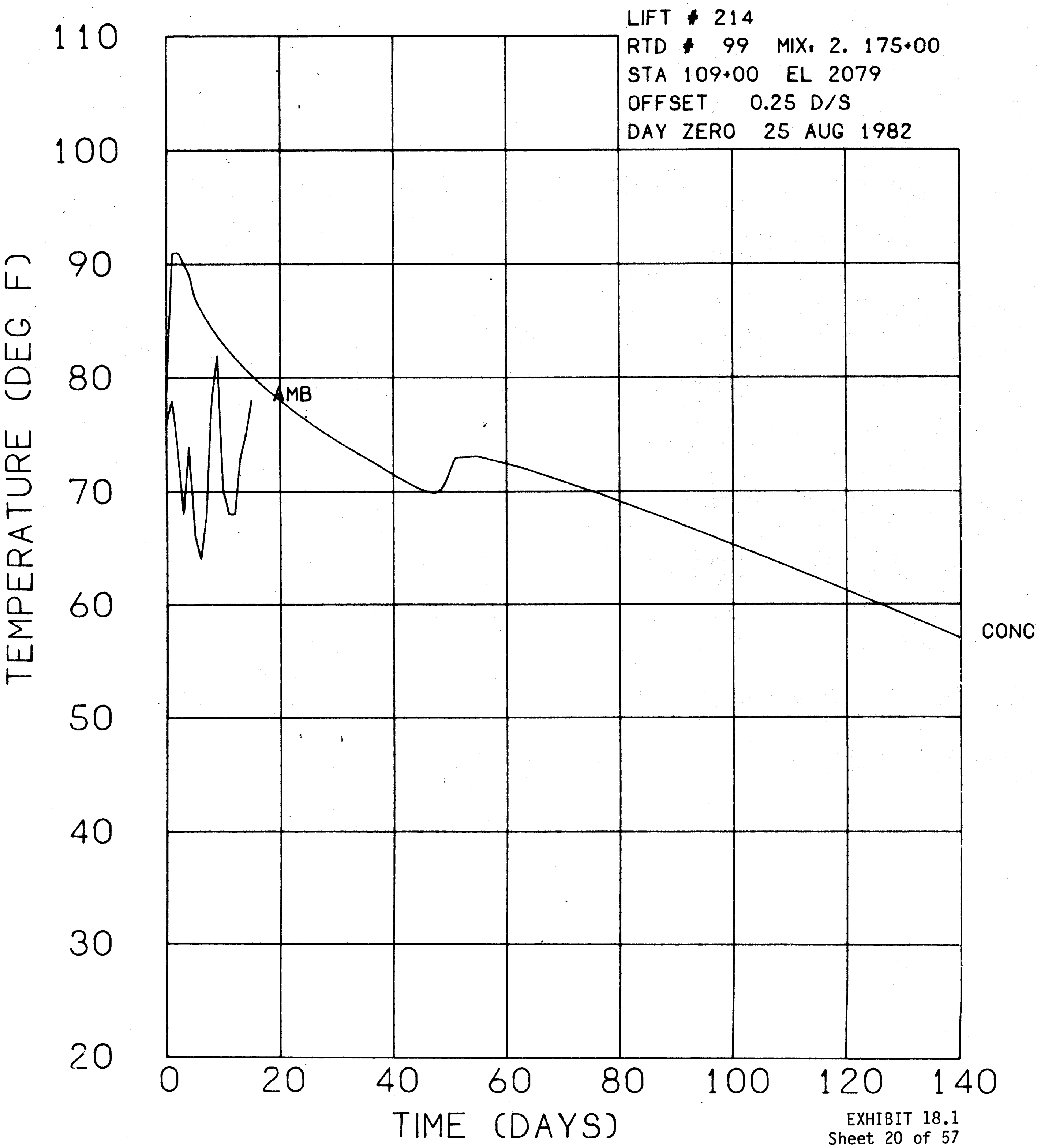


EXHIBIT 18.1
Sheet 20 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

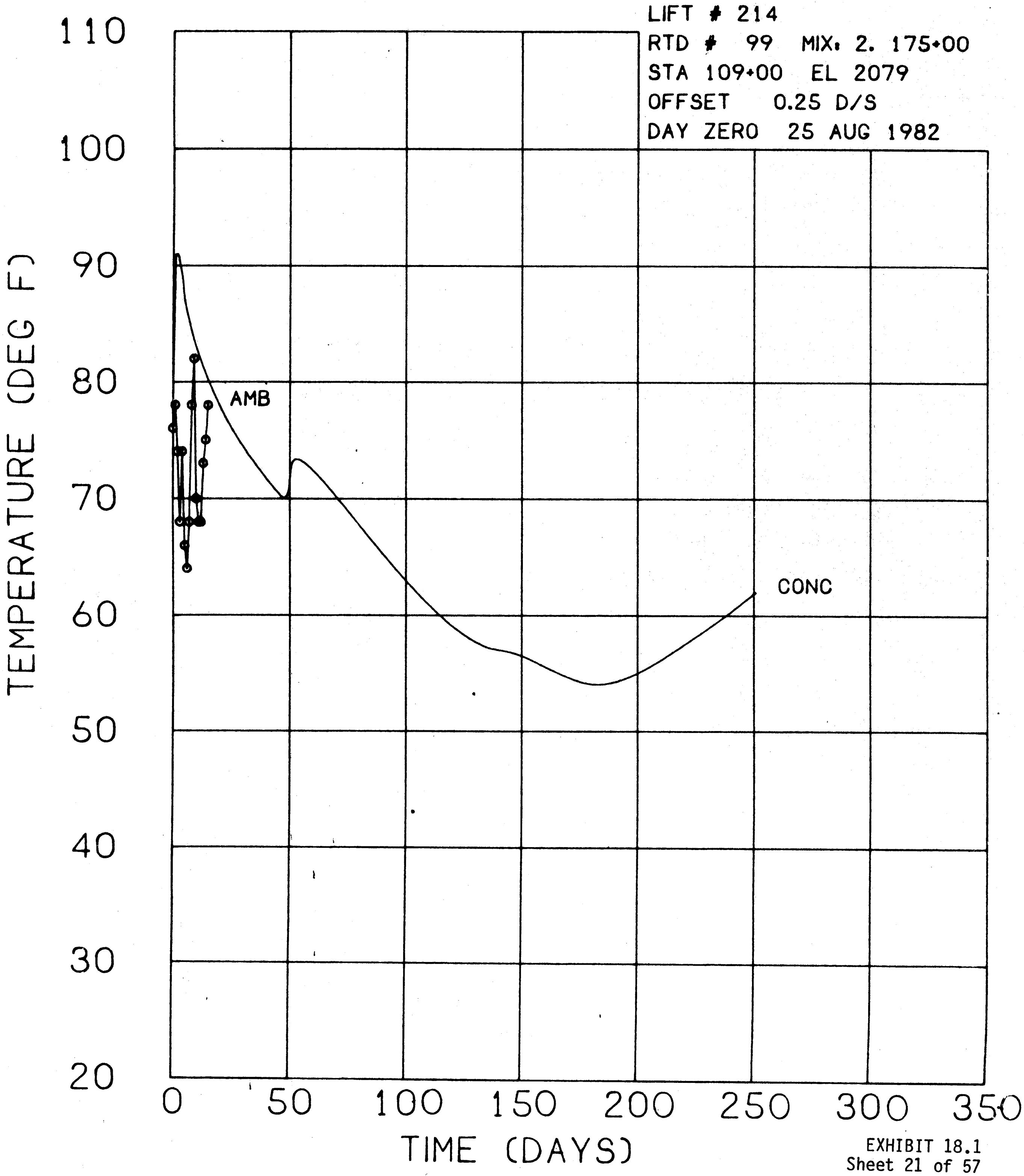
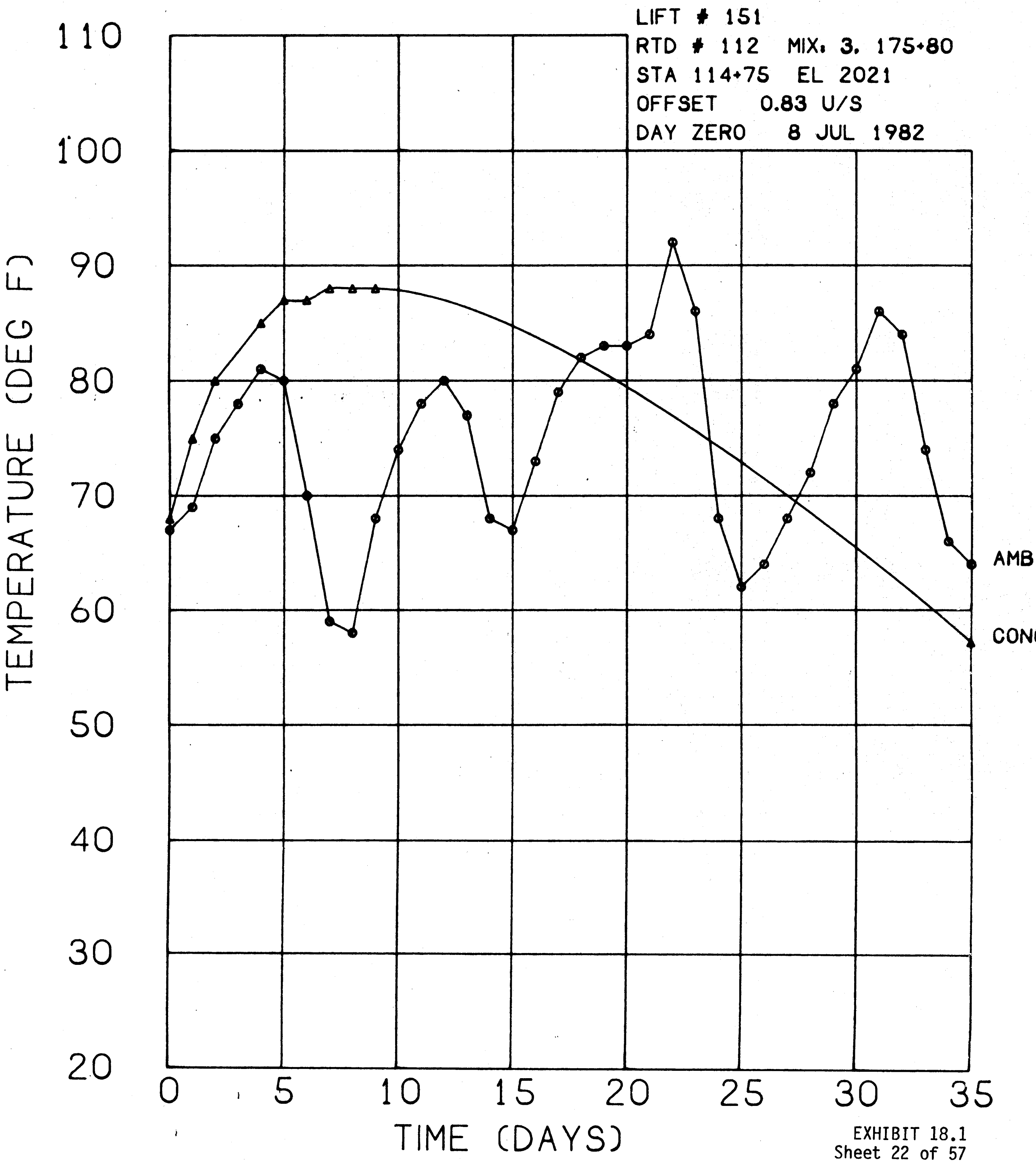


EXHIBIT 18.1
Sheet 21 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES



WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

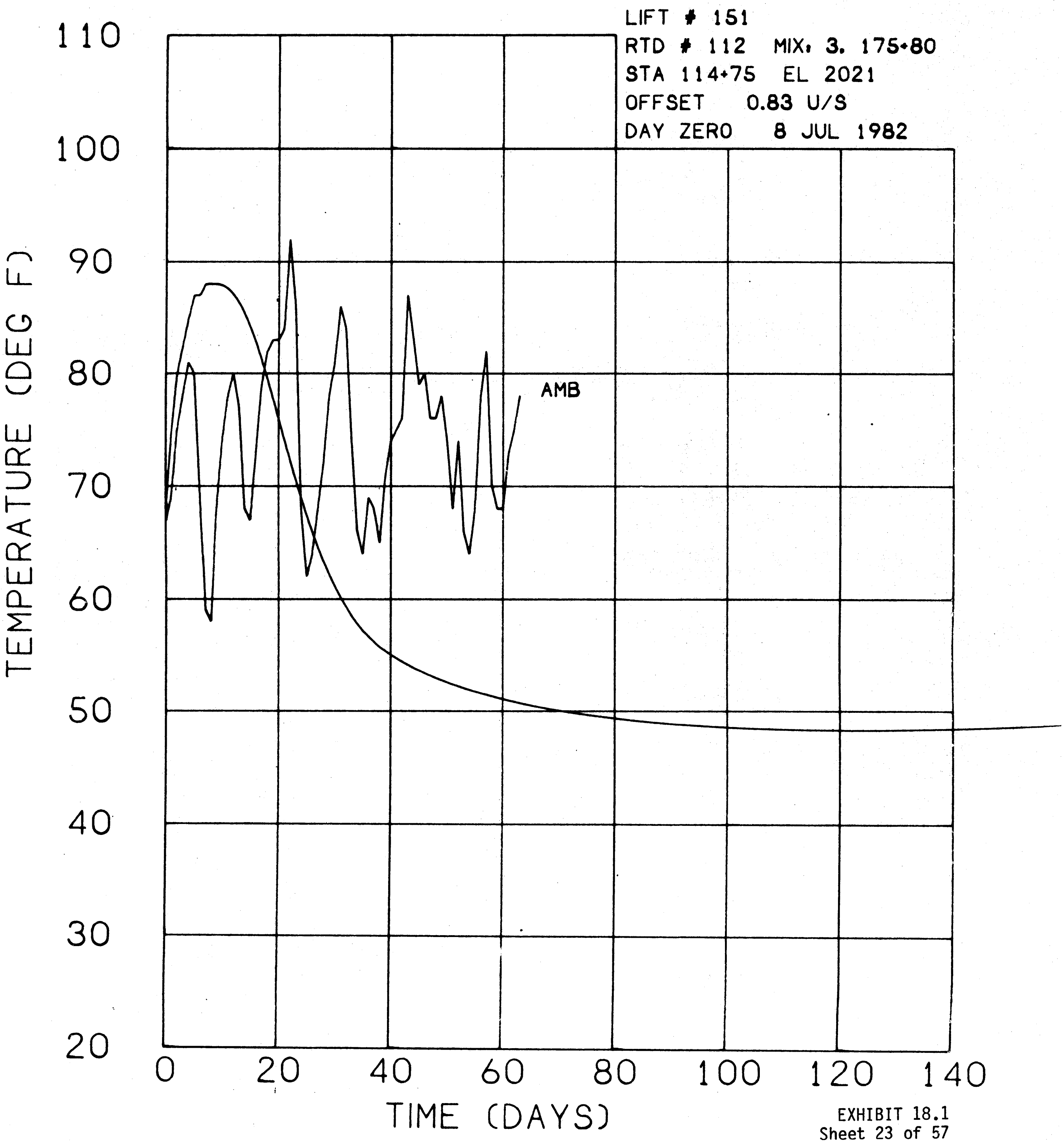


EXHIBIT 18.1
Sheet 23 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

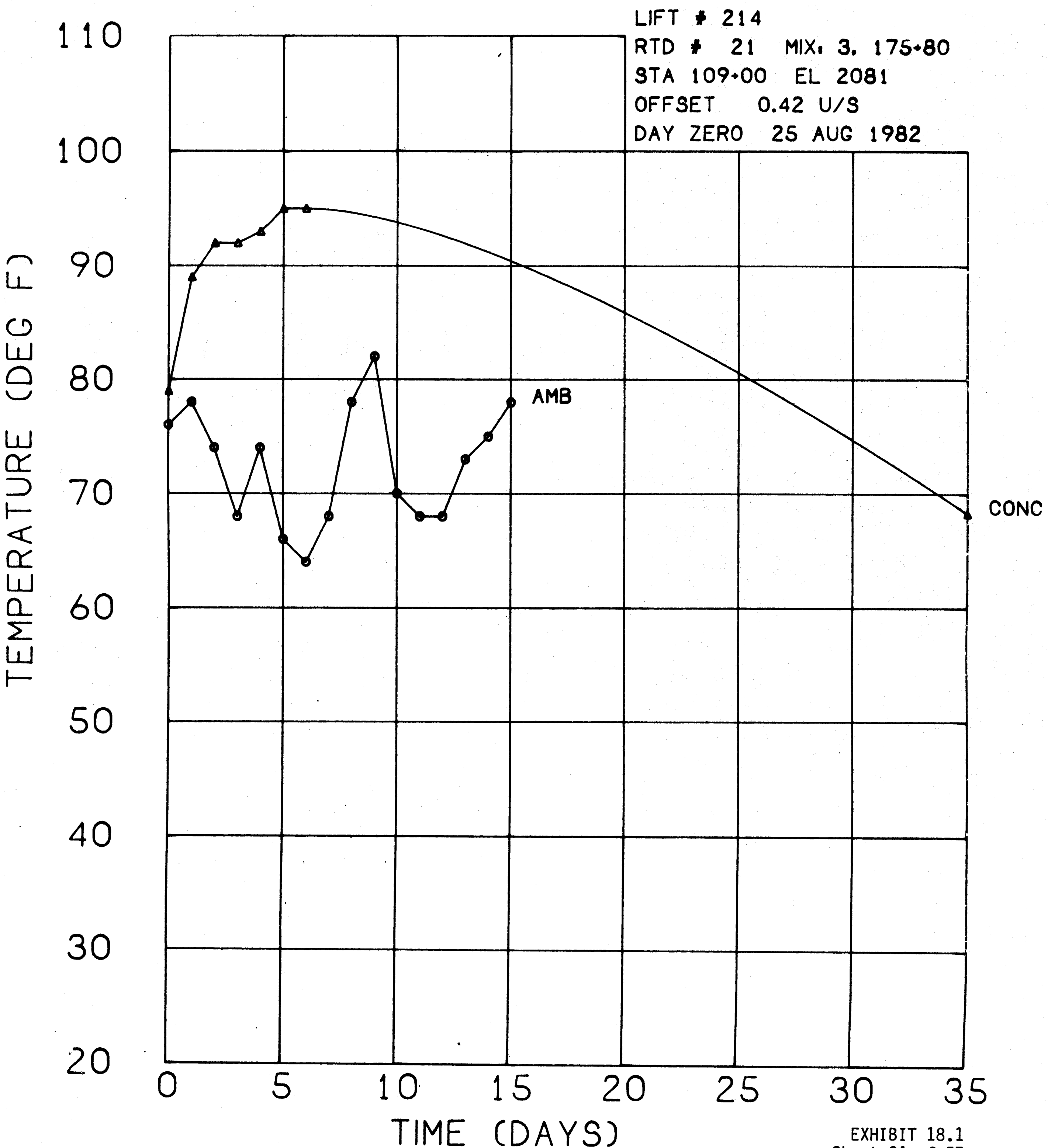
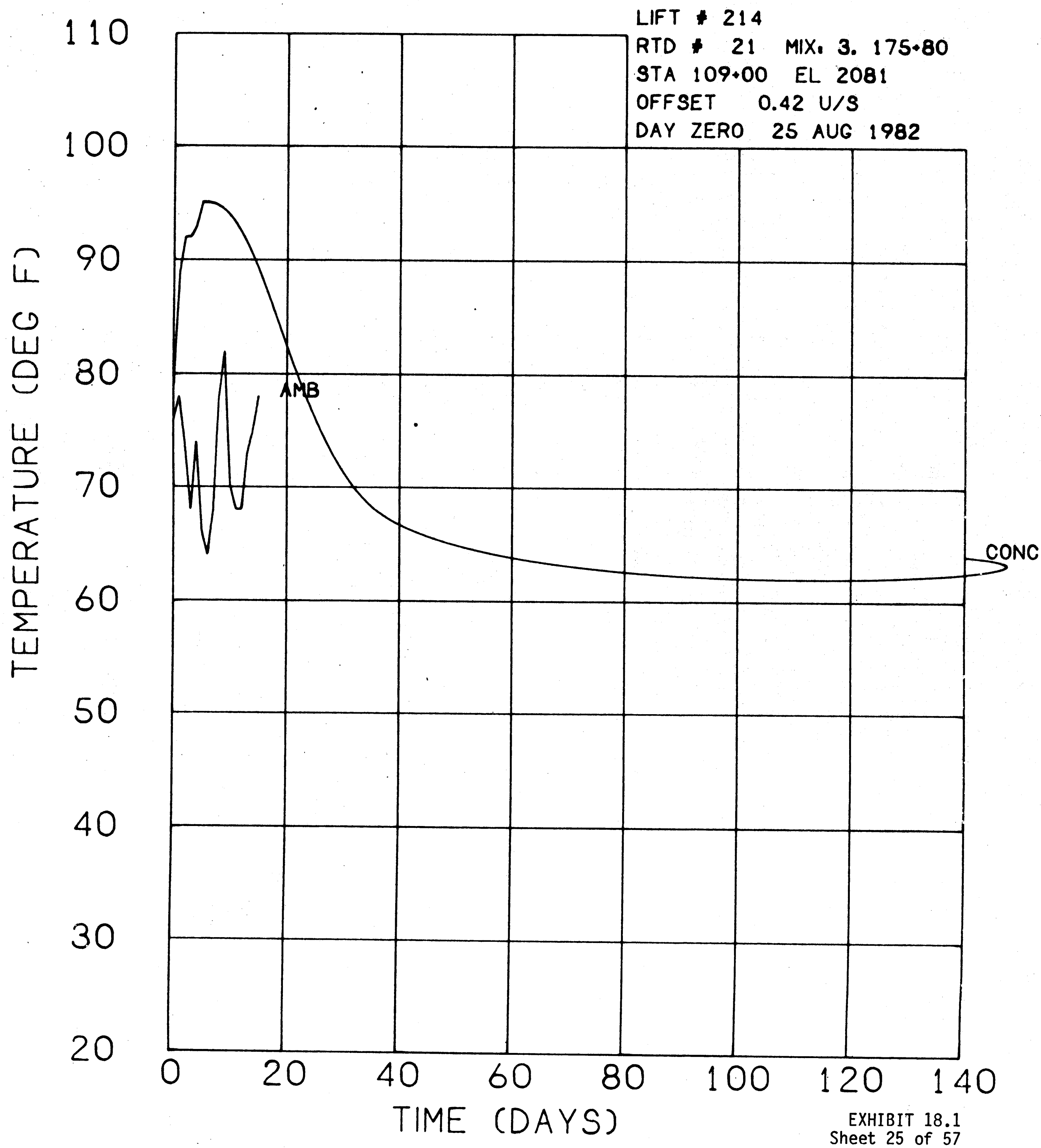
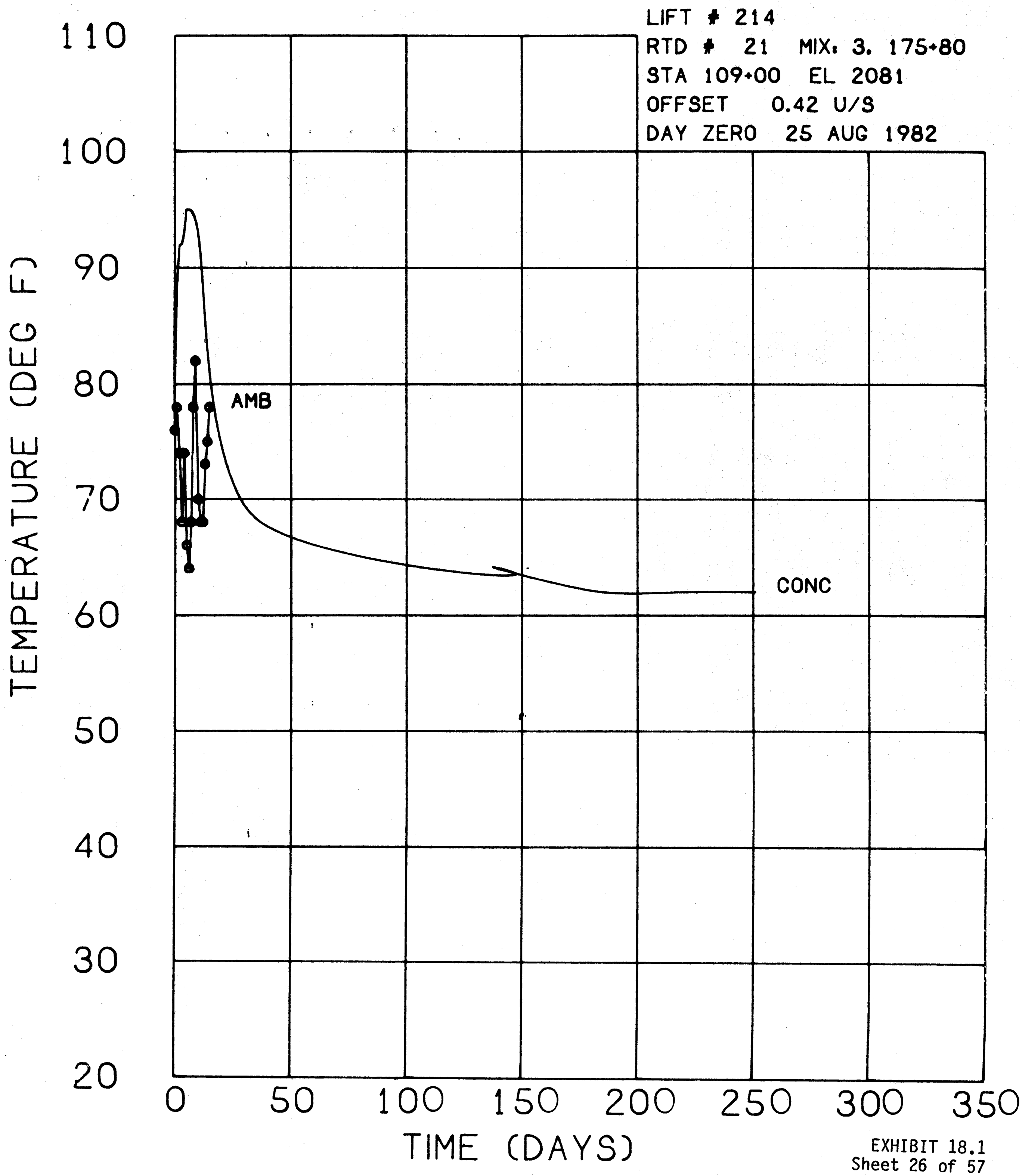


EXHIBIT 18.1
Sheet 24 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES



WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES



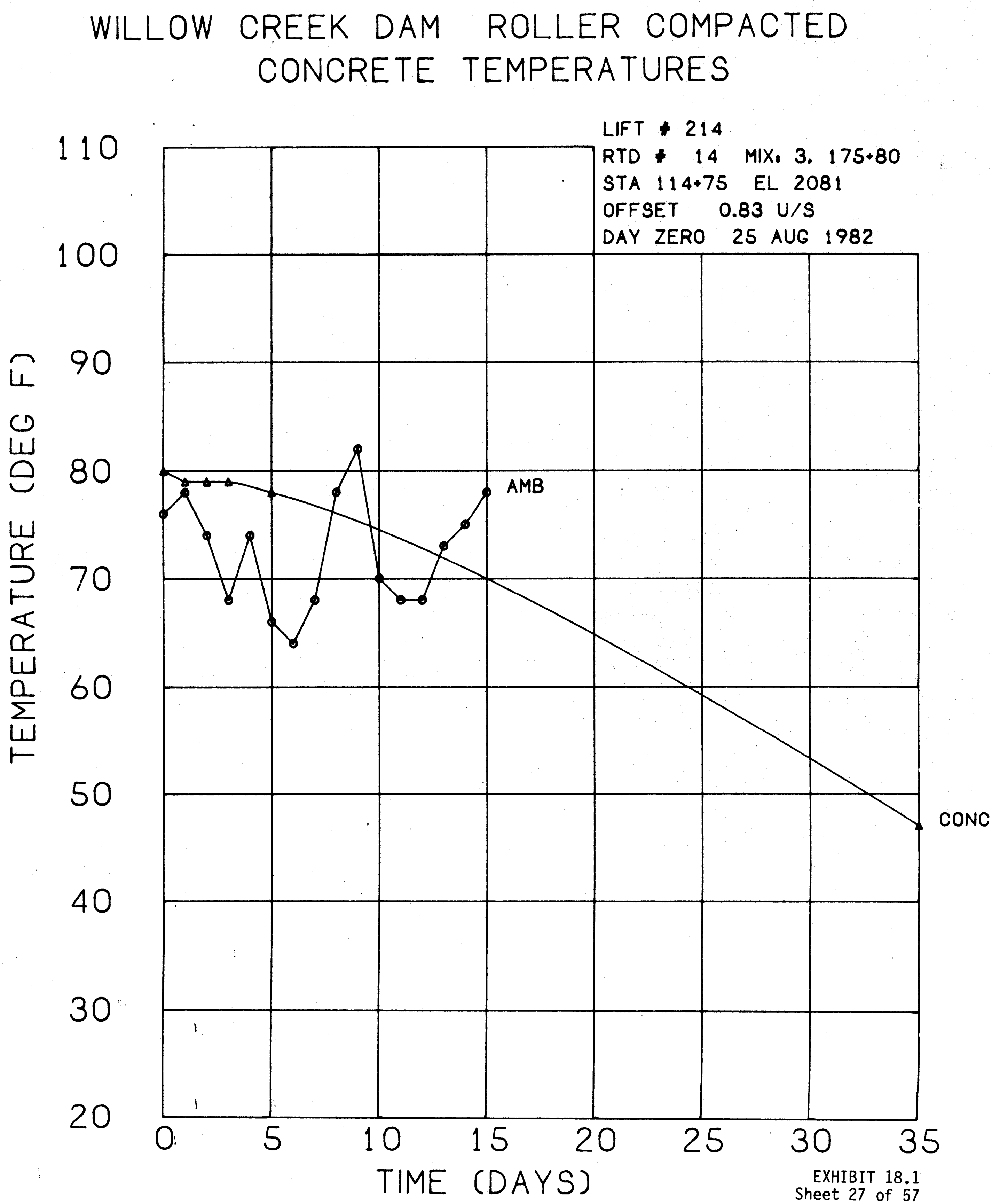


EXHIBIT 18.1
Sheet 27 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

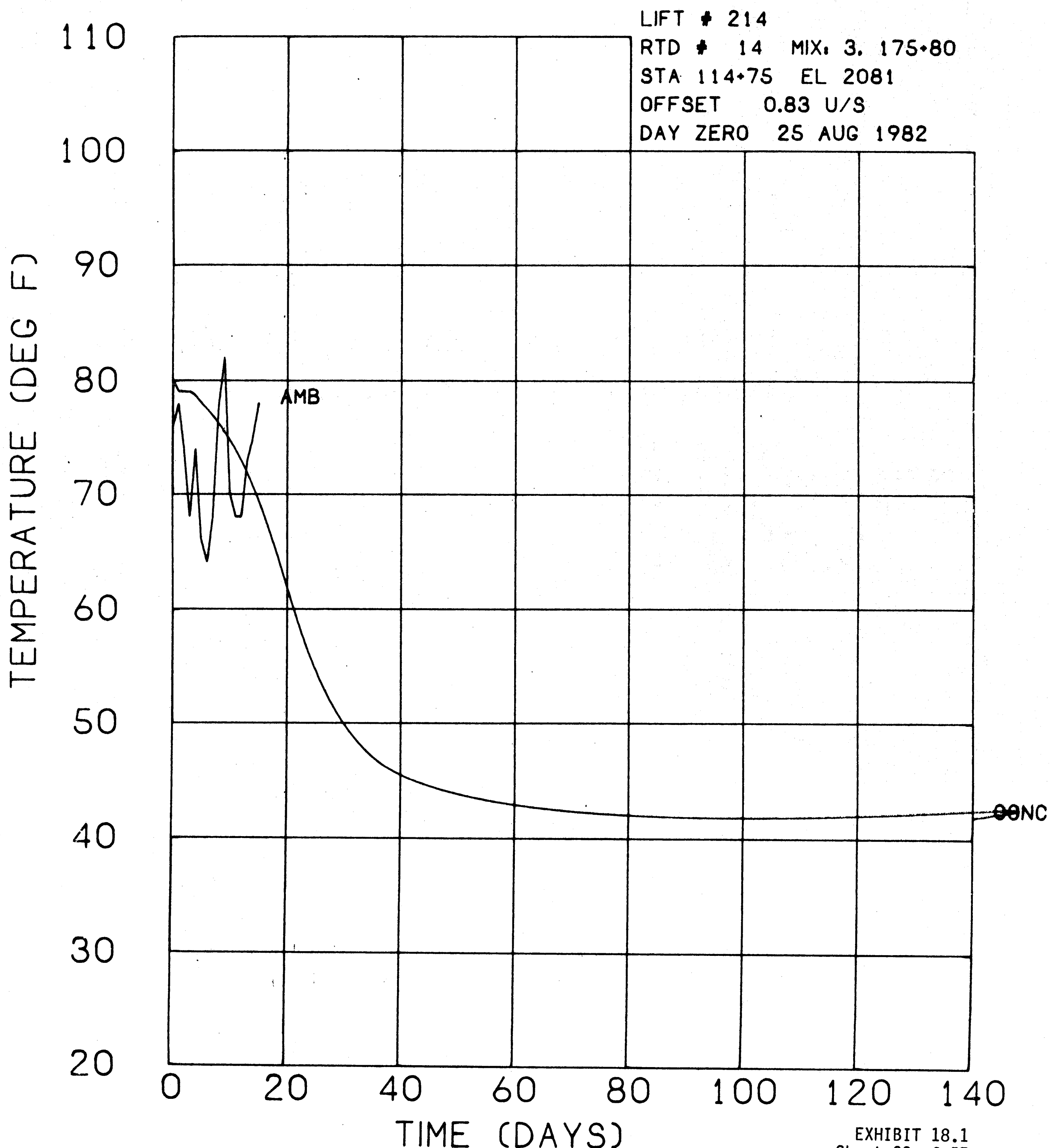


EXHIBIT 18.1
Sheet 28 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

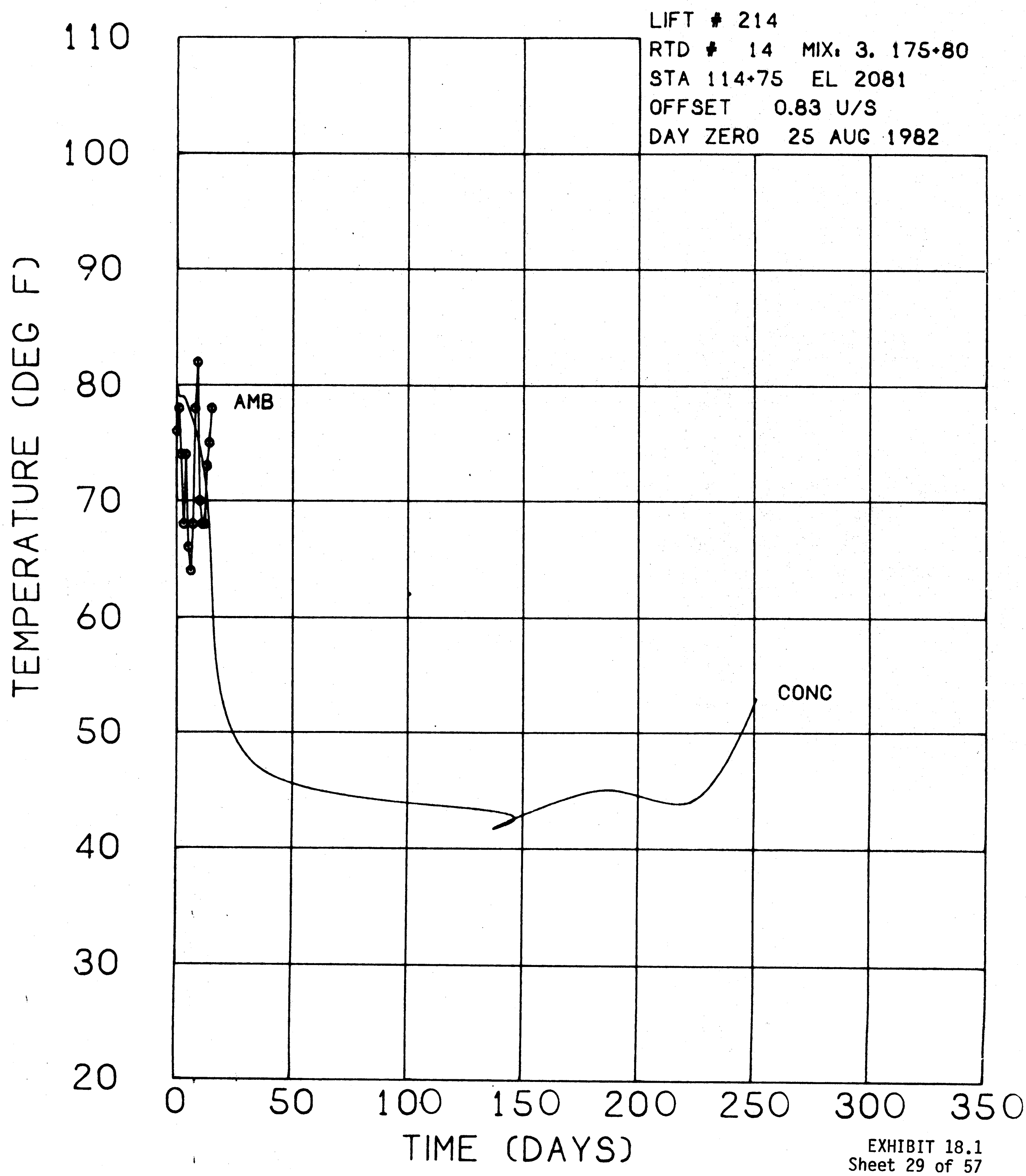


EXHIBIT 18.1
Sheet 29 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

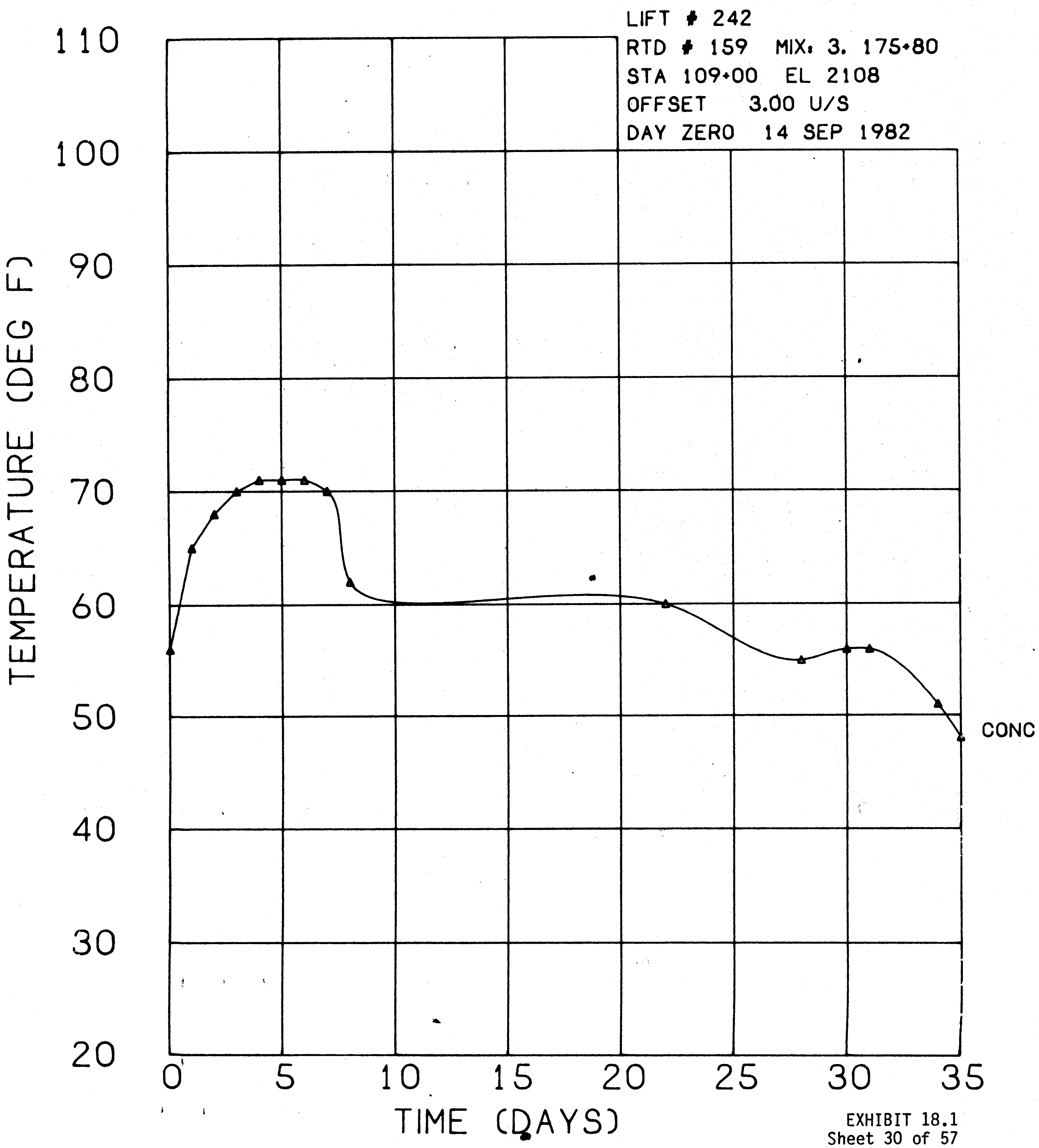


EXHIBIT 18.1
Sheet 30 of 57

AMR

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

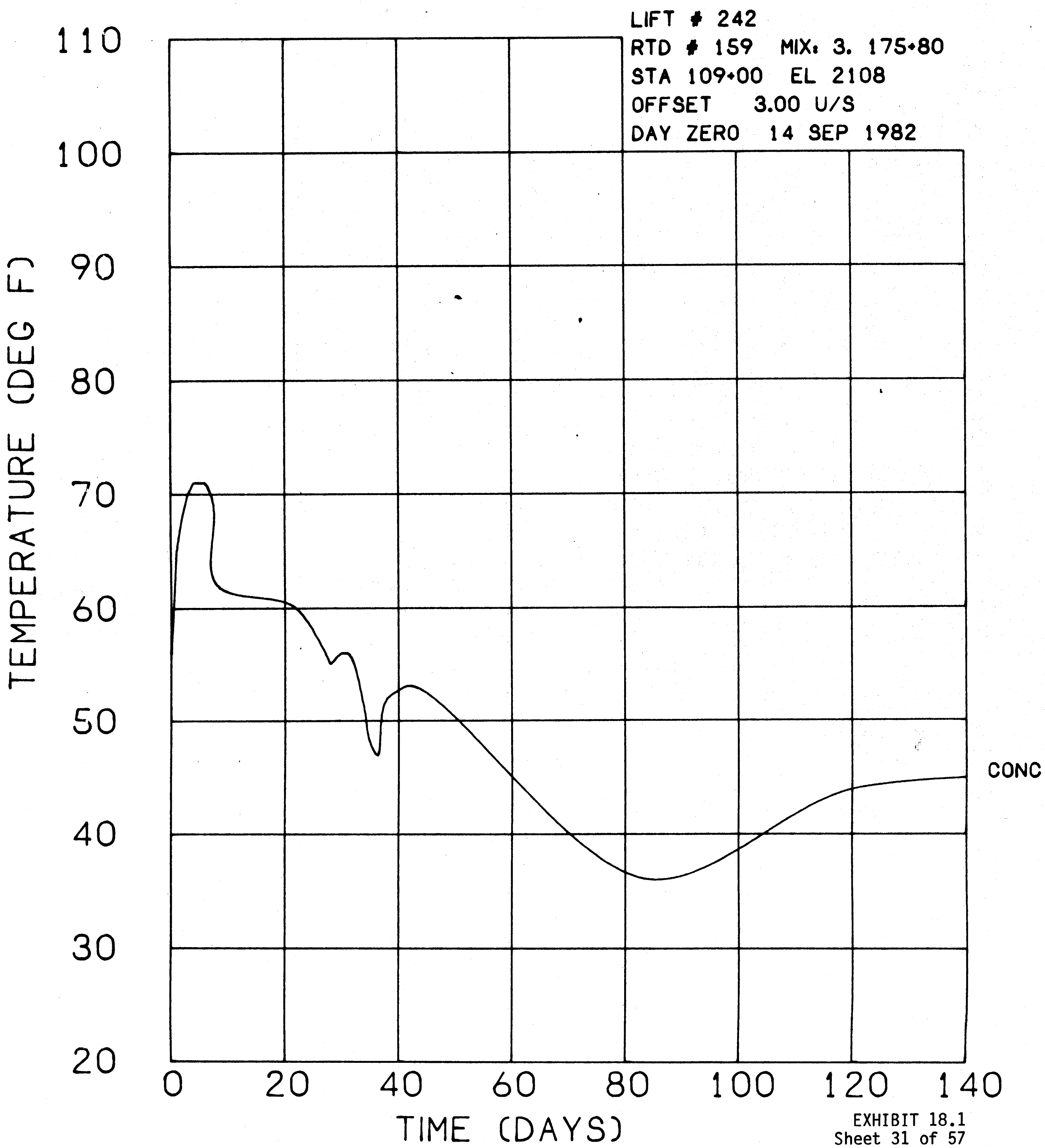


EXHIBIT 18.1
Sheet 31 of 57

MR

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

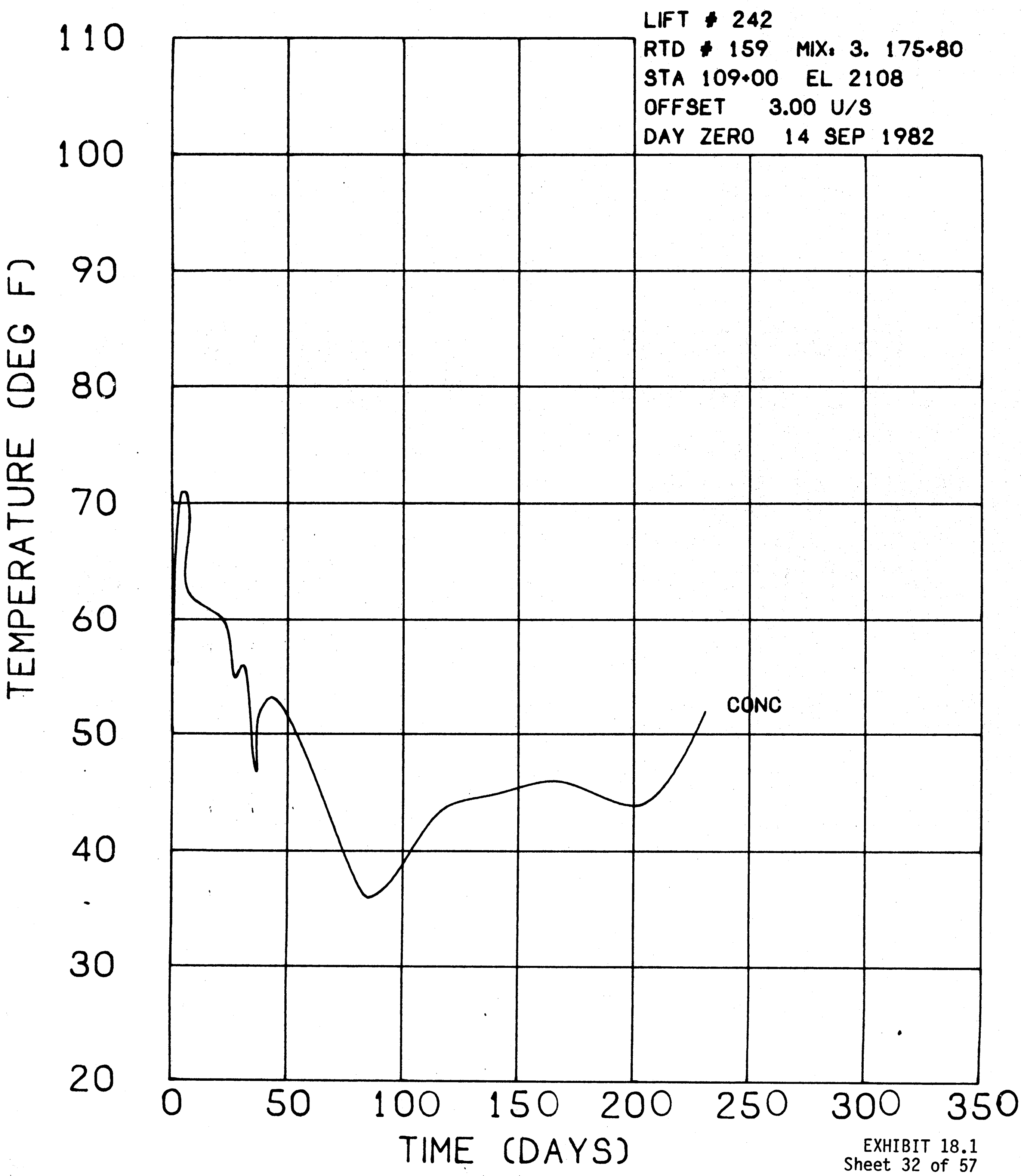


EXHIBIT 18.1
Sheet 32 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

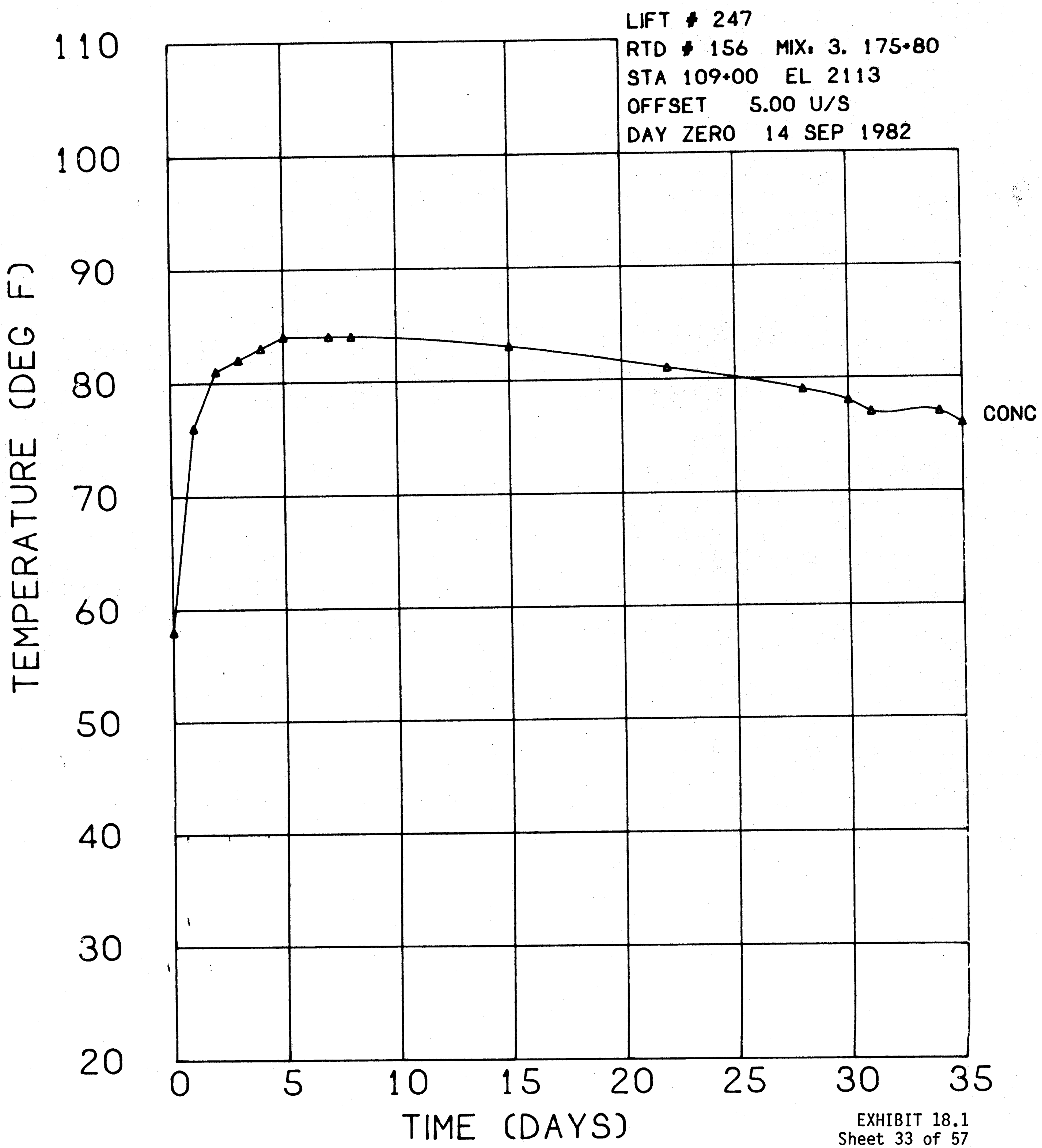


EXHIBIT 18.1
Sheet 33 of 57

AMB

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

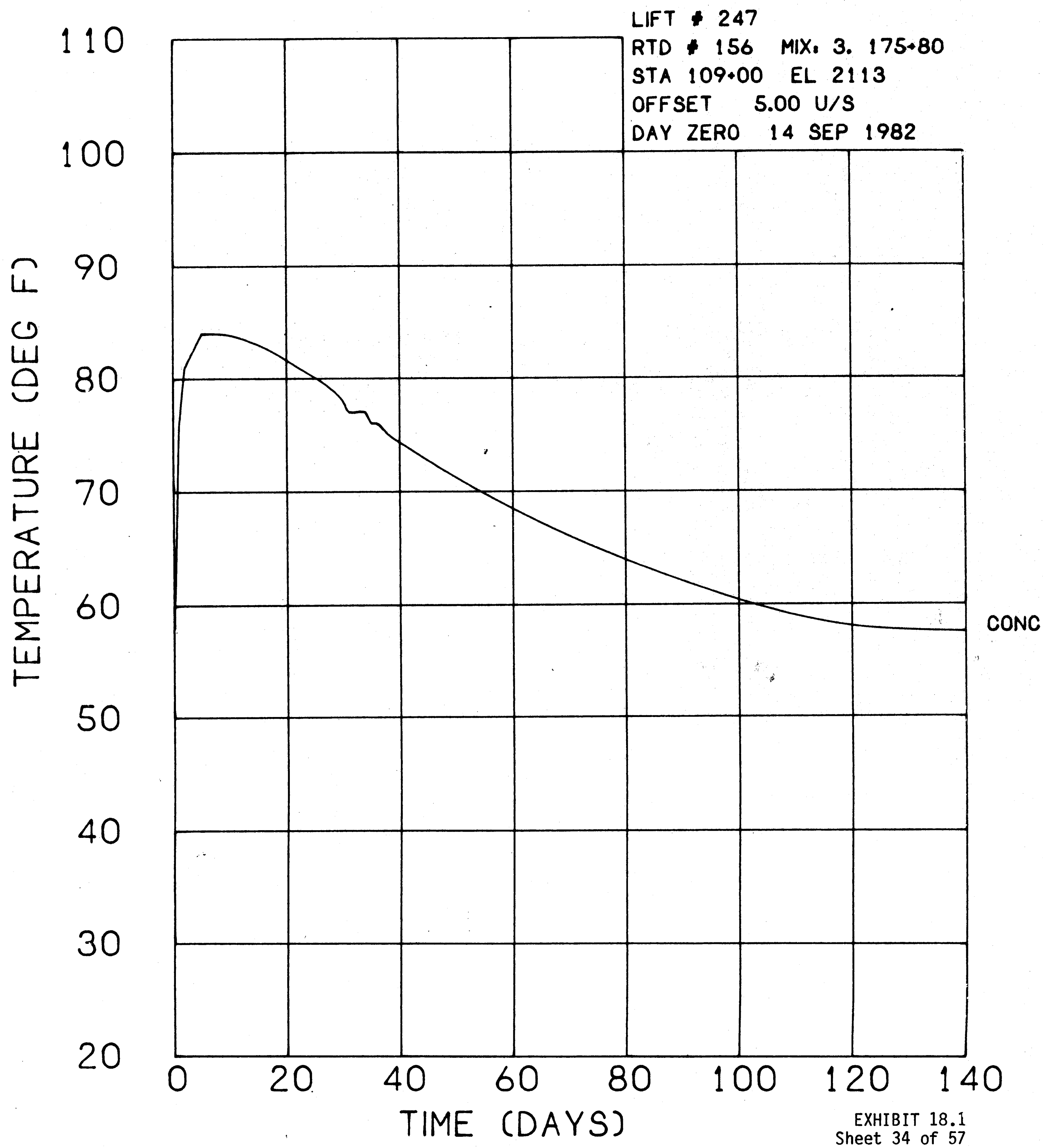


EXHIBIT 18.1
Sheet 34 of 57

AMR

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

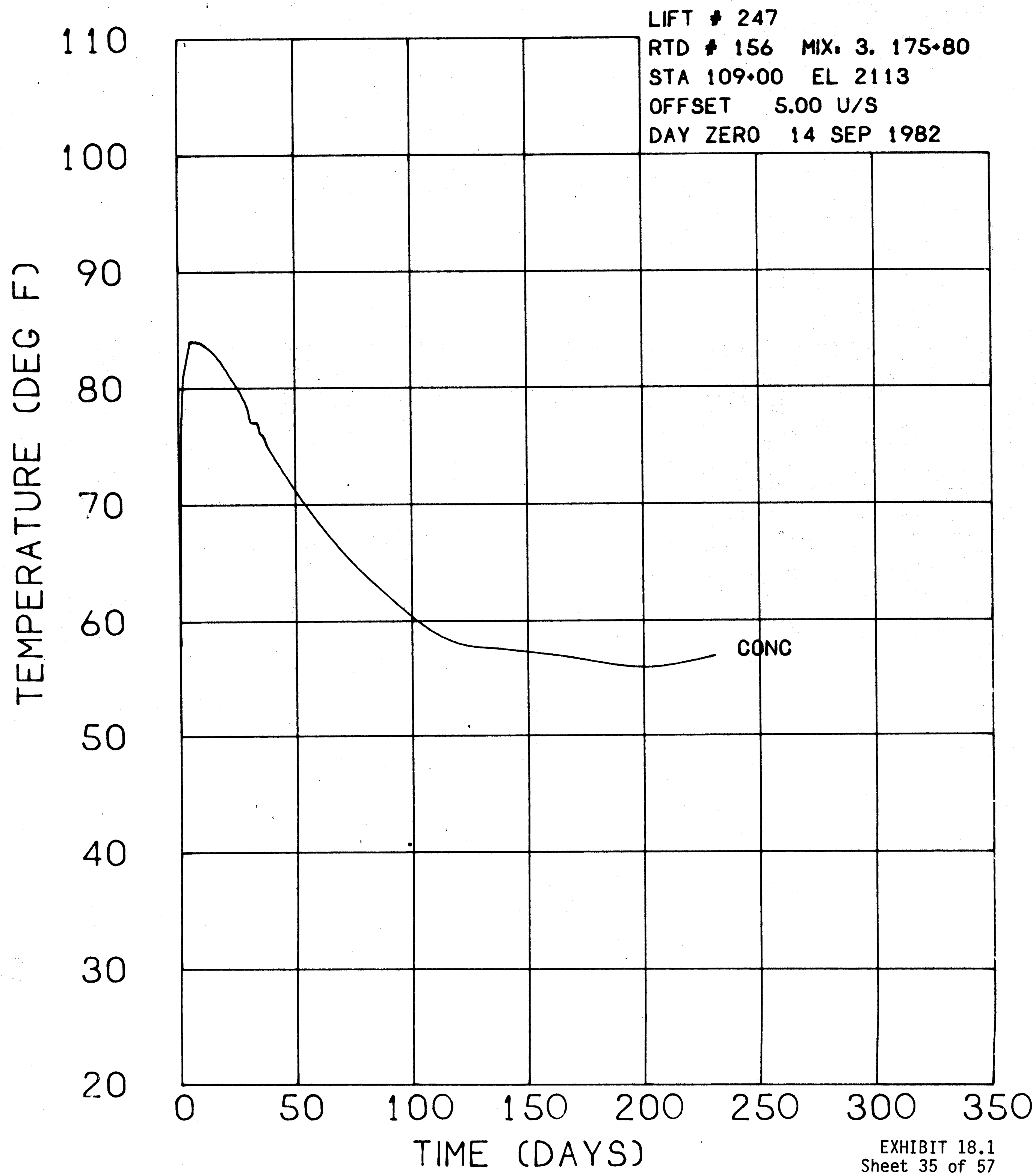


EXHIBIT 18.1
Sheet 35 of 57

AMB

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

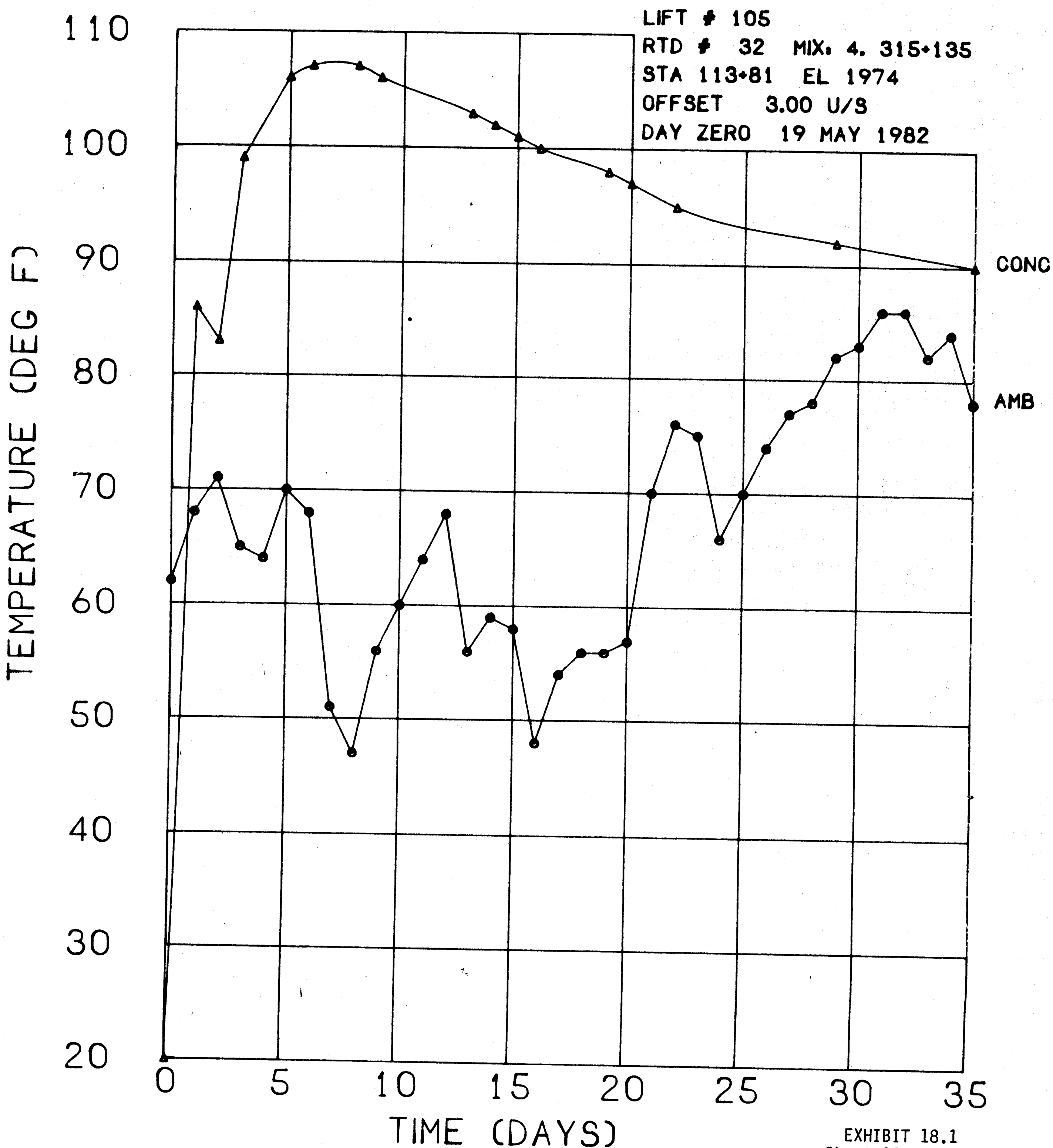


EXHIBIT 18.1
Sheet 36 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

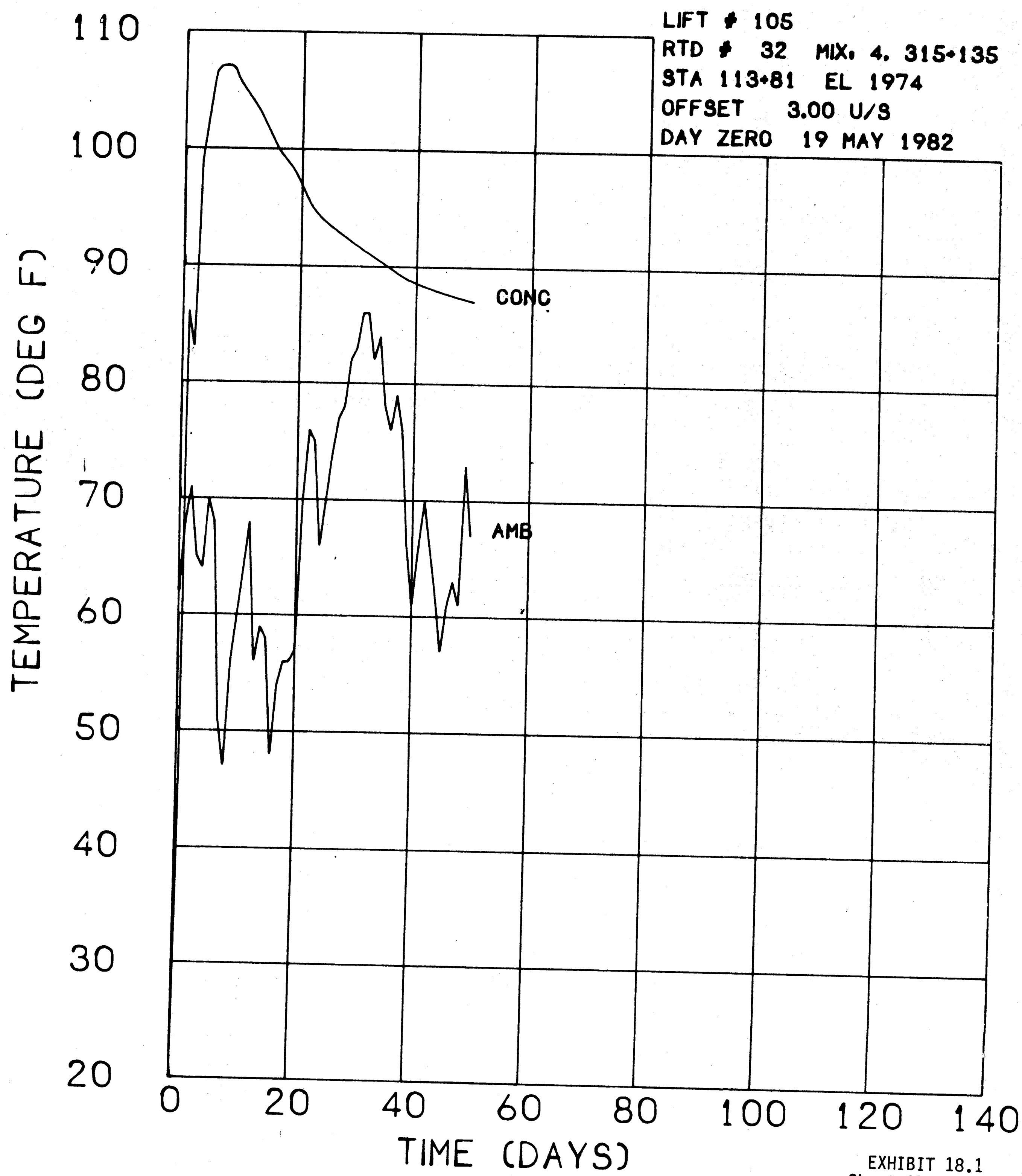


EXHIBIT 18.1
Sheet 37 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

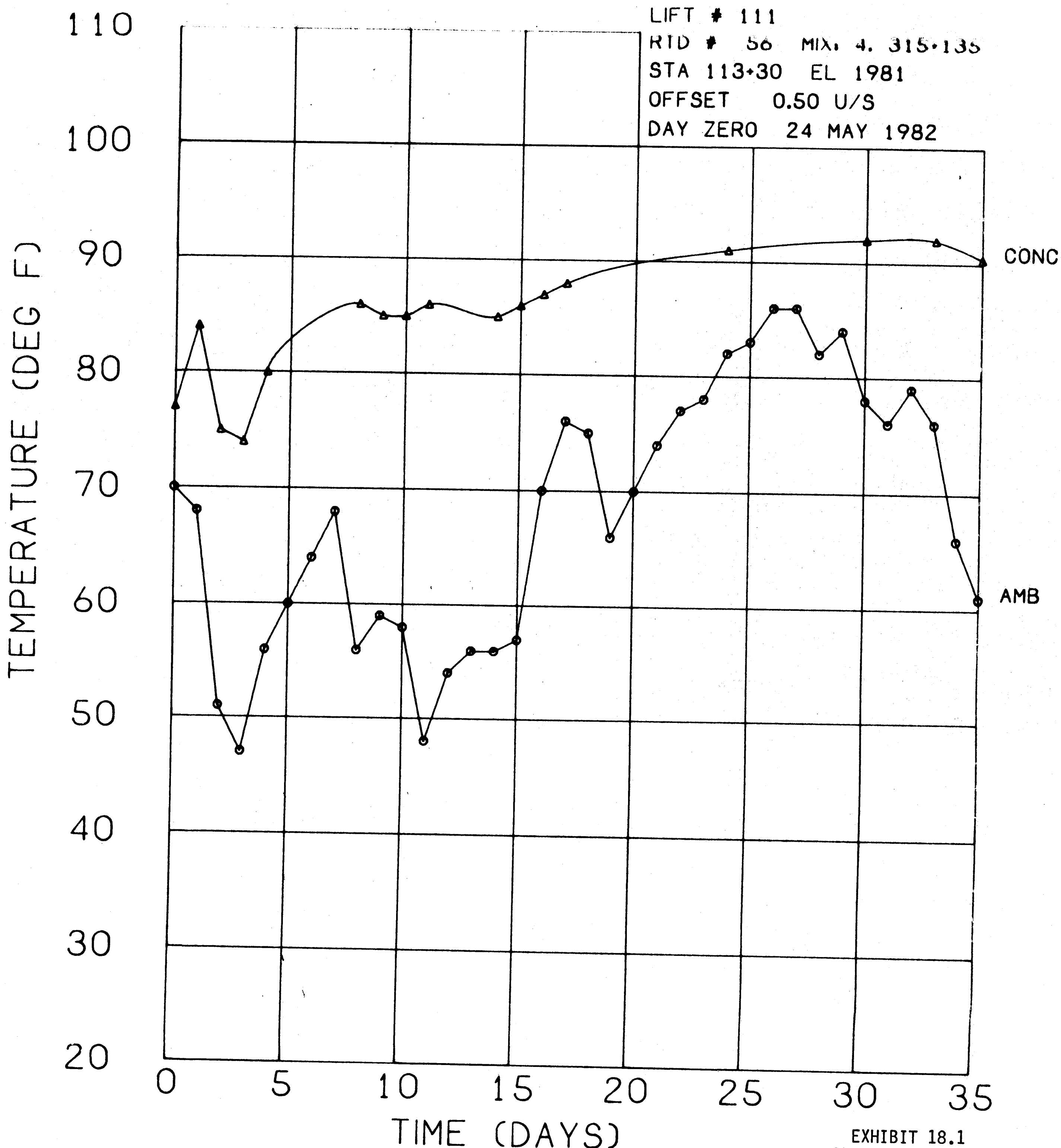


EXHIBIT 18.1
Sheet 38 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

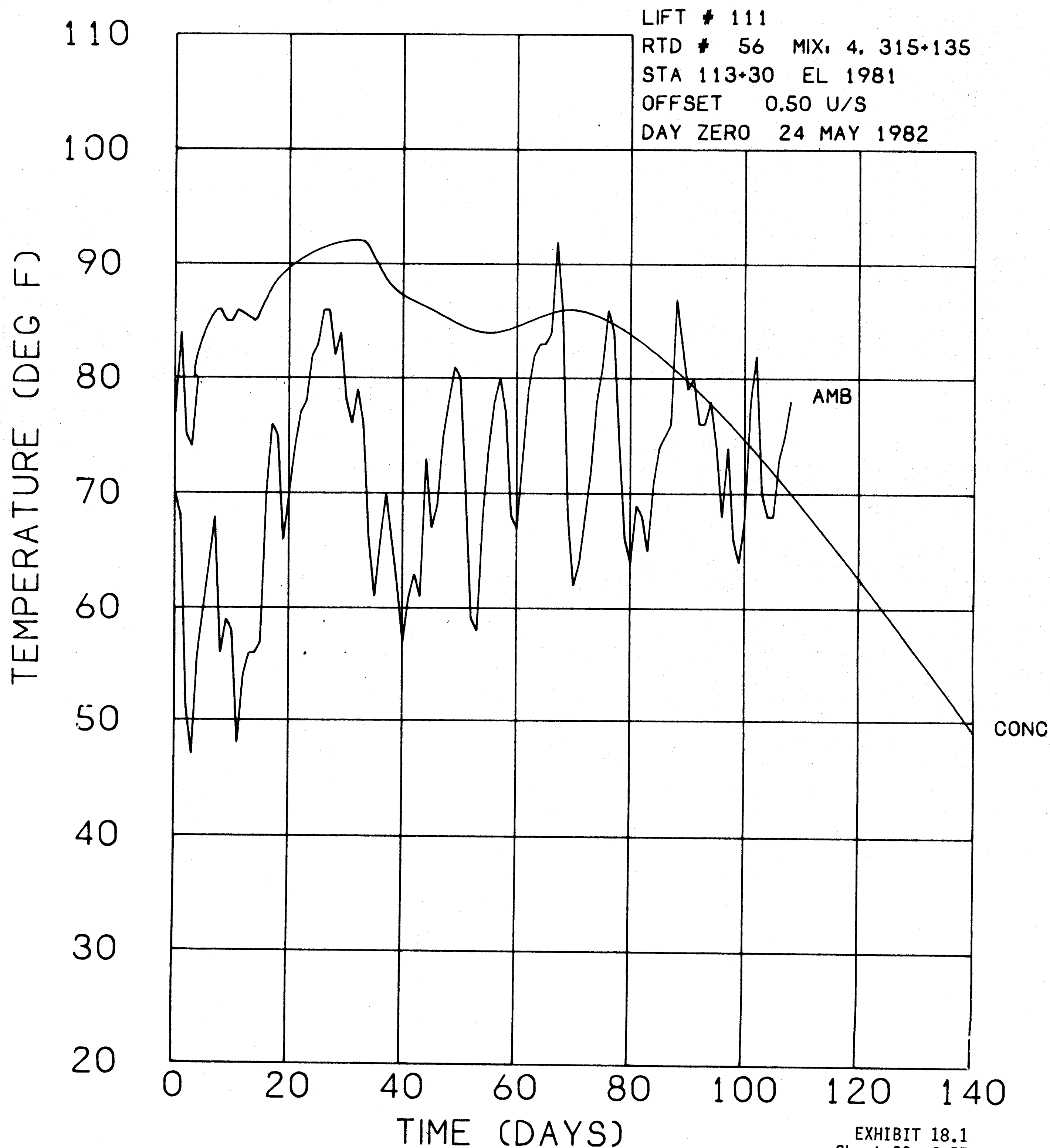


EXHIBIT 18.1
Sheet 39 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

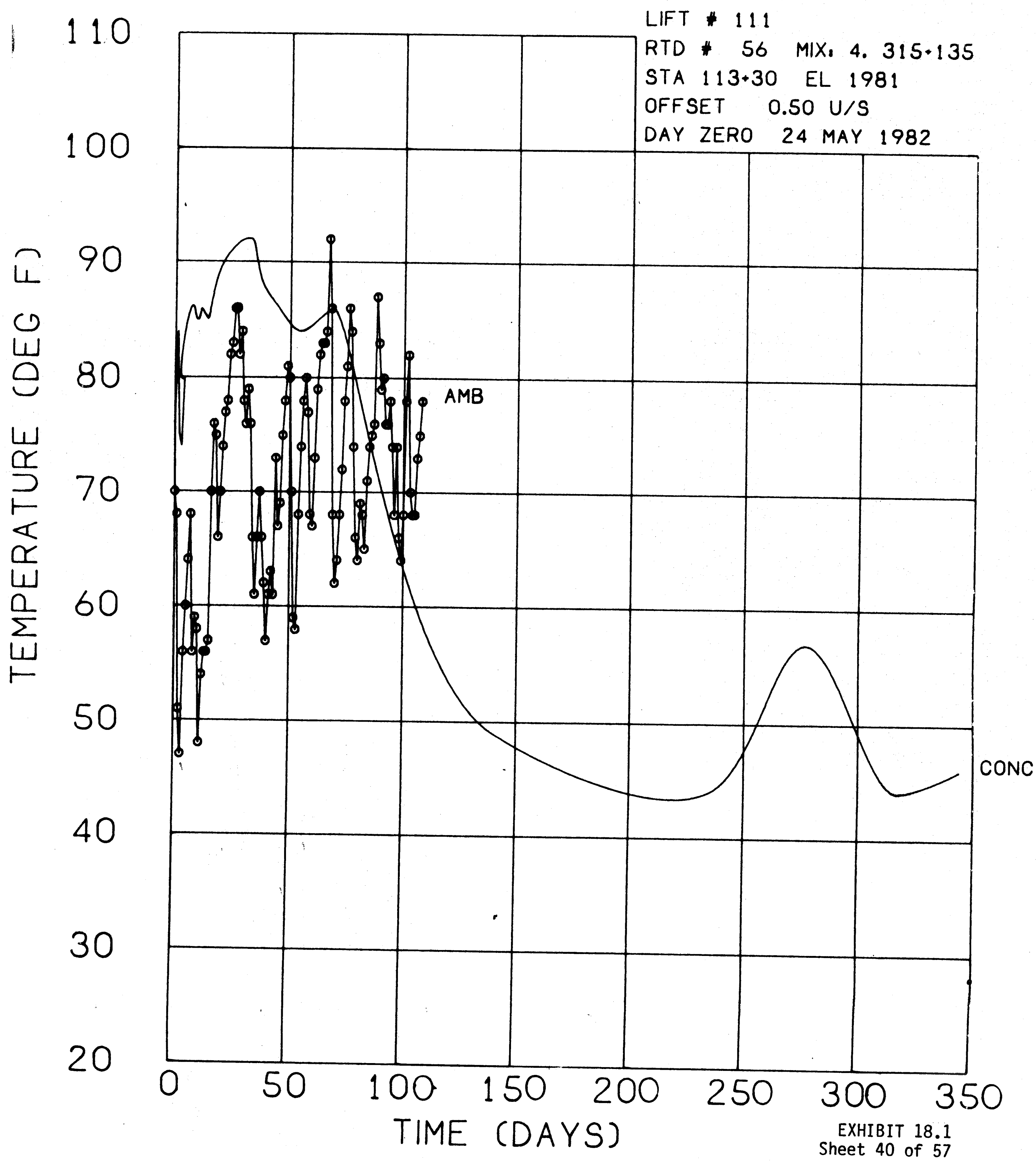
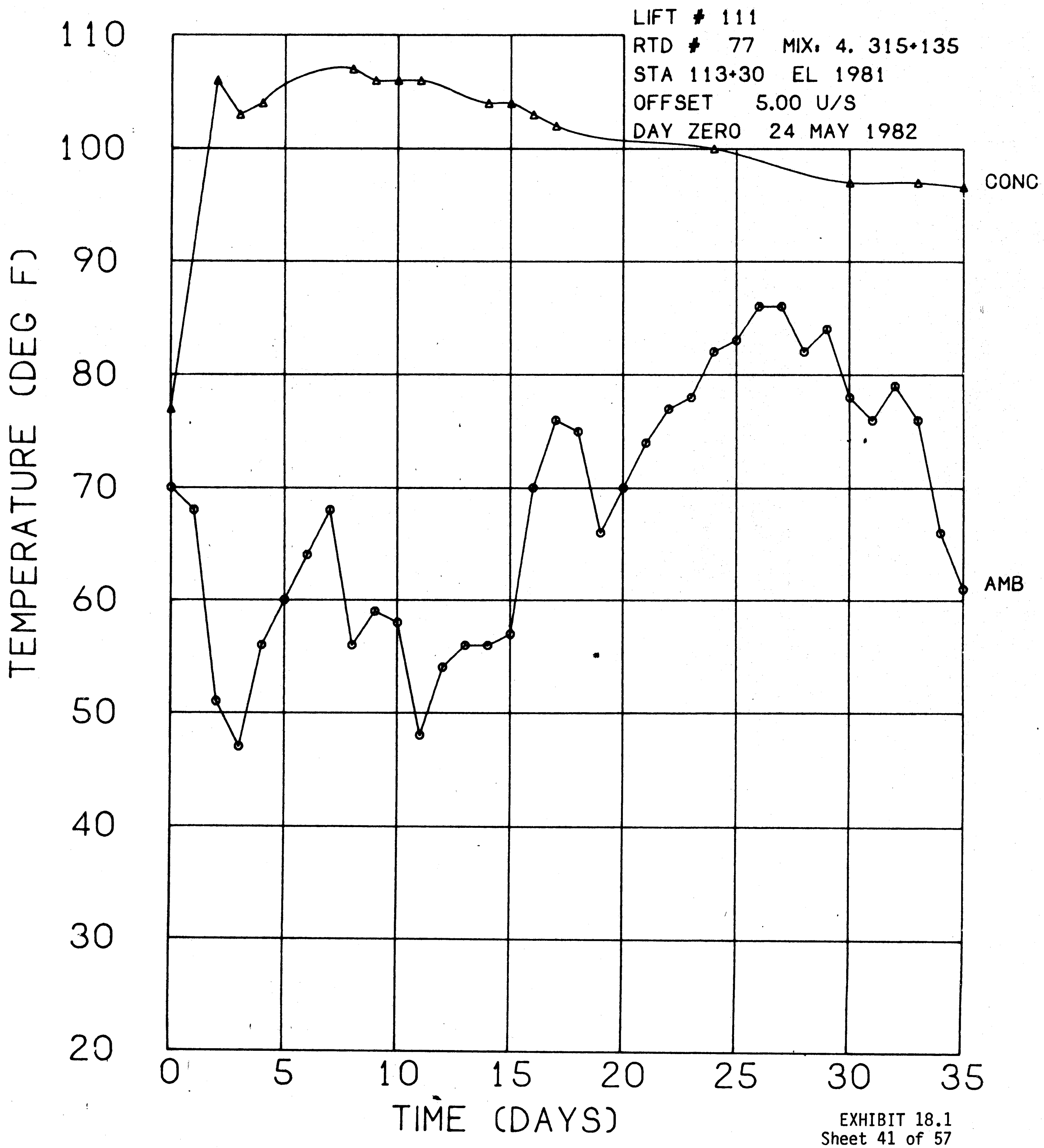


EXHIBIT 18.1
Sheet 40 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES



WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

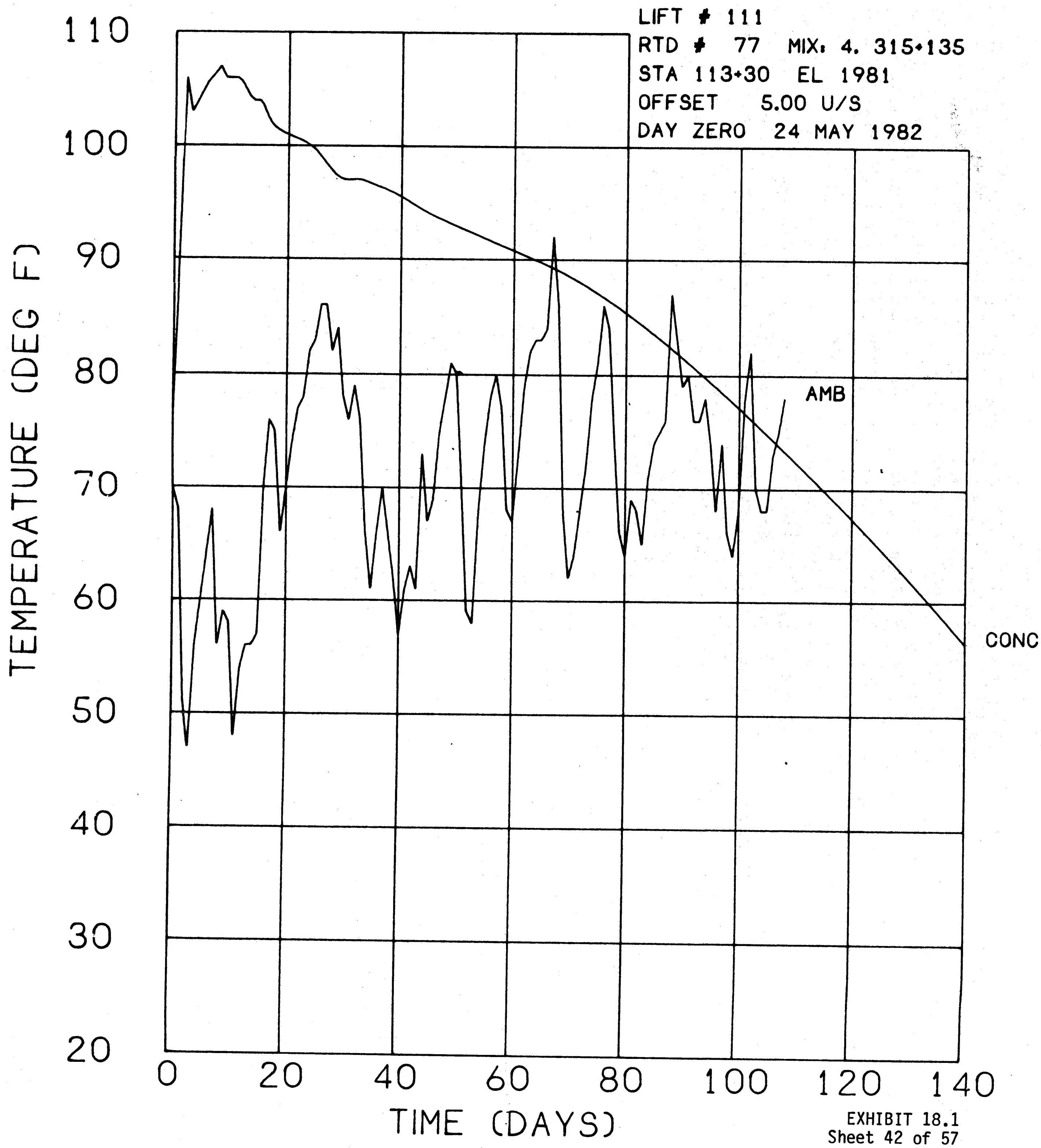


EXHIBIT 18.1
Sheet 42 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

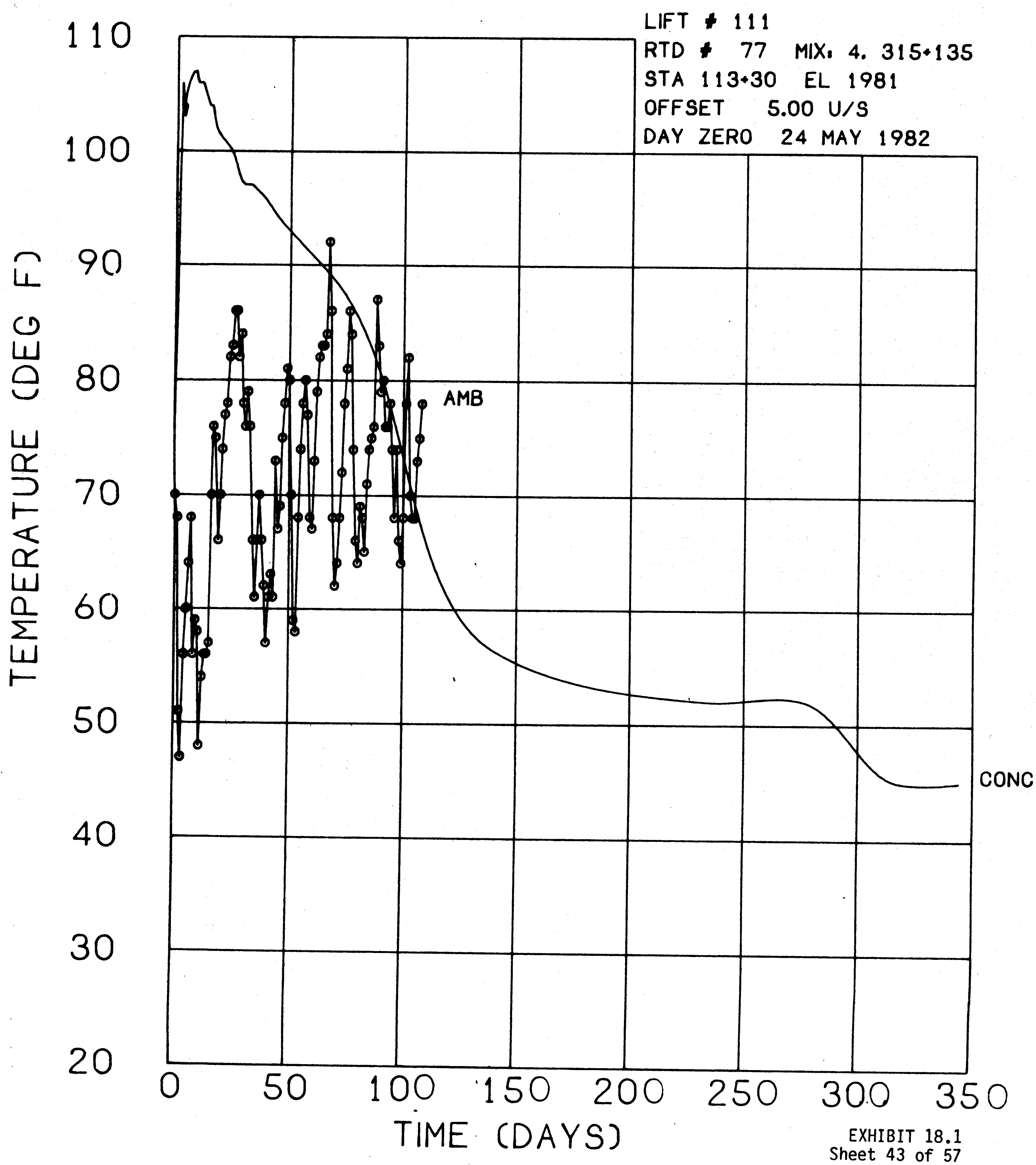


EXHIBIT 18.1
Sheet 43 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

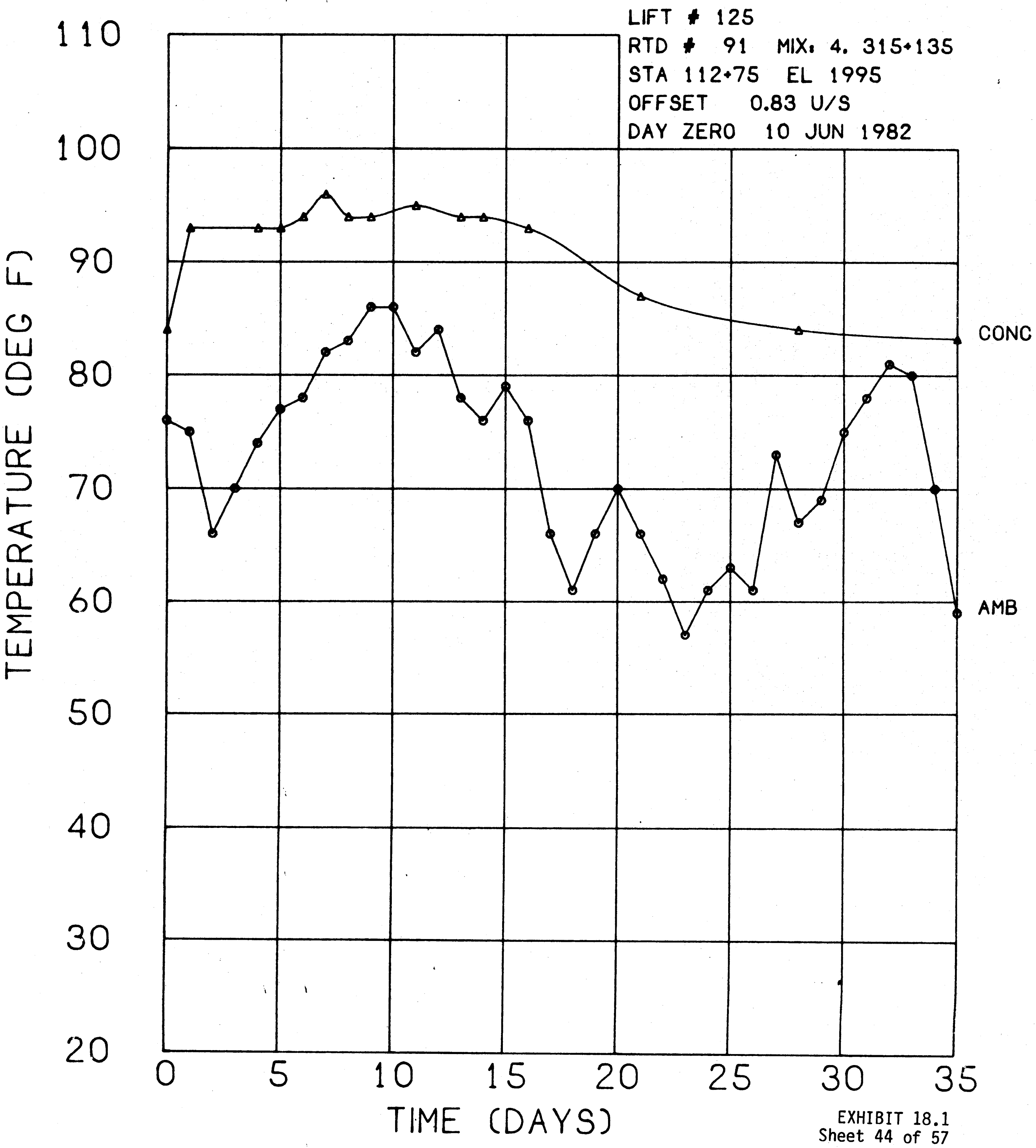
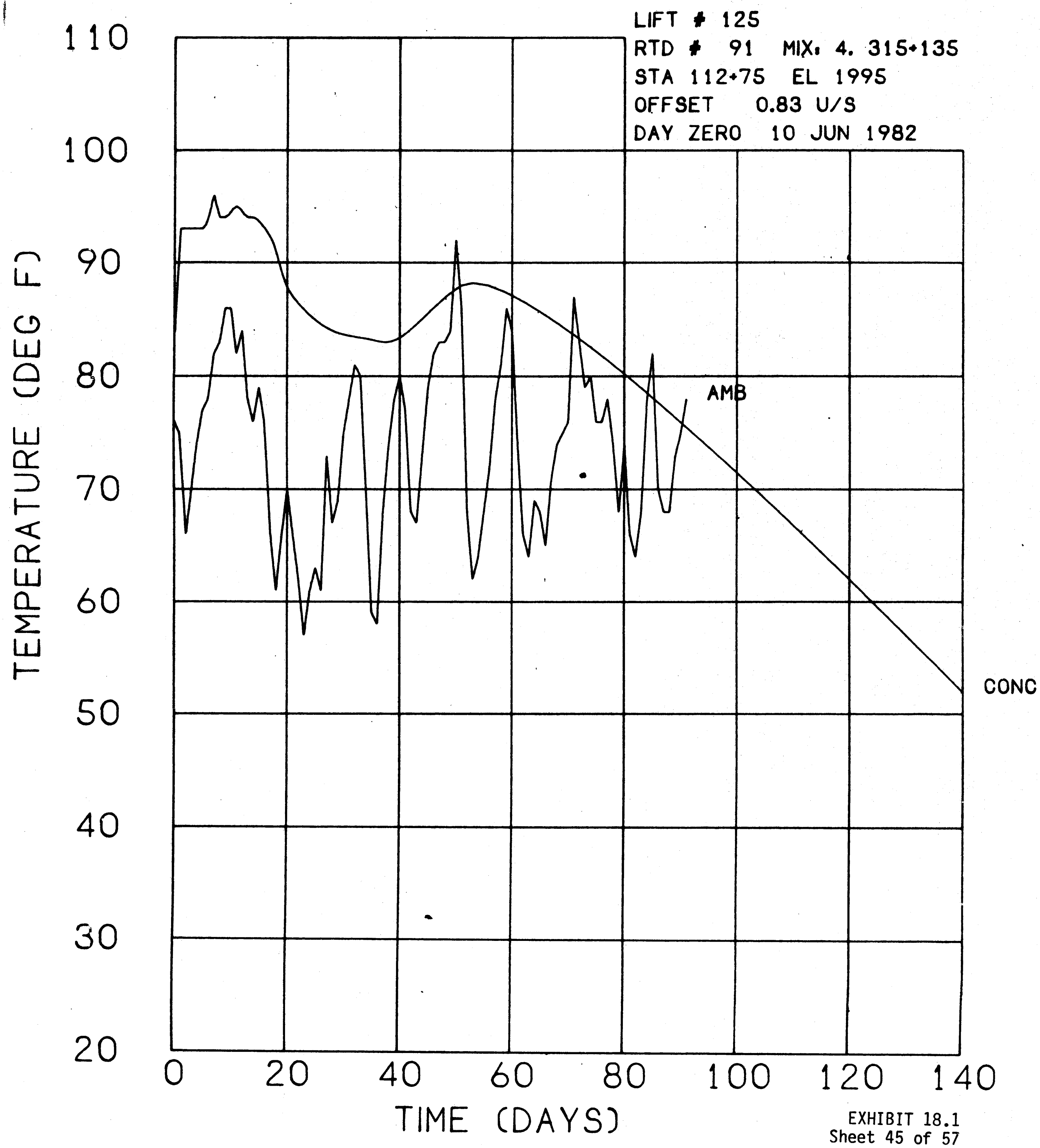


EXHIBIT 18.1
Sheet 44 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES



WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

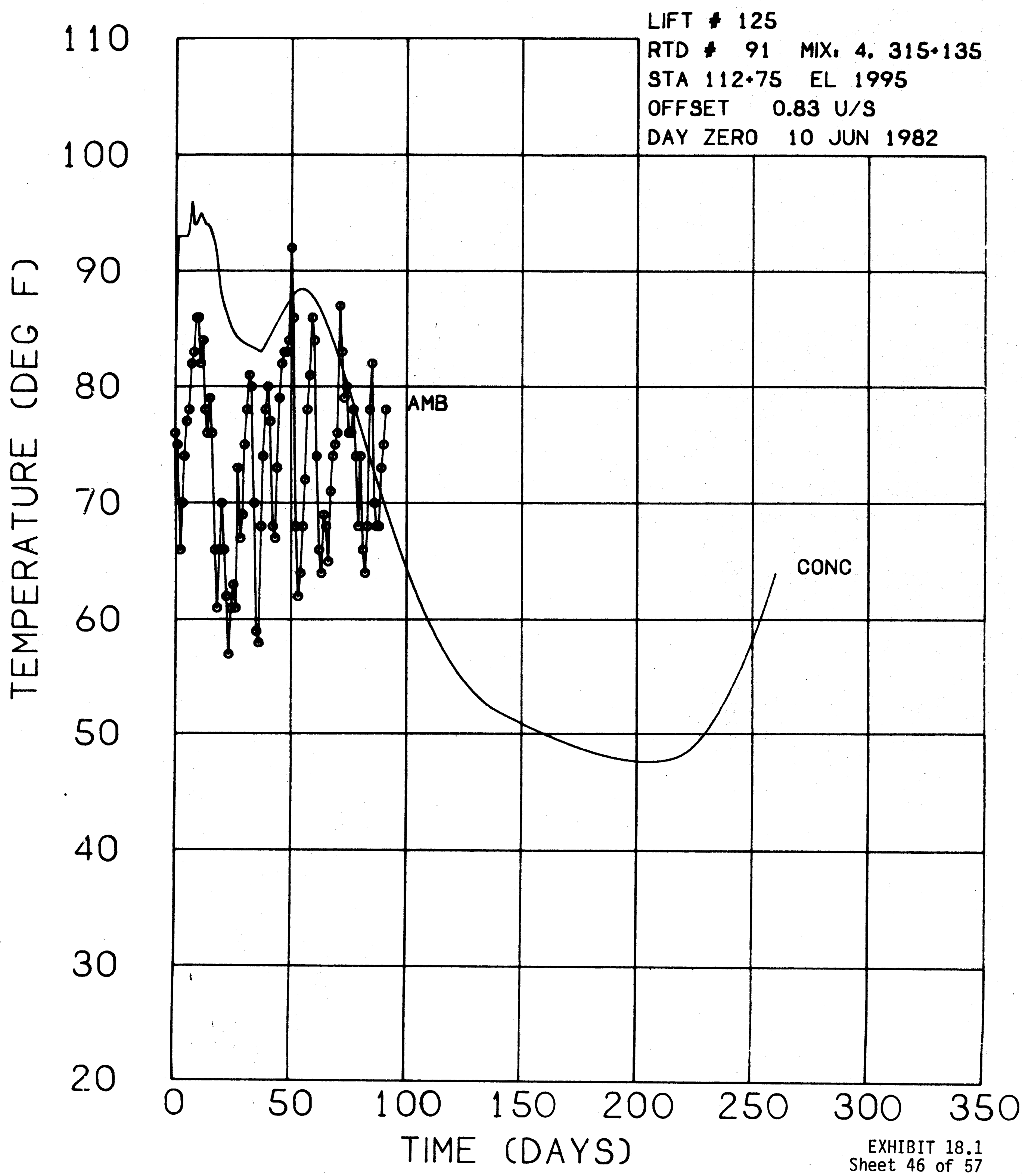
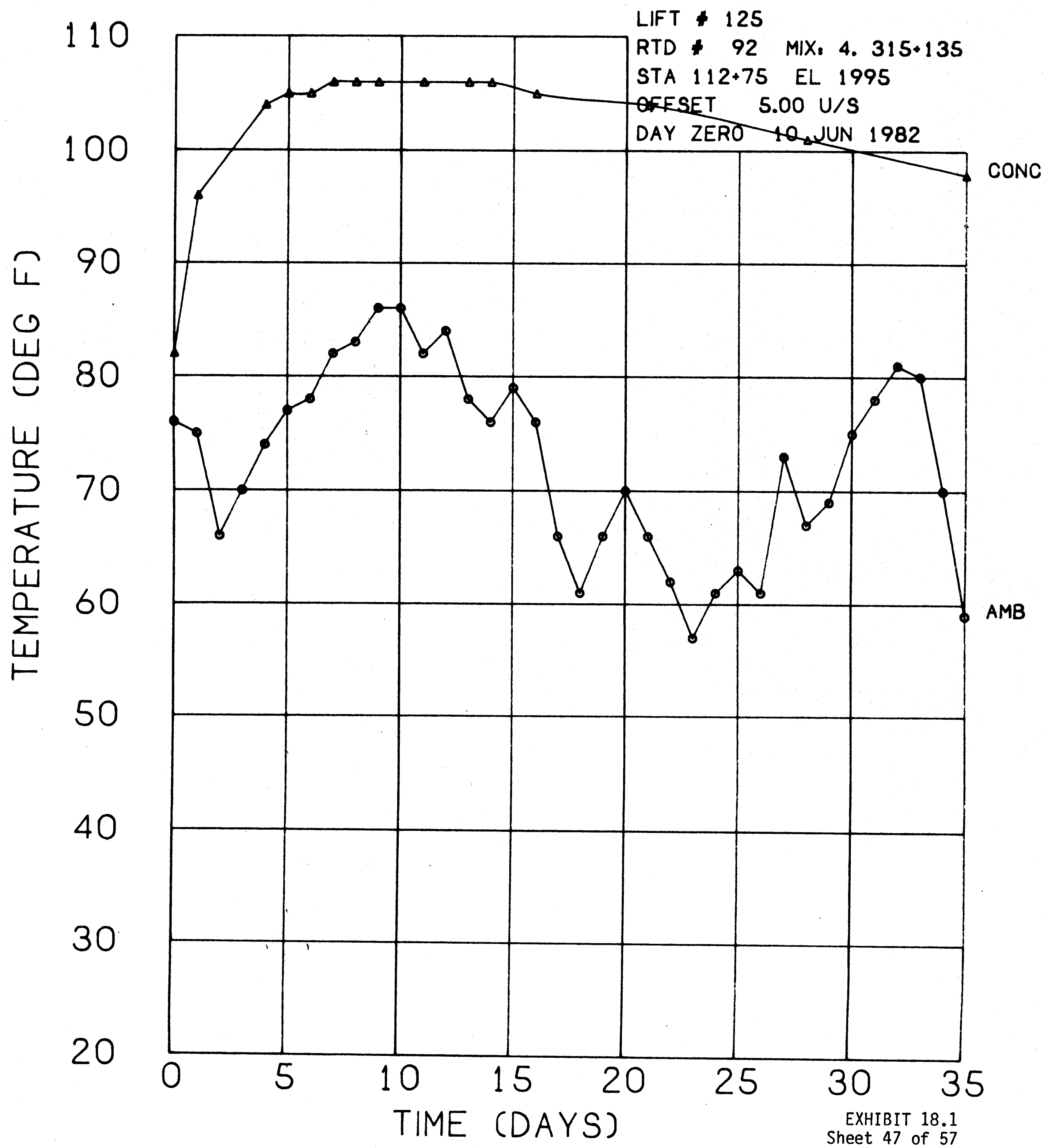
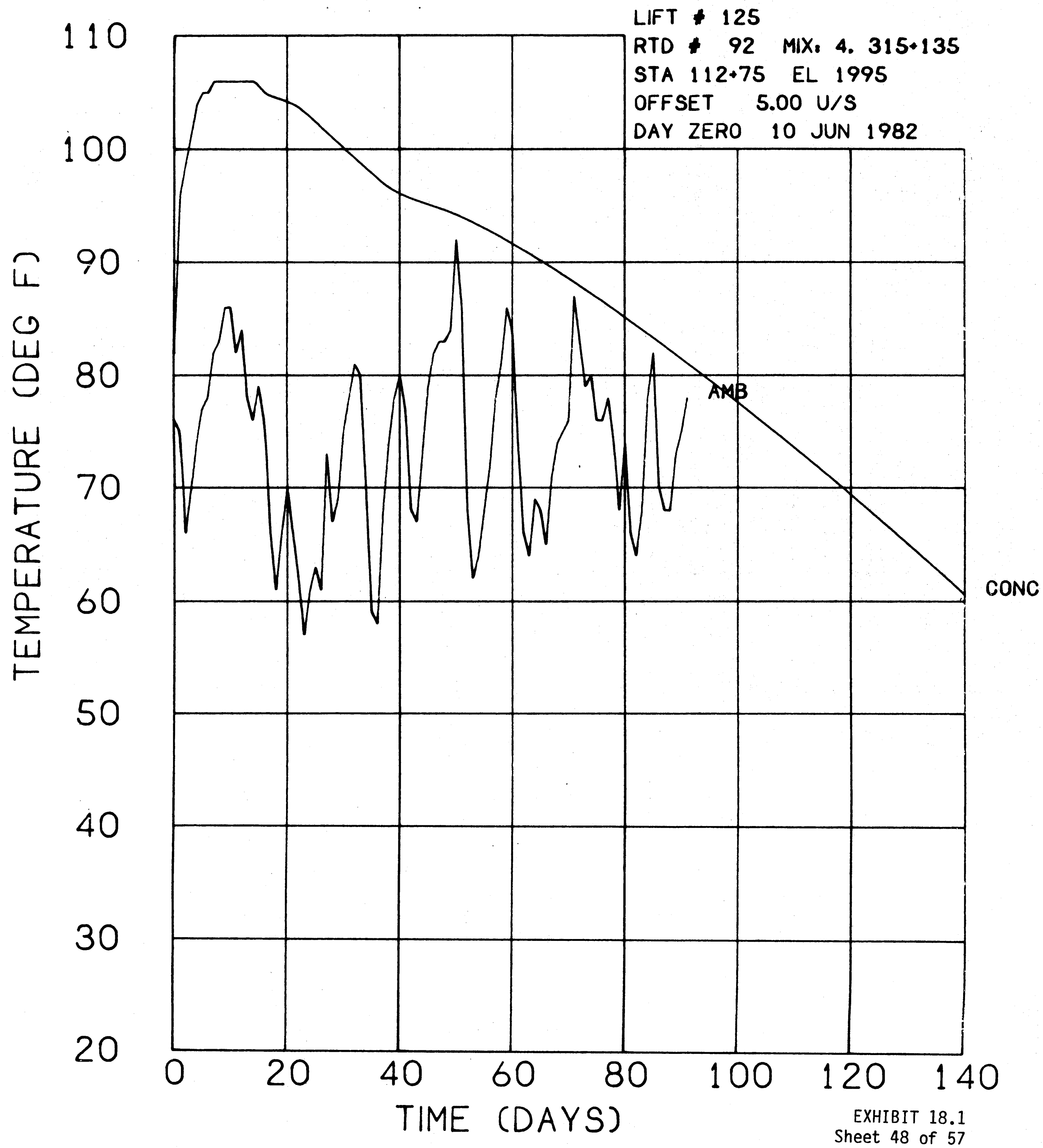


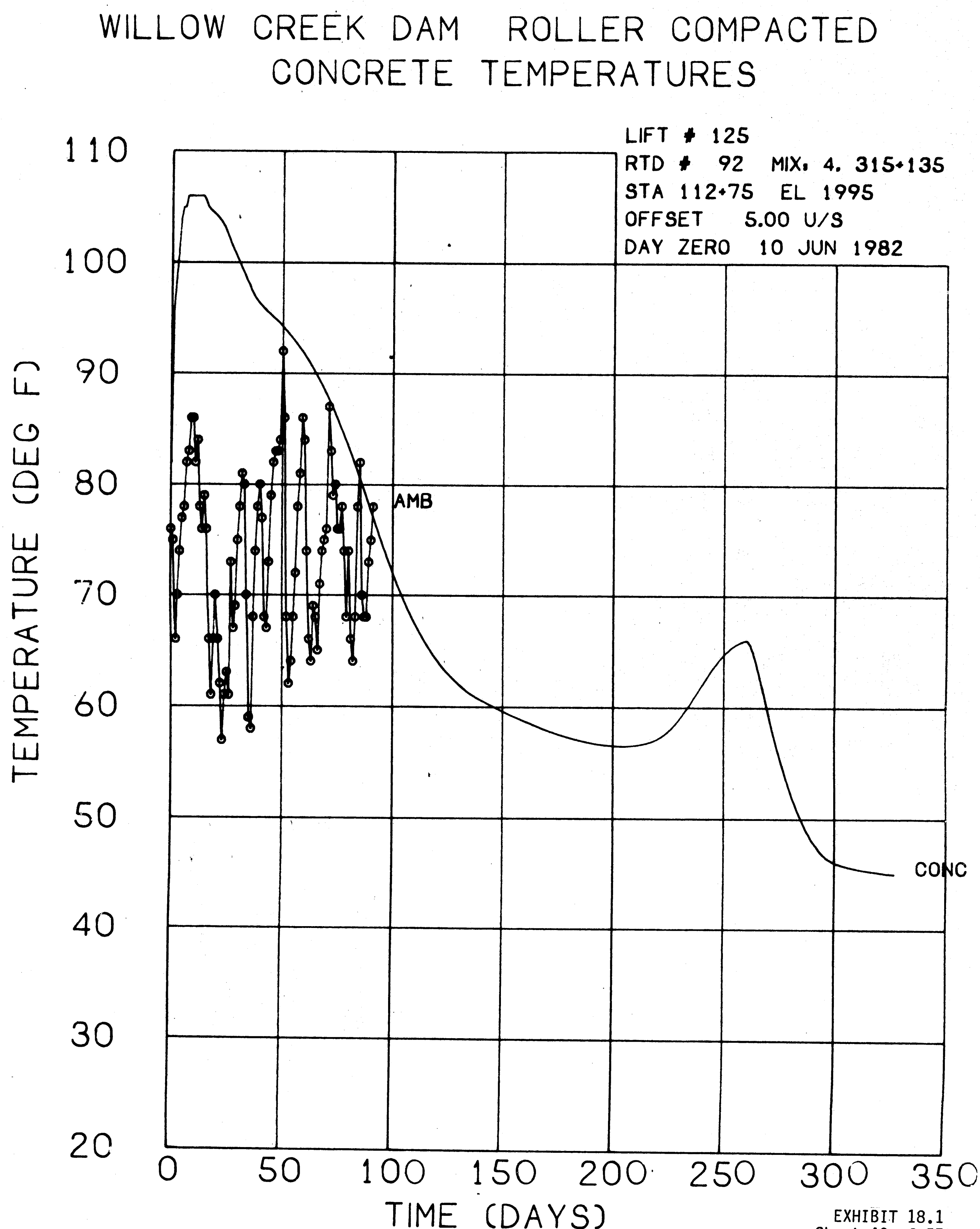
EXHIBIT 18.1
Sheet 46 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES



WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES




WILLOW CREEK DAM ROLLER COMPACTED
CONCRETE TEMPERATURES
LIFT # 125
RTD # 92 MIX: 4. 315+135
STA 112+75 EL 1995
OFFSET 5.00 U/S
DAY ZERO 10 JUN 1982
TEMPERATURE (DEG F)
TIME (DAYS)
AMB
CONC
110
100
90
80
70
60
50
40
30
20
0
50
100
150
200
250
300
350

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

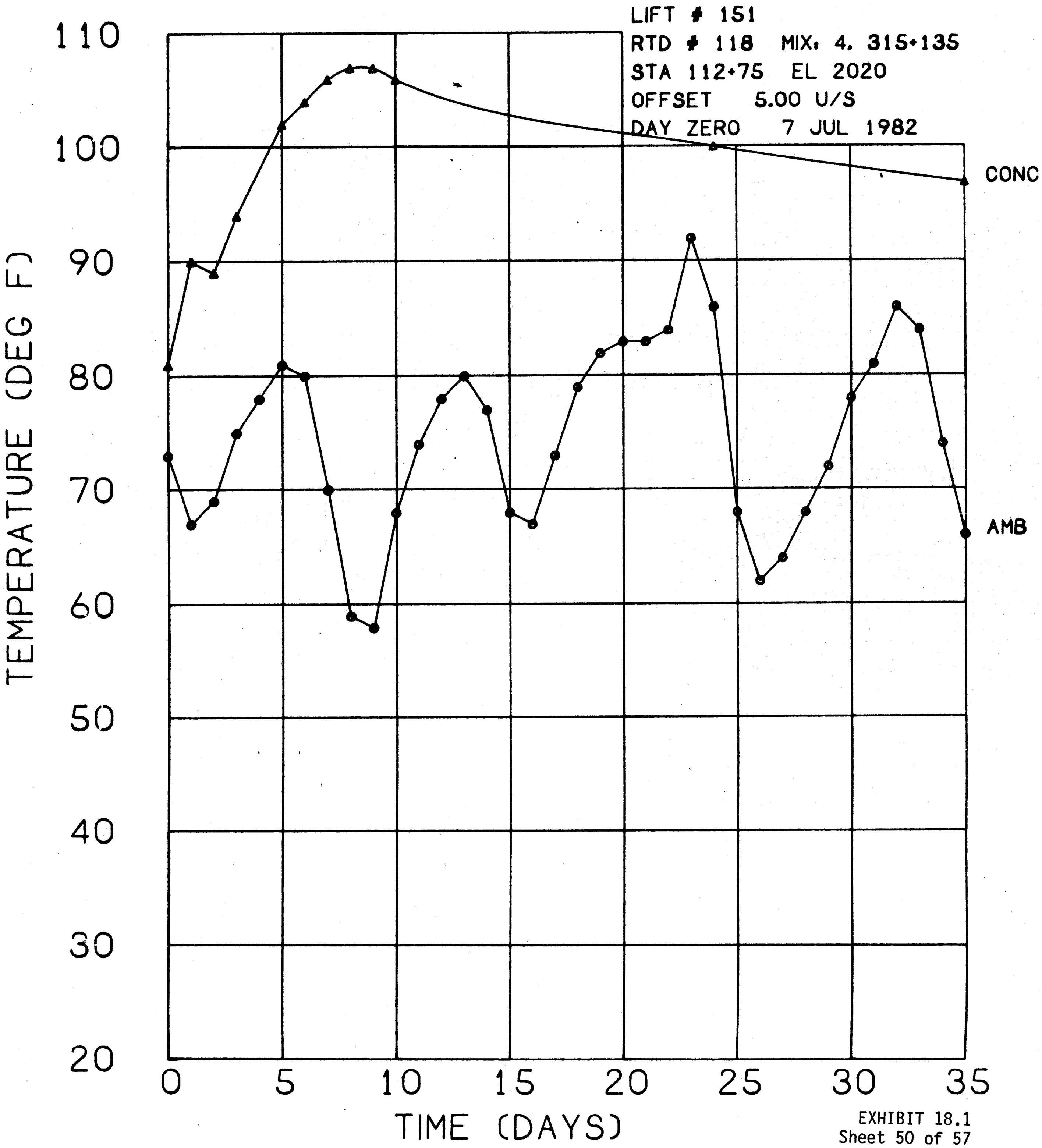
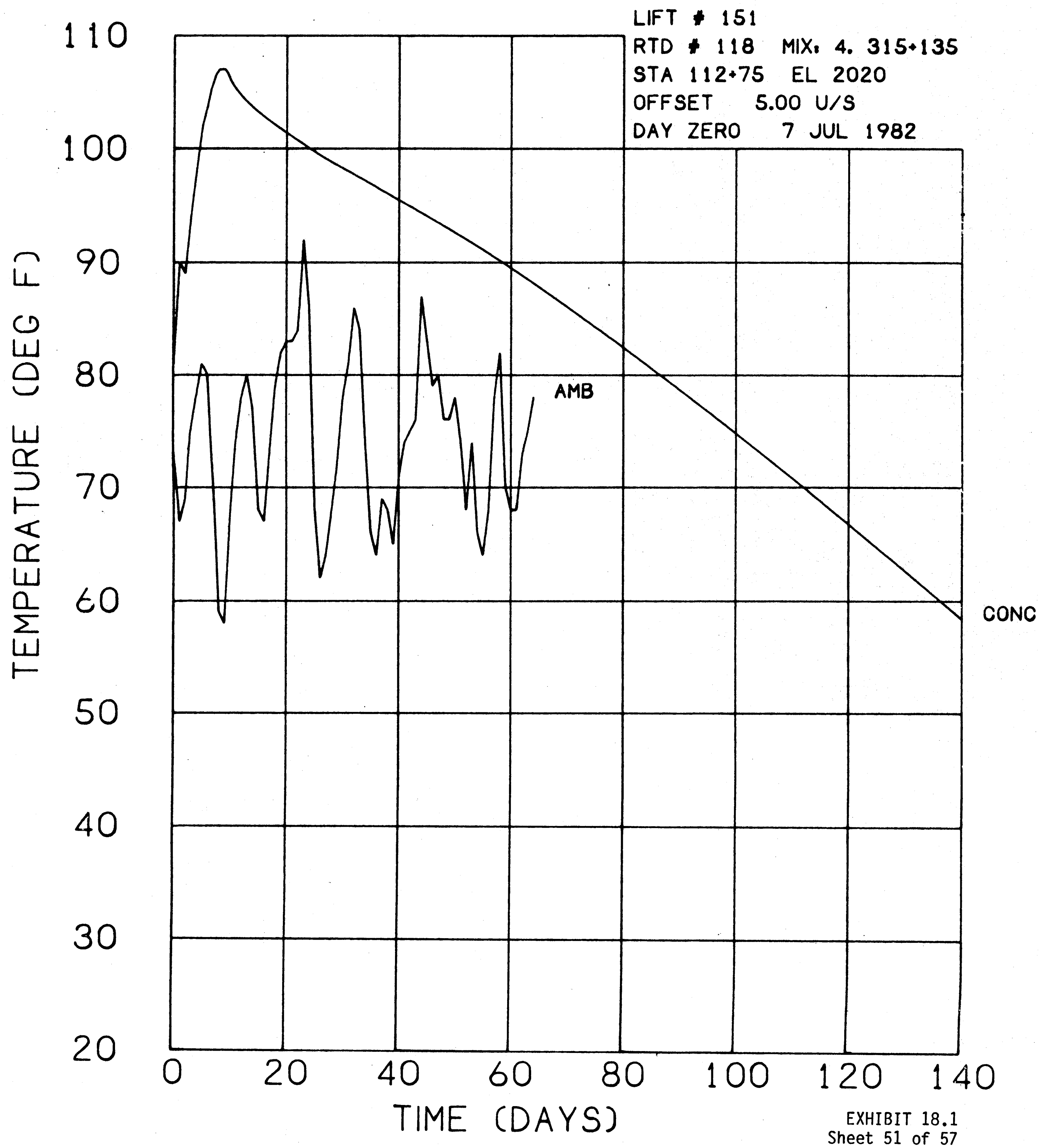


EXHIBIT 18.1
Sheet 50 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES



WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

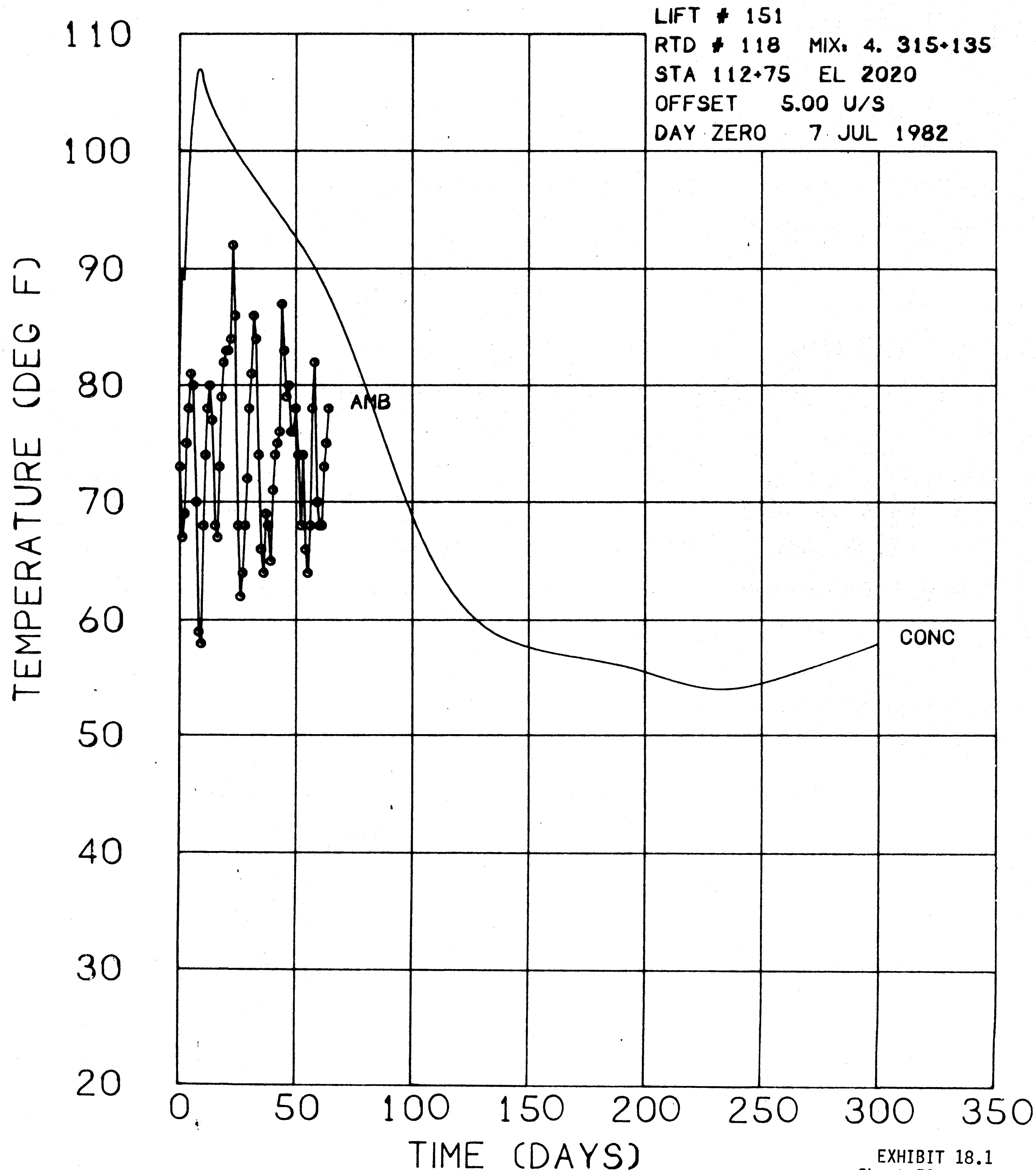


EXHIBIT 18.1
Sheet 52 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

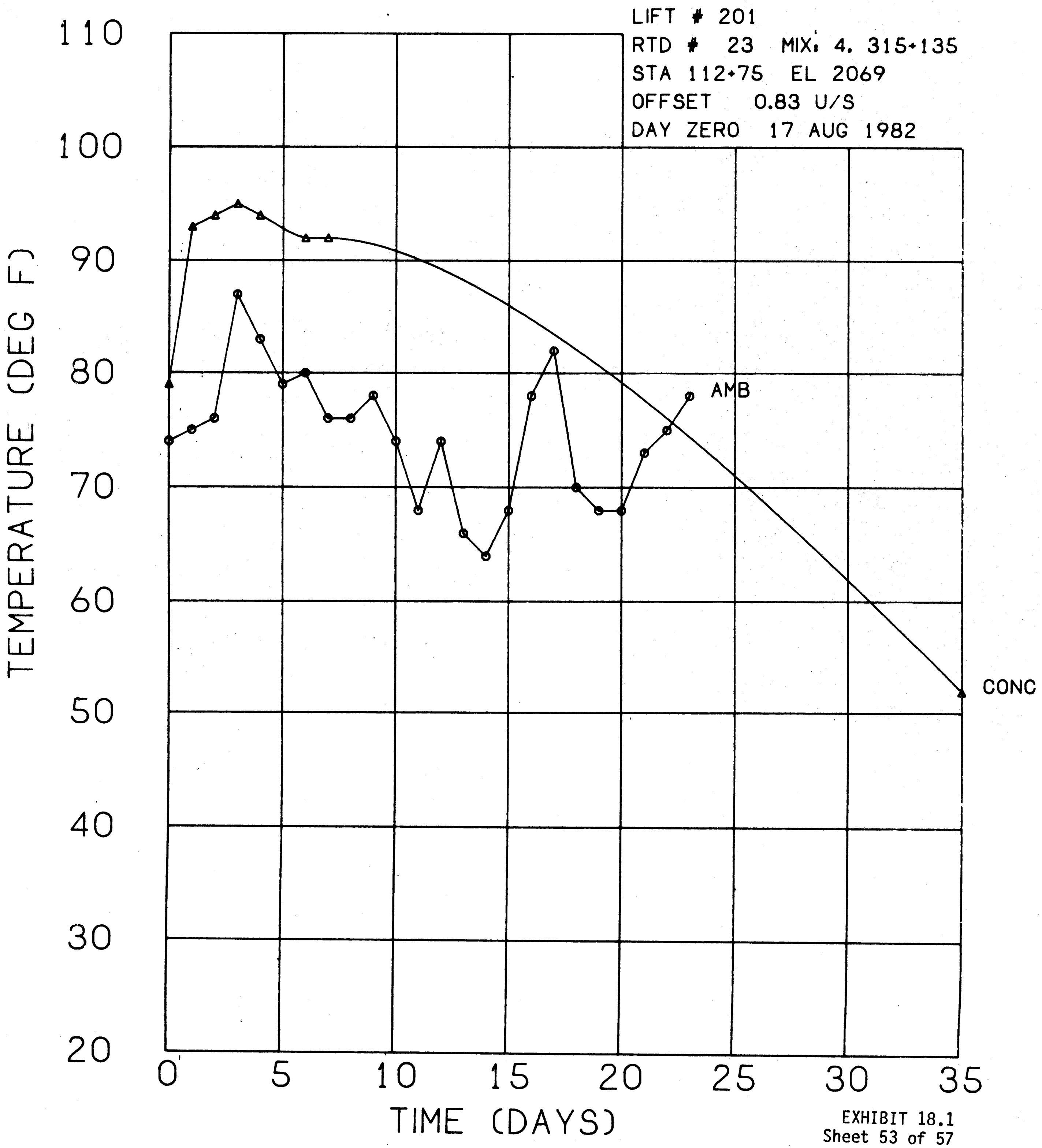


EXHIBIT 18.1
Sheet 53 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

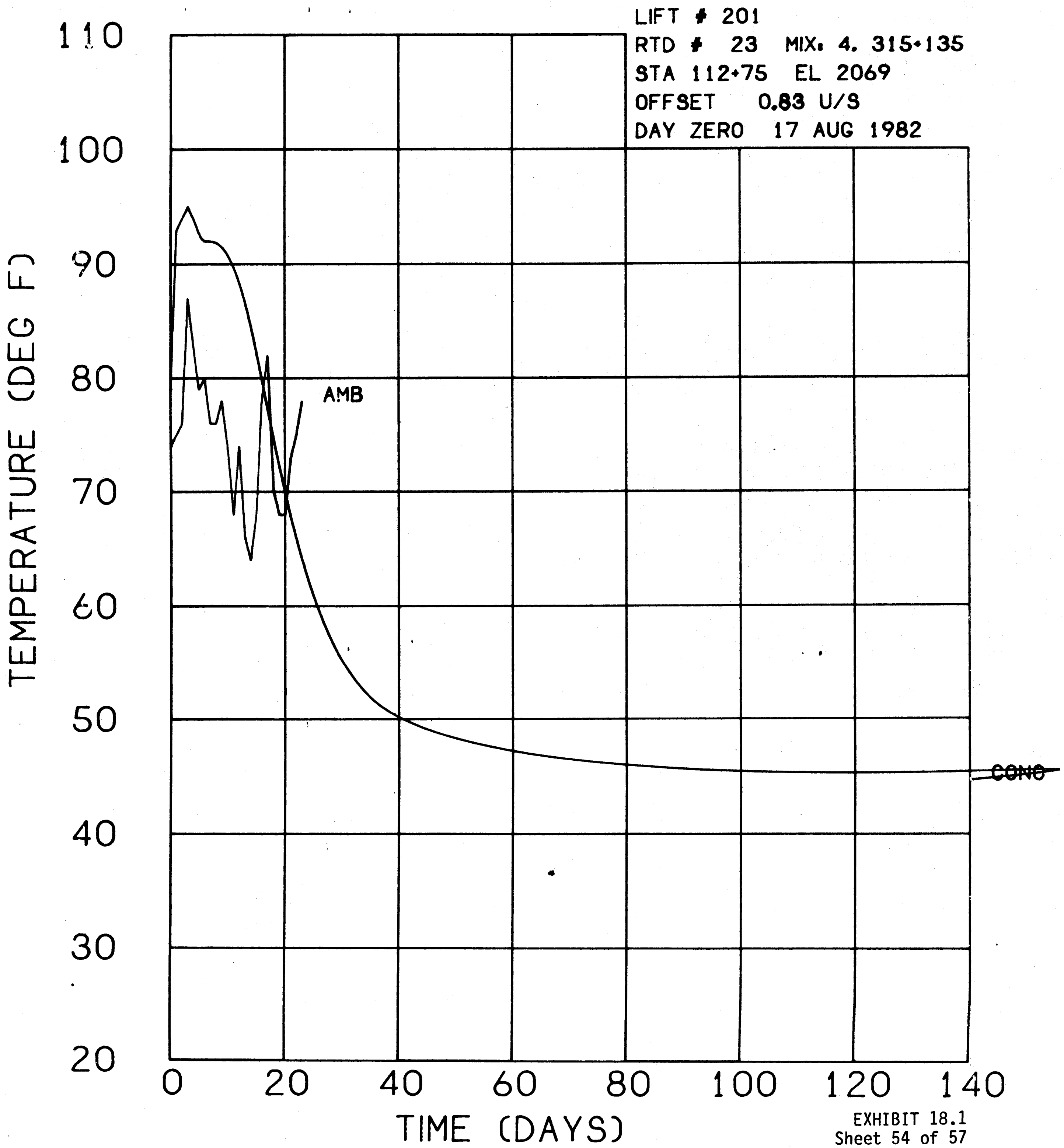


EXHIBIT 18.1
Sheet 54 of 57

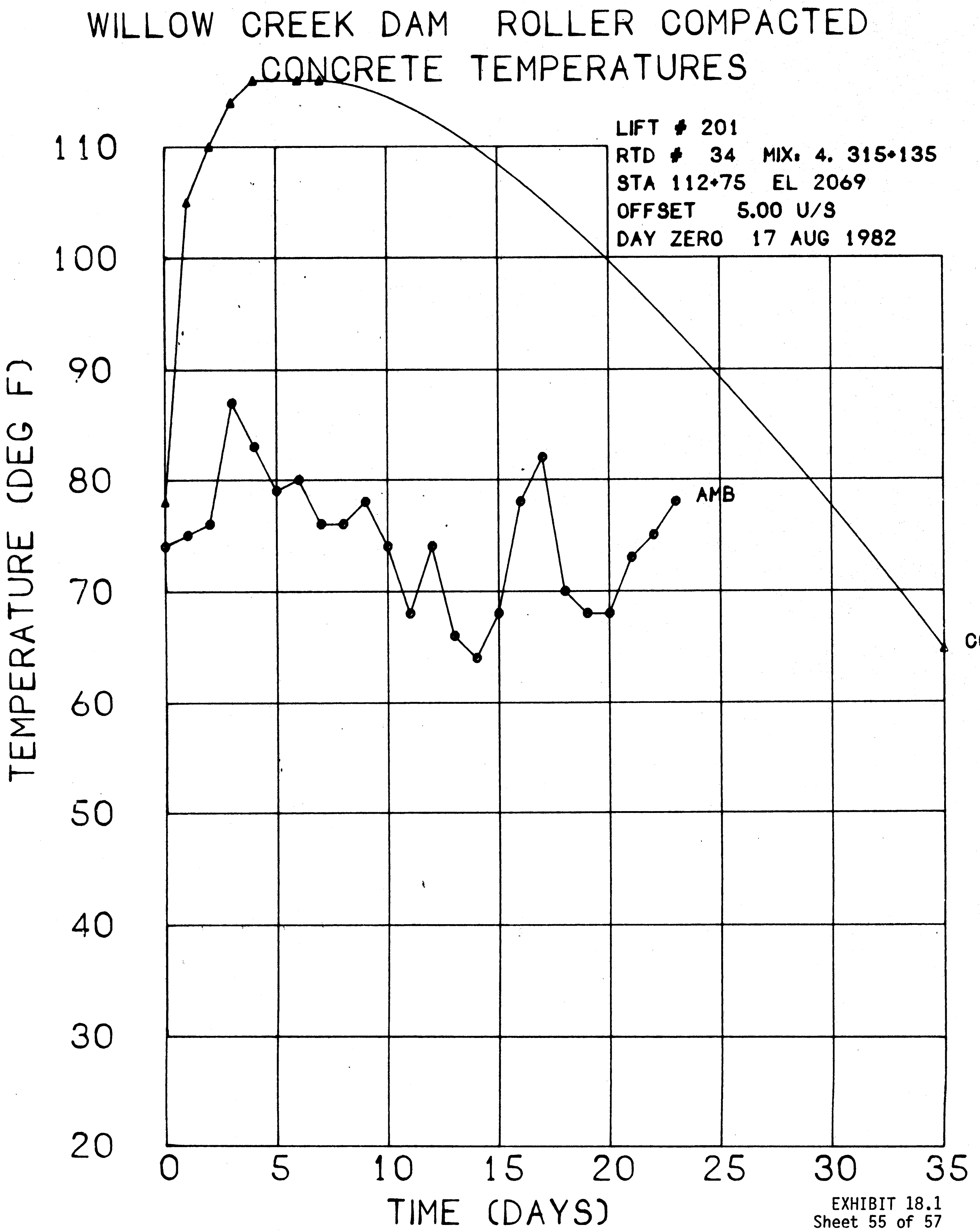


EXHIBIT 18.1
Sheet 55 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

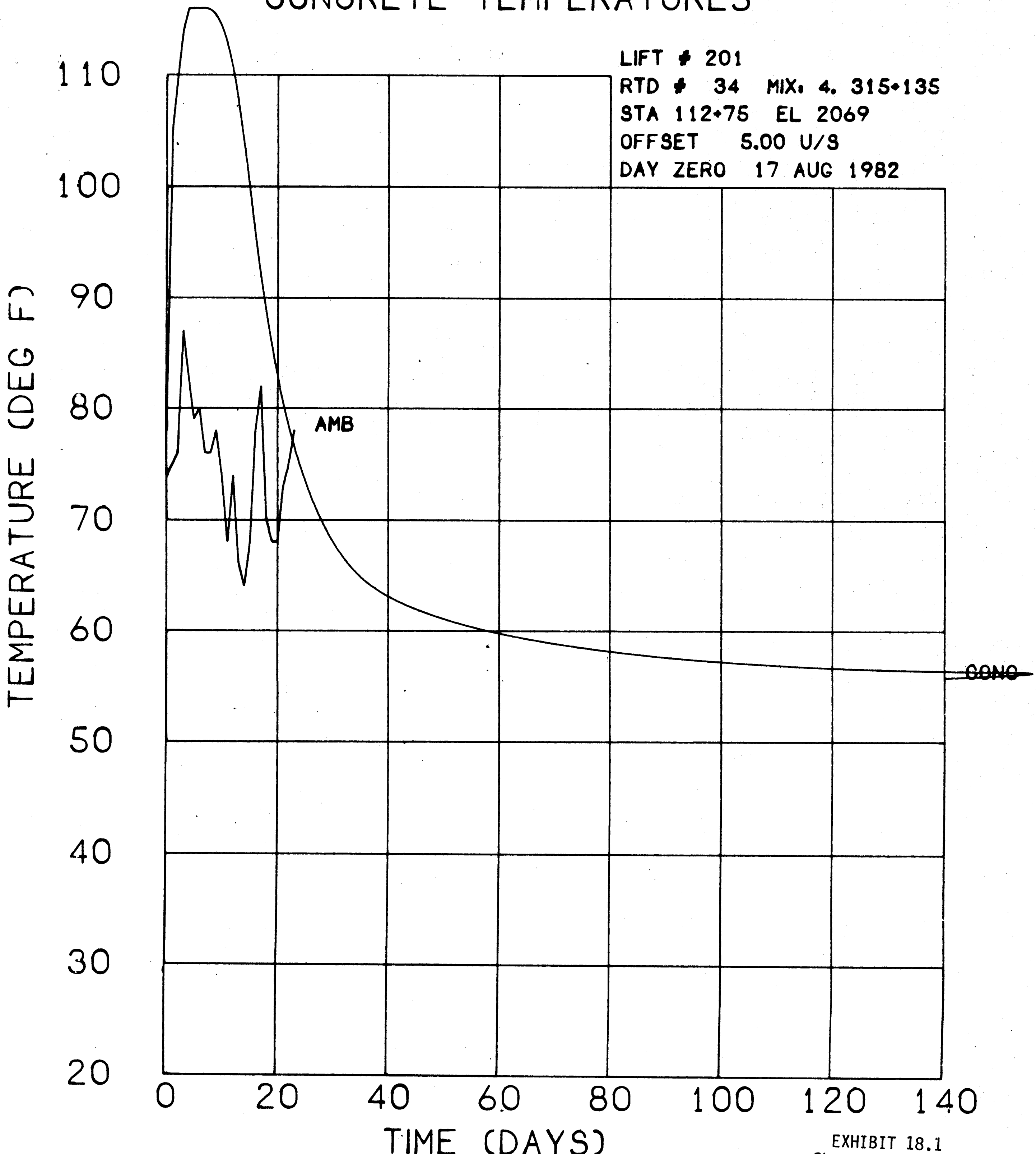


EXHIBIT 18.1
Sheet 56 of 57

WILLOW CREEK DAM ROLLER COMPACTED CONCRETE TEMPERATURES

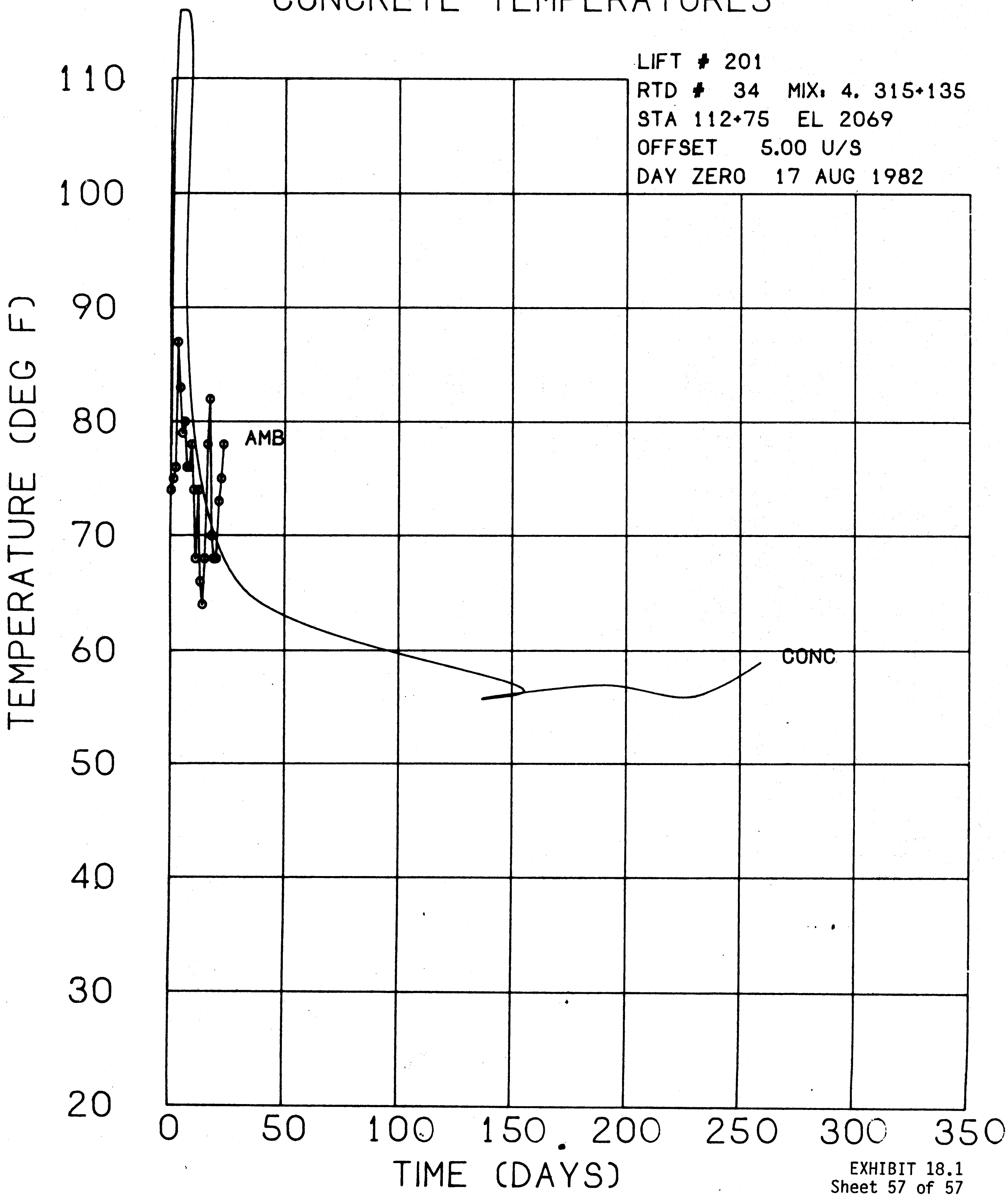


EXHIBIT 18.1
Sheet 57 of 57

EXHIBIT 18.2

DISPOSITION FORM DATED 5 OCT 82
"WILLOW CREEK DAM INSULATION"

NOTE: This exhibit contains a discussion of the problems, evaluation, and decisions concerning insulation for thermal shock protection.

DISPOSITION FORM

For use of this form, see AR 340-15; the proponent agency is TAGO.

REFERENCE OR OFFICE SYMBOL	SUBJECT
NPWEN-FM	Contract No. DACW68-82-C-0018 Willow Creek Dam Insulation

TO THRU Ch, F&M BR
Ch, Engr Div
Ch, Constr Div

FROM E. K. Schrader DATE 5 Oct 1982 CMT 1

TO Engrg Files

1. The purpose of this DF is to document and summarize why surface insulation was necessary at Willow Creek Dam, why and how the decision was made to modify insulating requirements to place it within 40 hours, and to explain why it was later determined best to remove most of the insulation about three weeks after it had been put in place.

2. Brittle materials that are exposed to excessive thermal shock will crack. An exterior surface subjected to a sudden drop in temperature will try to decrease in length by an amount that can be predicted based on the coefficient of thermal expansion. If the temperature - say several inches inside the surface remains at a sufficiently higher temperature than the surface concrete, it provides restraint which prevents surface contraction. Cracking results. The shattering of ice cubes when hot water is poured over them is an example of this phenomenon. If the temperature differential between the surface and the zone just inside the surface is controlled so that stresses and strains are within the elastic limits of the material, cracking will be prevented. With concrete, the problem is complicated by the fact that material properties change with time, and the rate of change is dependent upon several variables such as time, temperature, cement chemistry, and most importantly, the rate at which surface temperatures change.

3. During design of Willow Creek Dam, material properties needed for determination of permissible thermal shock values were determined as best as could be done through laboratory testing using procedures that simulate field placement. Based on these tests and probable ambient temperatures determined from a review of historical weather data for approximately 50 prior years, the contract specification requirements for insulation were established. This was to serve as the basis for bidding and as a guide for what probably would be necessary. As stated in the DM, actual insulation requirements would be modified, if necessary, in the field based on properties of the materials as they develop and on the actual weather.

4. When conditions which required insulation approached, large test samples of RCC were taken from the dam so that material as it was being placed and compacted in the field could be evaluated for thermal shock resistance. Results showed that better compaction and a harder concrete was being achieved at very early age near the downstream face of the dam than was thought. We had anticipated that the unconfined material near the downstream face would be so poorly consolidated and that it would gain strength and modulus at such a slow rate that it would be deformable for several days. This was not the case. The deformable stage lasted for only an estimated 40 hours. It was found that at 40 hours, a thermal gradient of 30 to 32 degrees F across a 3-inch distance could be tolerated in the 175+80 mix and a gradient 41 ~~on~~ to 45 degrees F could be tolerated in the 315+135 mix. Values were determined both by stress and strain analyses.

EXHIBIT 18.2
Sheet 1 of 4

5. Instruments in the dam were being monitored at this time to record the actual temperature differential from the surface to 3 inches inside the surface. During late August and early September, ambient temperatures dropped rapidly in the evening resulting in maximum differentials at about midnight. The amount of monitored data, testing, and calculations developed into an extensive analysis. A summary follows:

Mix	Measured Max ΔT 0 to 3 Inches	Dates	Max Allowable ΔT Based on Strain	Max Allowable ΔT Based on Stress
175+80	21°F	20-23 Aug	32°F	30°F
175+80	24°F	24-27 Aug	32°F	30°F
175+80	27°F	28-31 Aug	32°F	30°F
315+135	23°F	20-23 Aug	42°F	41°F
315+135	27°F	24-27 Aug	42°F	41°F
315+135	29°F	28-31 Aug	42°F	41°F

Based on the data, the developing trend, and the weather forecast, the Resident Office was advised that insulation should begin on 7 September for both the 175+80 and 315+135 mixes, and that insulation should be installed within 40 hours of placement.

6. When the modified insulation plan was implemented, the contractor "over-insulated", i.e, he hung his insulation mats over the downstream face covering more concrete than needed to be protected. However, once the insulation was in place and heat built up under it, the concrete would be subject to unacceptable thermal shock if the insulation was later pulled up as planned by the contractor. On 13 September, he was advised that all insulation in place had to remain in place and be pinned, weighted or tied down so that cold air did not blow under it. This interfered with his plans to let ravel from placing the RCC roll under the insulation, but it was necessary and he agreed to it. Where he had not tied down the insulation, it had blown back occasionally exposing the concrete surface, or cool air had blown under it. When the wind was not blowing, the insulation was effective. The reduced temperature differential over the 3-inch surface to interior distance as measured in the field for the day or two before and after insulation started is evident in the following data.

	ΔT Prior to Insulation	ΔT After Insulation
Mix 175+80	28°F	12°F
Mix 315+135	37°F	18°F

The upstream face was not insulated with blankets because as planned, the precast facing panels were acting as insulation themselves. Temperature differences across the panel were as much as 30 F degrees, but temperature differences from the face of the RCC to 3 inches inside it were only a few degrees.

7. Unfortunately, after it was first put in place, the insulation was not maintained in a continuously effective manner. Wind was allowed to blow under it, and at times entire sections of thousands of square feet were totally exposed when the unsecured mats blew back. A reevaluation of the situation was made. It was determined that on 29 September the best thing to do was to remove all insulation within the next week, except for the top of the non-overflow and above lift 257, 258 or 259. Removal was to be done during the hours of 0900 and 1500. Technical evaluations that led to this recommendation had to account for many variables including the different mixes, different ages of each RCC lift being insulated, weather predictions, actual temperatures in the dam as measured by embedded instruments, etc. Basically, the insulation had been so ineffective, the surface received little protection and had cooled to temperatures varying from 46 to 63 degrees F. The duration of poor insulation protection had been long enough so that temperatures 3 inches inside the surface had also cooled to between 44 and 75 degrees F. Because these temperatures were low, high values of ΔT could no longer develop. Thermal shock which would bring these temperatures down so low as to stress the concrete to the point of cracking had already occurred. That damage cannot be undone. In effect, the outside surface of the concrete (the already damaged material) is now acting as insulation for the interior mix. Measured changes in temperature from 3 inches to 5 feet inside the dam show tolerable differences. If the insulation were reestablished, temperatures under it would raise. If the insulation were to blow back as had been the typical situation to date, additional thermal shock and damage could result. It was therefore better to remove the insulation during the warmest part of the day than to try to reestablish it. An exception to this was concrete at the top of the non-overflow where it was too young to withstand thermal changes which could occur under the worst of predictable circumstances. The following data is a summary of part of the more pertinent data from the evaluation.

Tolerable ΔT over 3 inches based on an average of stress and strain analyses.

RCC AGE	MIX 175+80	MIX 315+135
40 hours	30°F	41°F
1 week	42°F	62°F
1 month	51°F	84°F
1 year	69°F	120°F

An example of results of analysis for the upper lifts of concrete on calendar date 28 September 1982 follows:

	MIX 175+80	MIX 80+32
Warmest temp 3" inside	62°F	75°F
Youngest concrete	5 days	14 days
Worst ΔT over 3"	23°F	9°F
Allow. ΔT at that age	39°F	72°F
Lowest allow surf temp	23°F	3°F
Lowest surf temp	50°F	46°F
Temp outside insulation	45°F	61°F
Ambient temp	33°F	33°F

From the last 2 years of continuous recording of temperatures:

	Oct 1980	Oct 1981	Jan/Feb/Mar
Ambient ΔT at night	50°F	20°F	10°F (typical)
Minimum T	10°F	15°F	-5°F (lowest)

E. K. SCHRADER
Civil Engineer

CF:
Res Engr, Willow Cr
NPDEN-GS&M

CHAPTER 19

CONCRETE QUALITY MONITOR

The CQM uses chemical analysis equipment normally used for medical purposes to rapidly determine the water and cement content of fresh concrete. The concept originally was called the Kelly-Vail system and used equipment less suited to the field. Its development started about 10 years ago. The Corps' Construction Engineering Research Laboratory developed the state of the art to a field-suitable system. They provided valuable guidance, training, onsite assistance with adapting the system to RCC, and help with the evaluation of results at Willow Creek. Willow Creek Dam was probably the first major project to use CQM on a routine basis during construction. It was run on every mix from which compressive cylinders were made. Literally hundreds of tests were done so that a fair evaluation of its value on RCC projects could be made.

The equipment is shown in the photographs on Plate 9.1. Details concerning the procedure are available in report M-293, "Rapid Testing/ Plastic PCC," published by the Corps' Construction Engineering Research Laboratory. Basically the process for cement determination consists of obtaining a sample of the mix, thoroughly washing it with a known volume of recycled water to remove all material finer than a No. 100 sieve, obtaining a sample of the wash water and diluting it further with more water, adding nitric acid and mixing the solution, and finally putting several drops of the final solution into a calibrated electrochemical calcium analyzer. The analyzer provides a digital numerical reading that is an indicator of calcium content. The value corresponds to the cement content in pounds per cubic yard as indicated on previously determined calibration charts for the particular water, cement, admixtures, and aggregate being used. Typical calibration charts for the Willow Creek mixes are shown on Plates 19.1 through 19.9. It should be noted that extreme care must be taken to thoroughly wash (and hand scrub) all cement coatings and fines from each coarse aggregate particle, to be sure no solution is lost or spilled, to add exactly the correct amount of acid of the correct concentration, and especially to put exactly the right amount of final solution (measured in microliters) into the analyzer. The procedure is suitable for use in a well maintained field laboratory but must be done precisely.

The procedure for water content determination is not as difficult. It consists of adding a known amount of salt solution to a sample of the mix, shaking it to develop a slurry, subjecting a portion of the slurry to a centrifuge, and putting a portion of the fluid above the resulting precipitate into an electrochemical chloride meter. The digital readout value of the meter can be used to determine the water content of the original mix in pounds per cubic yard.

A compilation of CQM test results showing the average test values for cement and water for each mix at each test cylinder age along with the corresponding average compressive cylinder results is given in Exhibit 9.1 of Chapter 9, "Test Cylinders and Compressive Strength Results." Plates 19.10 through 19.19 show the relationship between CQM values for cement and the corresponding compressive cylinder strengths for each mix at each age. An unsuccessful effort was made to establish a direct, predictable, and consistent relationship between the two. In general, the higher CQM values gave higher strengths but frequently the opposite was true.

The original intent was to use the CQM equipment as an acceptance/rejection test for cement content and to use it as a backup for water content tests. After questions developed as to its accuracy with RCC mixes, it was actually used more with the idea of obtaining sufficient data for evaluation of its usefulness in future projects. Differences in cement contents on the order of up to 40 percent from the mix design amount were not uncommon. It is still not certain as to whether this is what actually occurred, if there can be that much error within the test method, if it was due to technician error, or if it was a result of improper sample preparation. Probably it was a combination of all of these items. In order of most influential to least influential, they are judgmentally listed as sample preparation, actual variation in the mix sample, technician error, and test method.

Peculiar to RCC is the problem that the aggregate typically contains a high amount of fines passing the No. 100 sieve. At Willow Creek it thoroughly coated the large aggregate particles along with the cement. This coating was very difficult to remove in the washing process. Hand scrubbing each aggregate piece with fine wire brushes was necessary. The addition of a water softening agent (Calgon) was found to help also.

Another comment for future work is to keep the analysis equipment and screens in clean and accurate condition. The validity of the calibration charts should be routinely verified. The calcium reading includes calcium in the mix water, fly ash, aggregate, and admixture. If this changes or if the chemistry of the cement changes significantly, the calibration chart from which the calcium meter reading is converted to a value of cement in pounds per cubic yard can be in error. Plates 19.1 through 19.9 show the contribution of each mix material to the calcium content.

The average value of all CQM cement tests for each mix and the resulting overall variability follows:

Mix	Design Cement Content (lbs/cy)	Average CQM Value (lbs/cy)	Standard Deviation (lbs/cy)	Coefficient of Variation (%)
1	80	78	19	25
2	175	173	34	20
3	175	178	32	18
4	315	296	43	15
5	330	303	31	10

Considering the fact that coefficients of variation for 6- x 12-inch compressive cylinders ranged from about 24 percent to 58 percent for the 3-, 7-, 14-, and 28-day strengths of each mix (average of 38 percent), the CQM test for cement content looks quite acceptable. However, as explained in Chapter 9, "Test Cylinders and Compressive Strength Results," most of the variability in strength is attributed to problems in making the cylinders, not in mix variability. The update to this report scheduled for October 1983 will include a more conclusive evaluation of the CQM equipment. At that time all of the test cylinder data including the 90-, 180-, and 365-day breaks will be available. A comparison between core strengths from concrete in the dam and the CQM values corresponding to that concrete will also be made.

As discussed in the section on mixer proficiency tests in Chapter 5, "Roller-Compacted Concrete Production and Plant Capacity," the CQM method of rapidly determining cement content was absolutely essential for establishing required mix times and evaluating various batching methods. In this regard it should be required for future RCC projects. It not only provides rapid results as needed but also allows testing of the full mix. It is the best option available for testing the cement content of the mortar portion of the mix and the only option for testing the full mix. Before deciding that it was acceptable to use the CQM-determined cement values for the mixer proficiency evaluations, companion tests were also run using the standard CRD C-55-73 method for determining cement content. That procedure requires sending sieved and dried samples containing the mortar portion of the mix to a chemical laboratory for evaluation using a centrifuge and 1, 1, 2, 2 tetrabromoethene. It takes about a week to get the results. The coefficient of variation for the standard procedure was determined to be 7.3 percent when retesting the same sample. Average results for each of three separate samples tested by both the standard and CQM methods were as follows:

	Cement Content (% by weight)		
	Sample 1	Sample 2	Sample 3
CQM	9.6	9.7	8.3
Standard	10.8	9.5	7.3

Since the difference between the CQM and standard test was basically within the range of accuracy of the standard test, and because from a chemist's judgmental view that both procedures have about the same degree of accuracy (actually, in his opinion, the CQM probably was slightly more accurate and reproducible), it was decided that the CQM test was an acceptable alternate for mixer proficiency evaluations.

The part of the CQM test that determines moisture content is not necessary for future RCC projects. The nuclear density method described in Chapter 11, "Workability and Moisture Tests," is a preferred, faster, and probably more accurate method. It determines moisture of the mix in the field, not in a sample that has been transported to the laboratory. Based on an overall average of 136 comparisons taken randomly throughout the job, the CQM value of moisture was 16 percent less than the moisture determined in the field for the same mix by the nuclear gage. However, within the scatter of data there also were cases where the CQM value was higher than the nuclear gage reading. The coefficient of variation with the nuclear method was 13 percent and for the CQM it was 19 percent. At any rate, as discussed in Chapter 11, the numerical value of moisture content has little practical use.

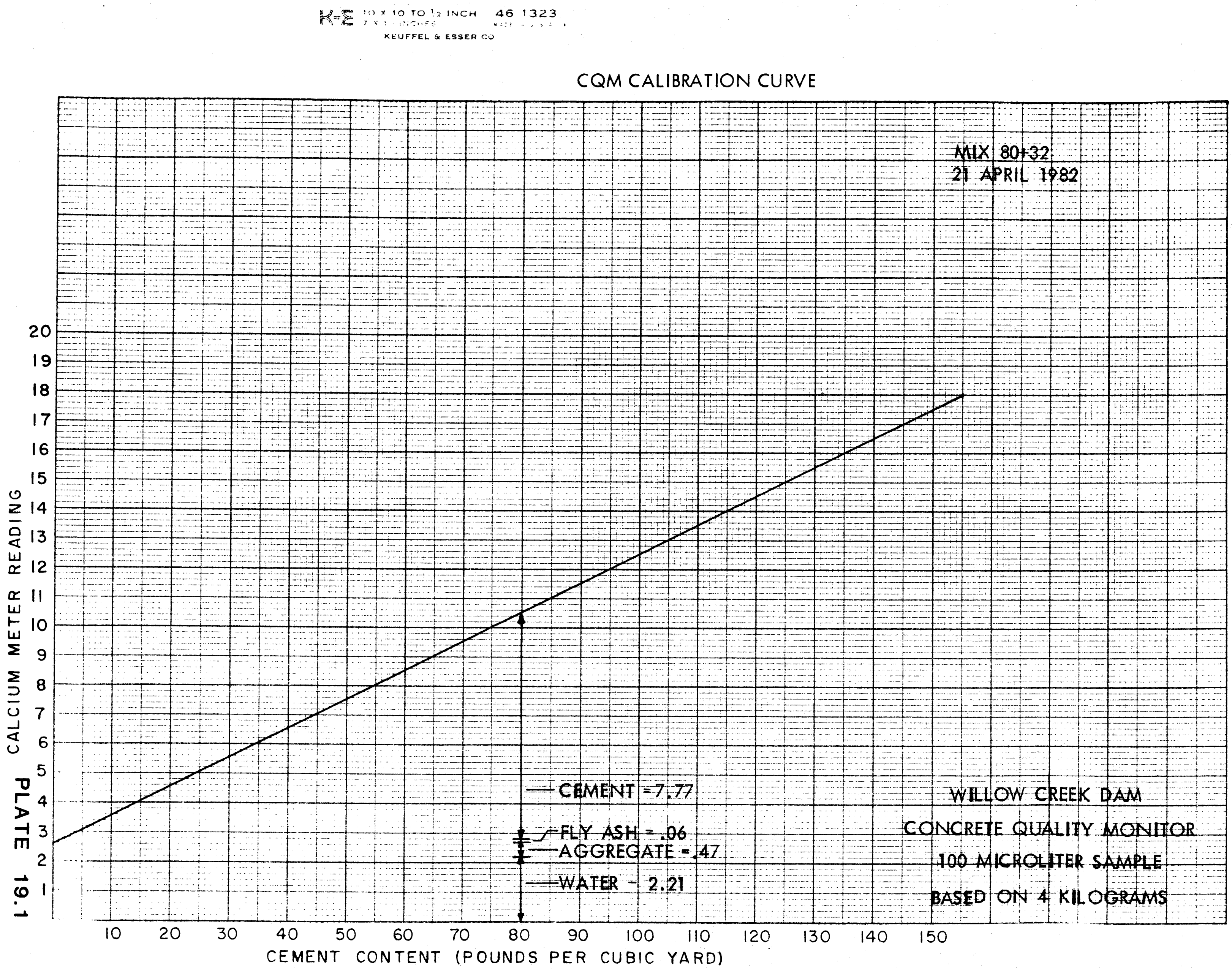
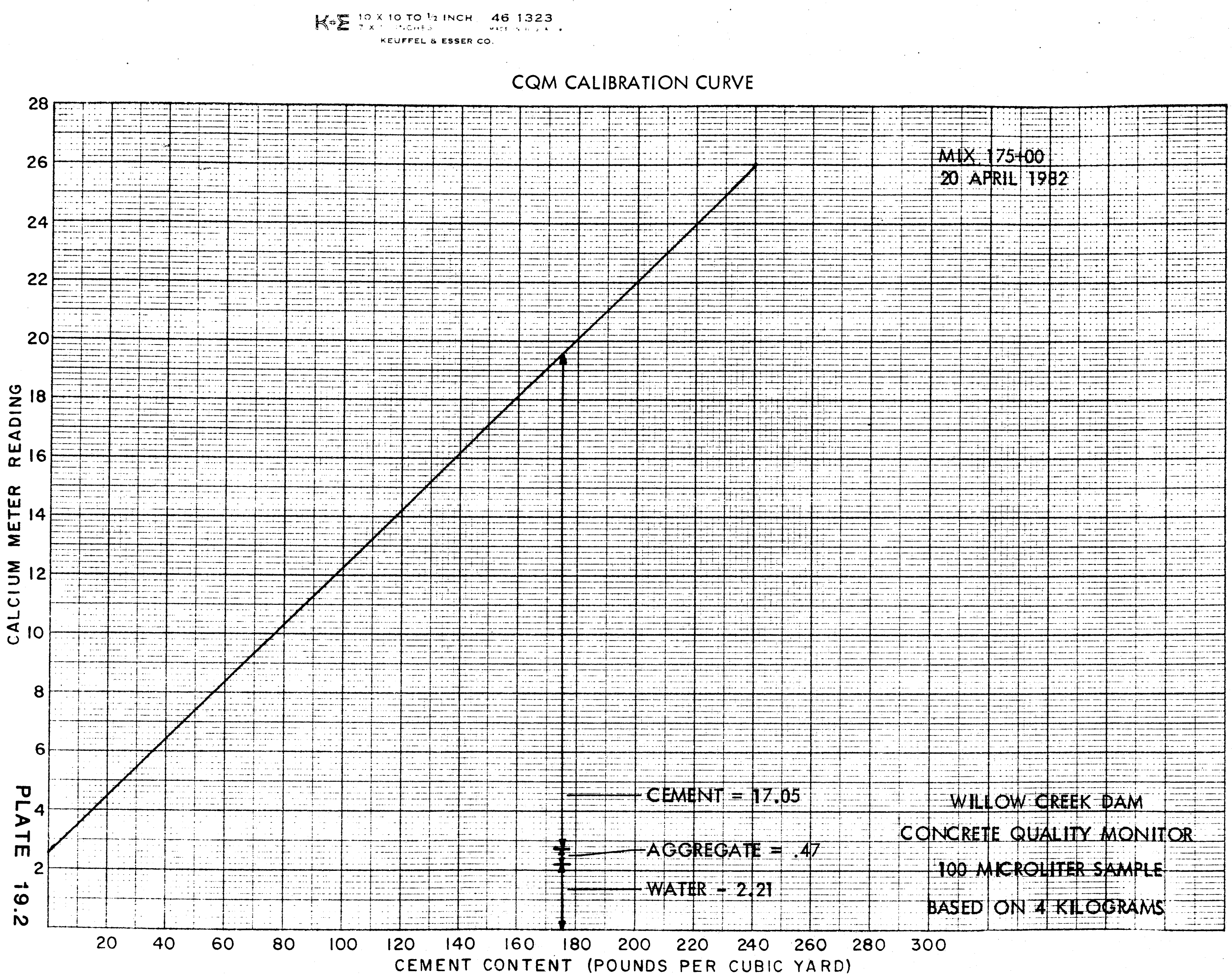

K+E 10 X 10 TO ½ INCH 46 1323
KEUFFEL & ESSER CO
CQM CALIBRATION CURVE
MIX 80+32
21 APRIL 1982
CALCIUM METER READING
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
CEMENT = 7.77
FLY ASH = .06
AGGREGATE = .47
WATER - 2.21
WILLOW CREEK DAM
CONCRETE QUALITY MONITOR
100 MICROLITER SAMPLE
BASED ON 4 KILOGRAMS
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
CEMENT CONTENT (POUNDS PER CUBIC YARD)

PLATE 19.1



K+E 10 X 10 TO ½ INCH 46 1323
KEUFFEL & ESSER CO.
CQM CALIBRATION CURVE
MIX 175+00
20 APRIL 1982
CALCIUM METER READING
28
26
24
22
20
18
16
14
12
10
8
6
4
2
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
CEMENT CONTENT (POUNDS PER CUBIC YARD)
CEMENT = 17.05
AGGREGATE = .47
WATER - 2.21
WILLOW CREEK DAM
CONCRETE QUALITY MONITOR
100 MICROLITER SAMPLE
BASED ON 4 KILOGRAMS

PLATE 19.2

CQM CALIBRATION CURVE

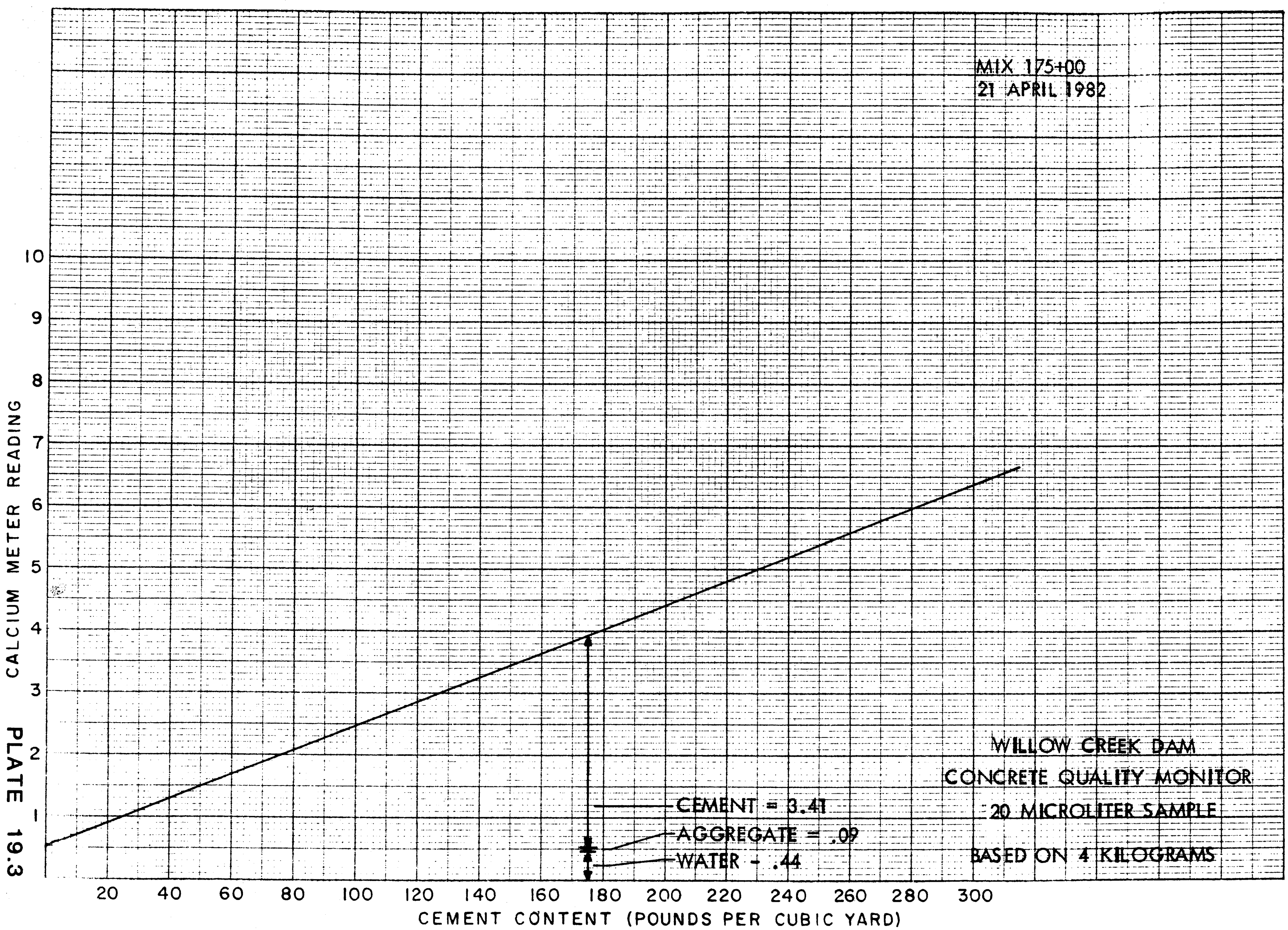


PLATE 19.3

CQM CALIBRATION CURVE

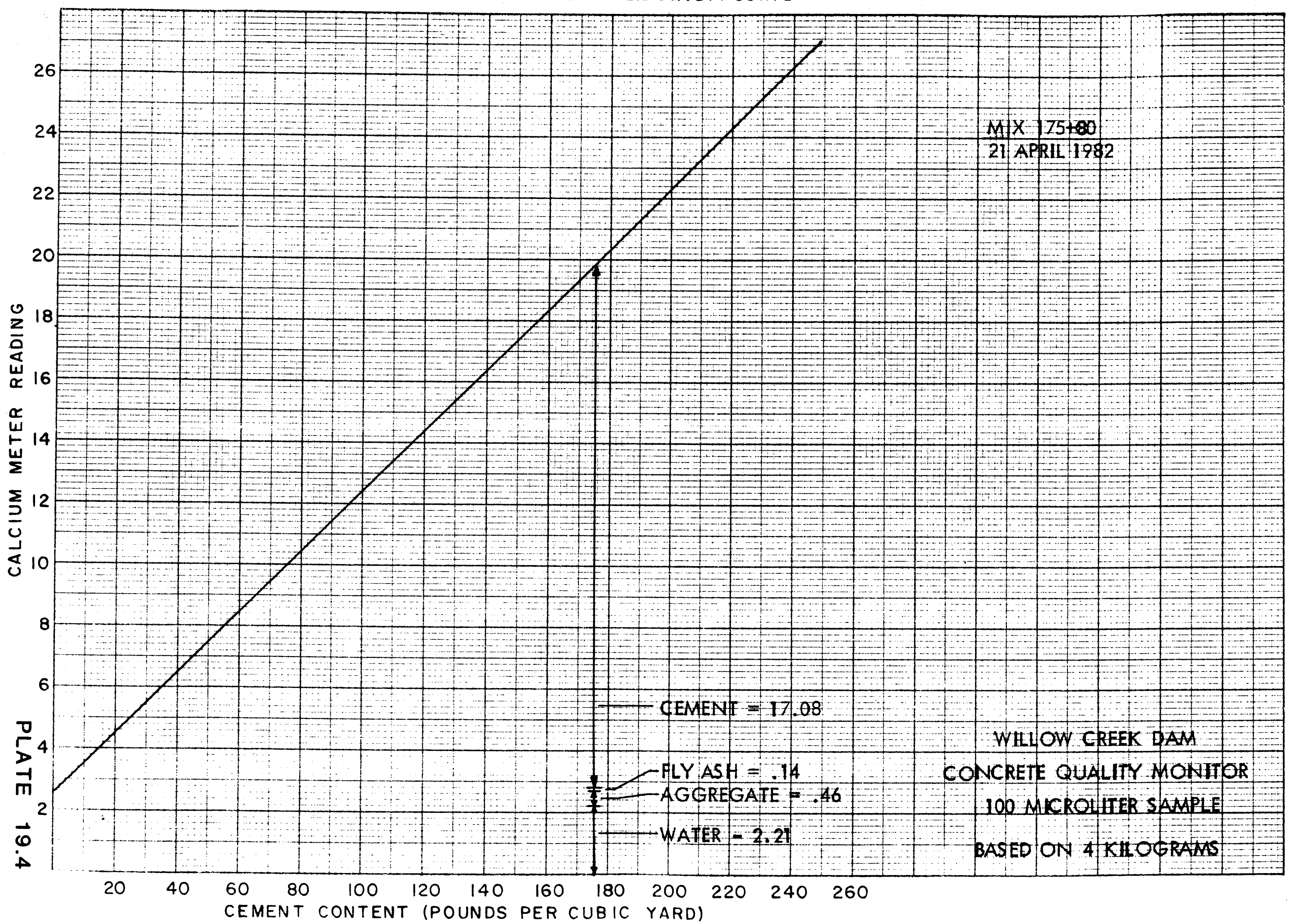


PLATE 19.4

CQM CALIBRATION CURVE

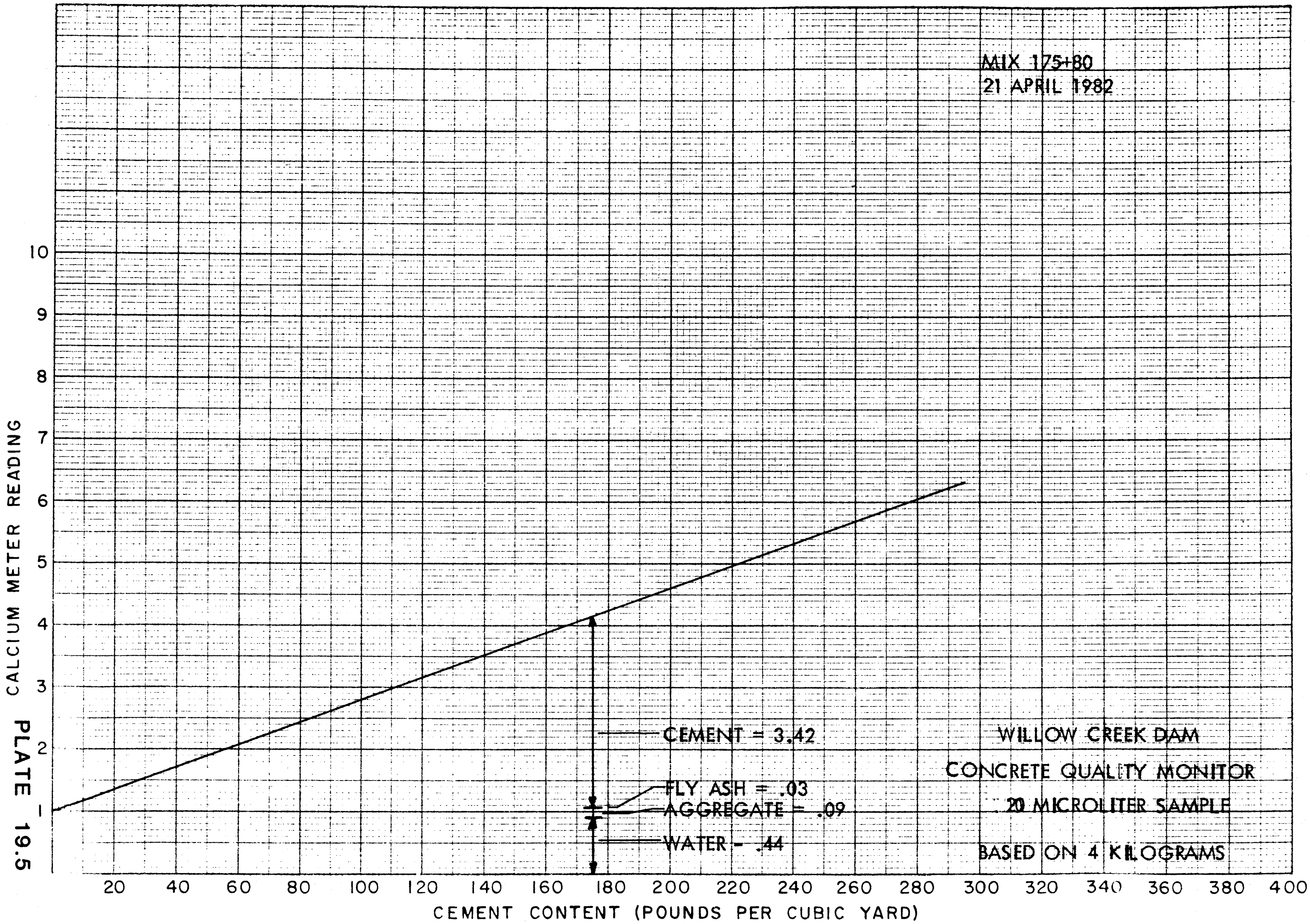


PLATE 19.5

K&E 10 X 10 TO ½ INCH 46 1323
KEUFFEL & ESSER CO.

CQM CALIBRATION CURVE

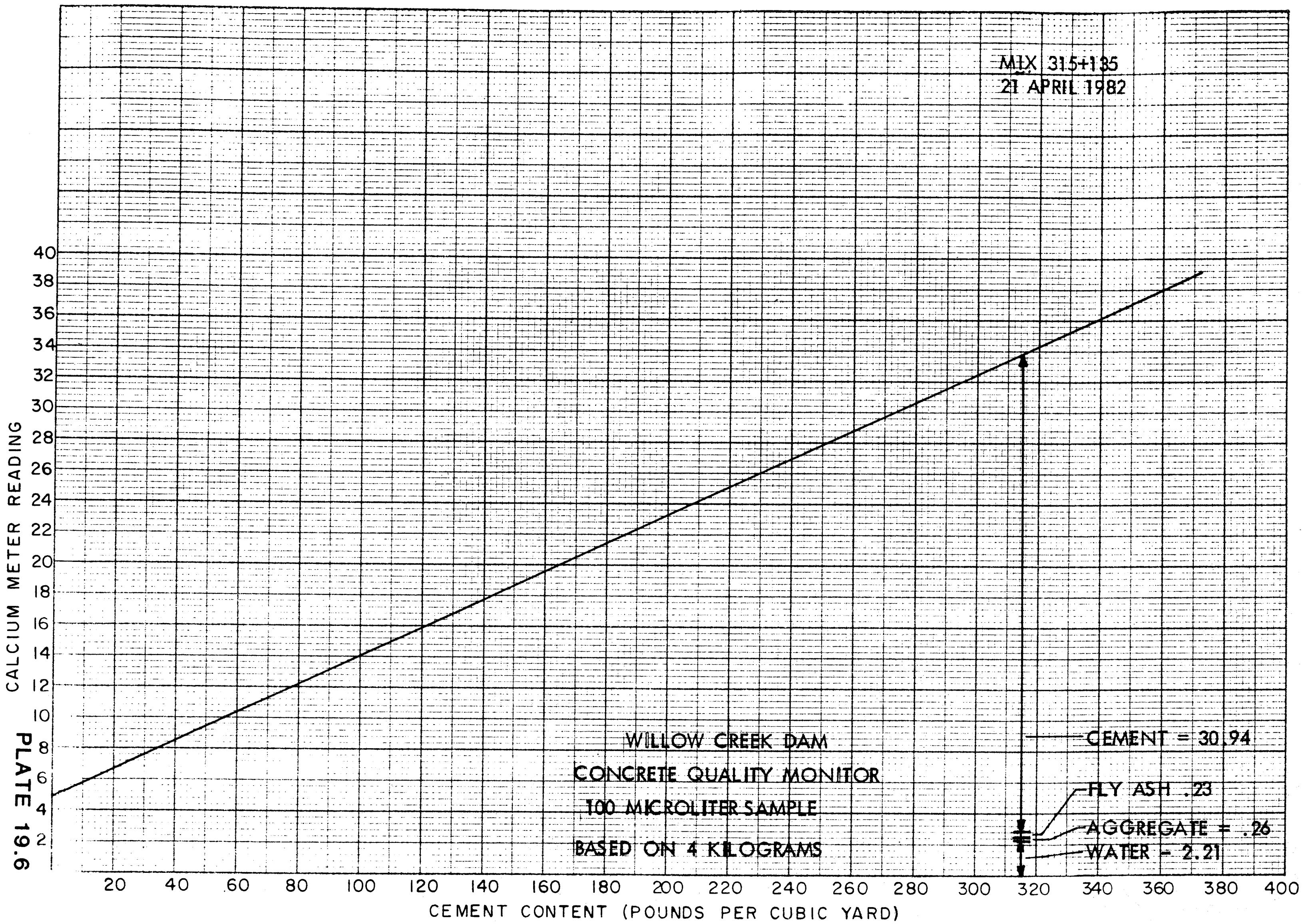


PLATE 19.6

CQM CALIBRATION CURVE

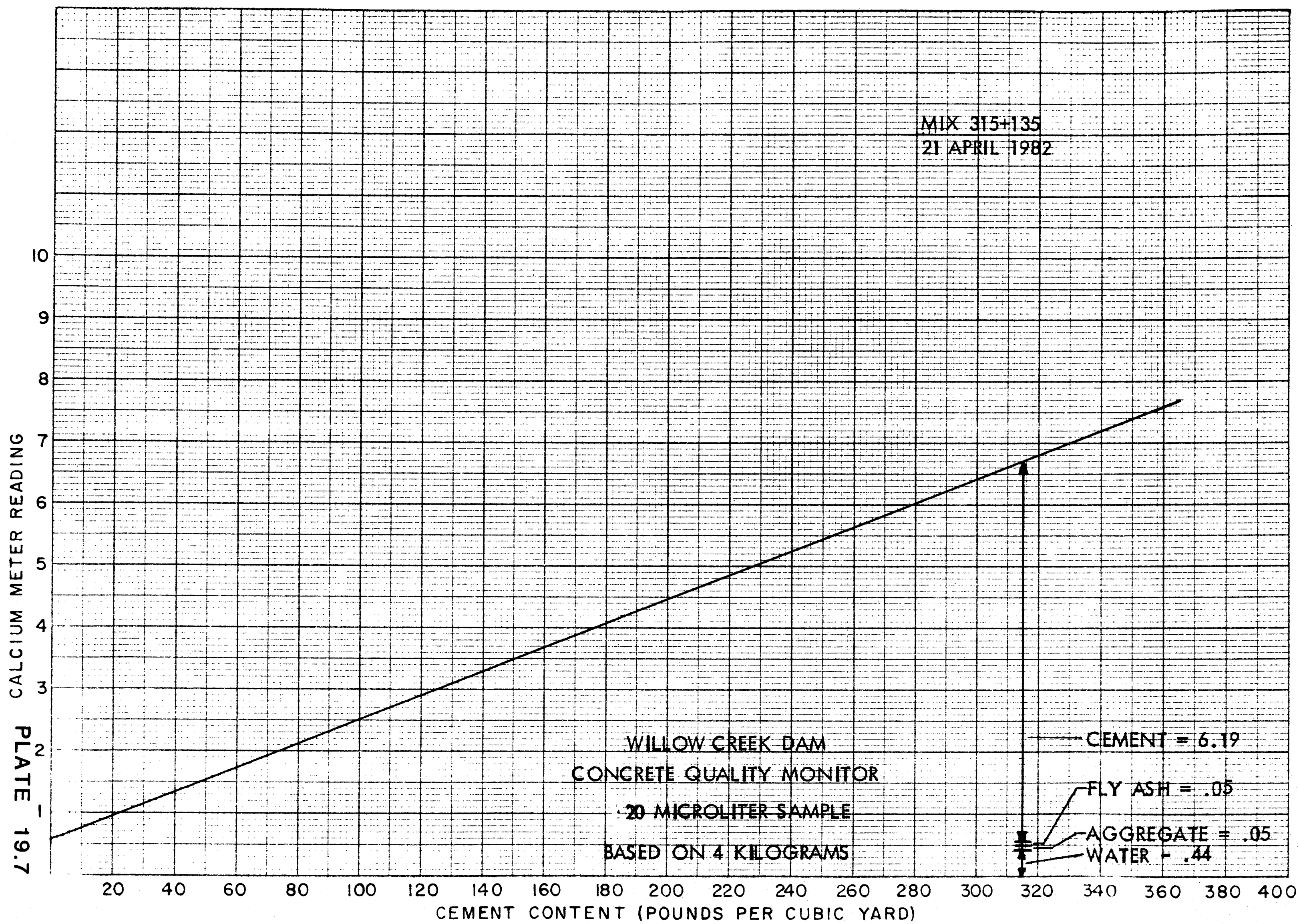


PLATE 19.7

K+E 10 X 10 TO 1/2 INCH 46 1323
KEUFFEL & ESSER CO

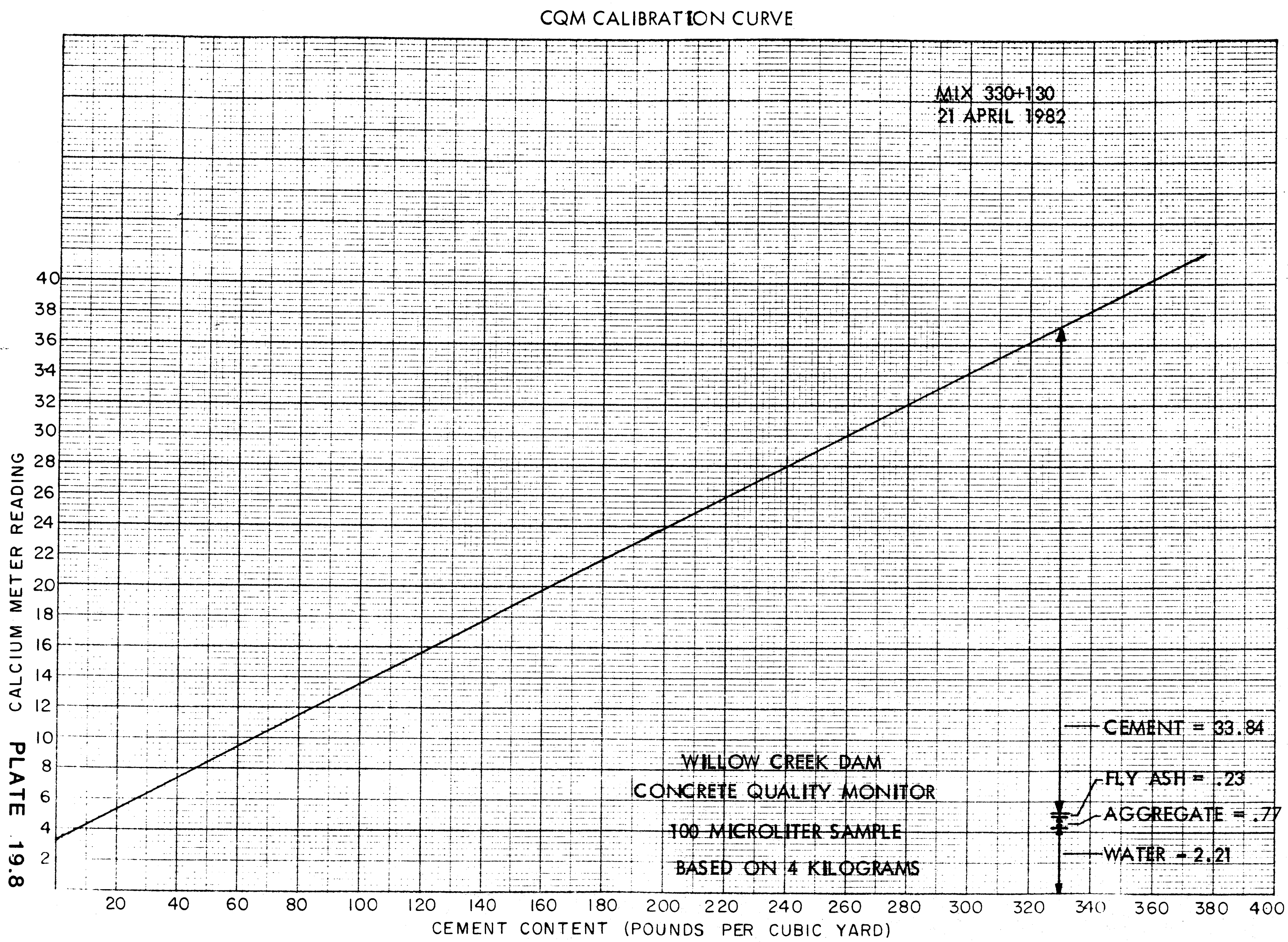


PLATE 19.8

CQM CALIBRATION CURVE

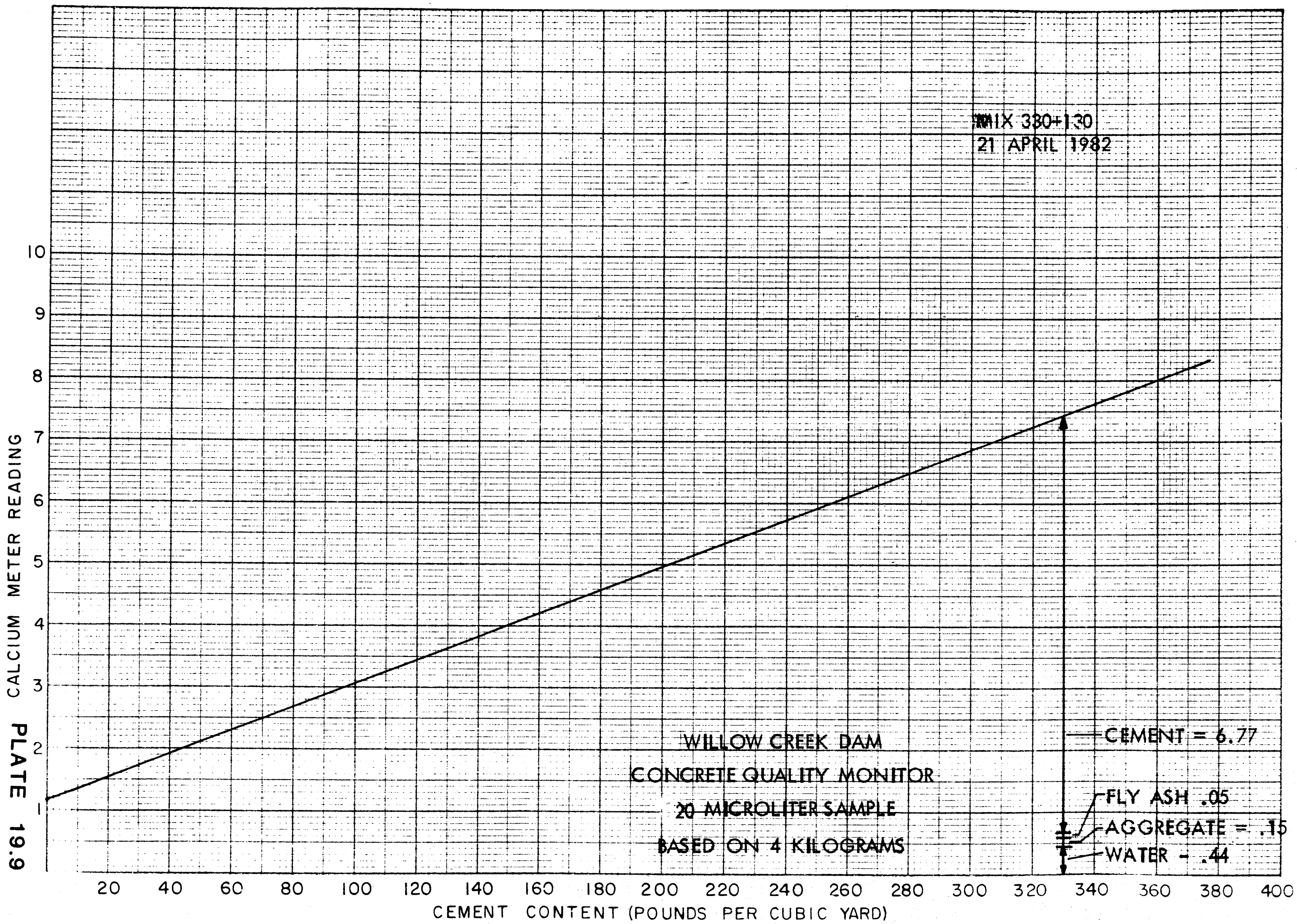


PLATE 19.9

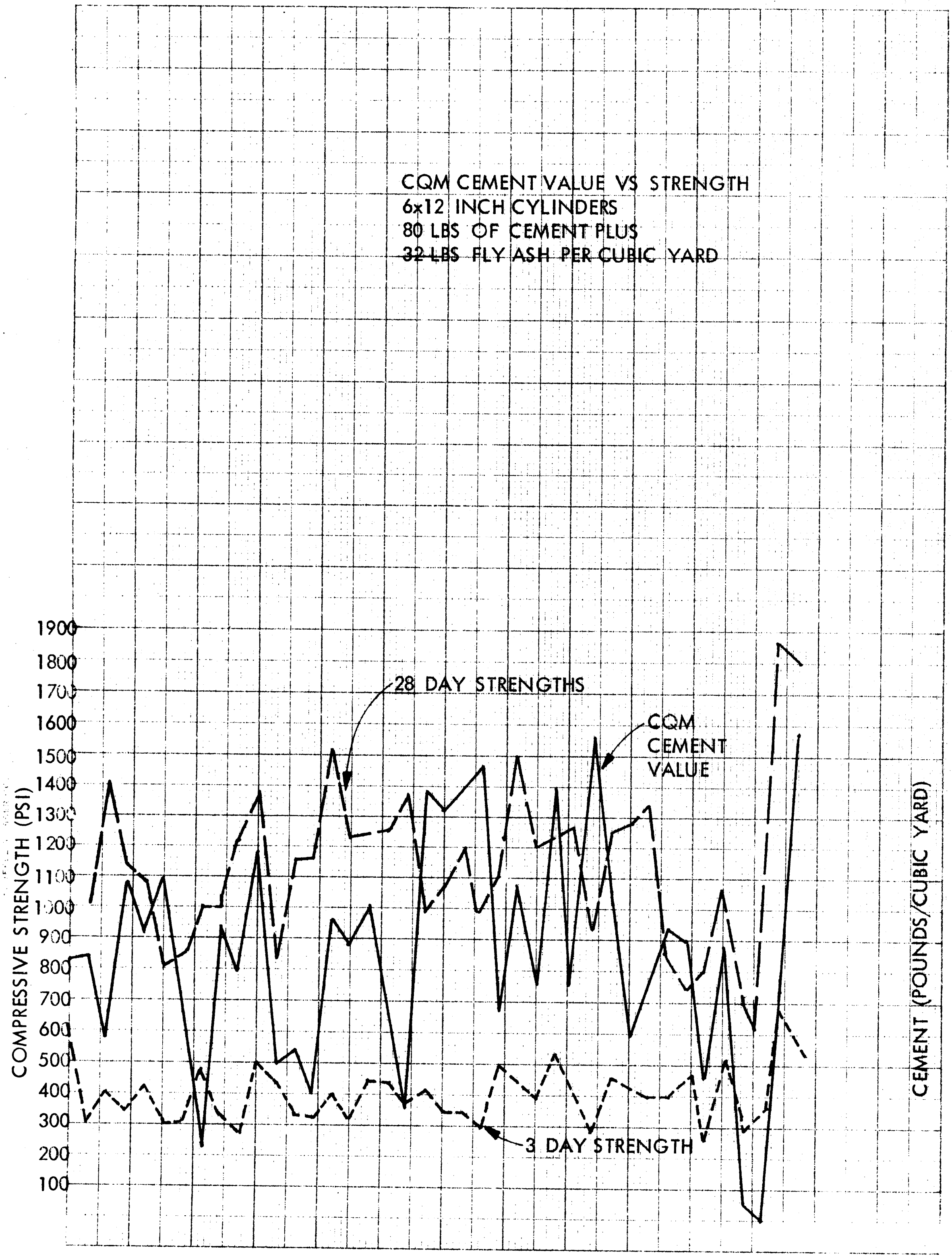

CQM CEMENT VALUE VS STRENGTH
6x12 INCH CYLINDERS
80 LBS OF CEMENT PLUS
32 LBS FLY ASH PER CUBIC YARD
28 DAY STRENGTHS
CQM CEMENT VALUE
3 DAY STRENGTH
COMPRESSIVE STRENGTH (PSI)
CEMENT (POUNDS/CUBIC YARD)
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
130
120
110
100
90
80
70
60
50
40

PLATE 19.10

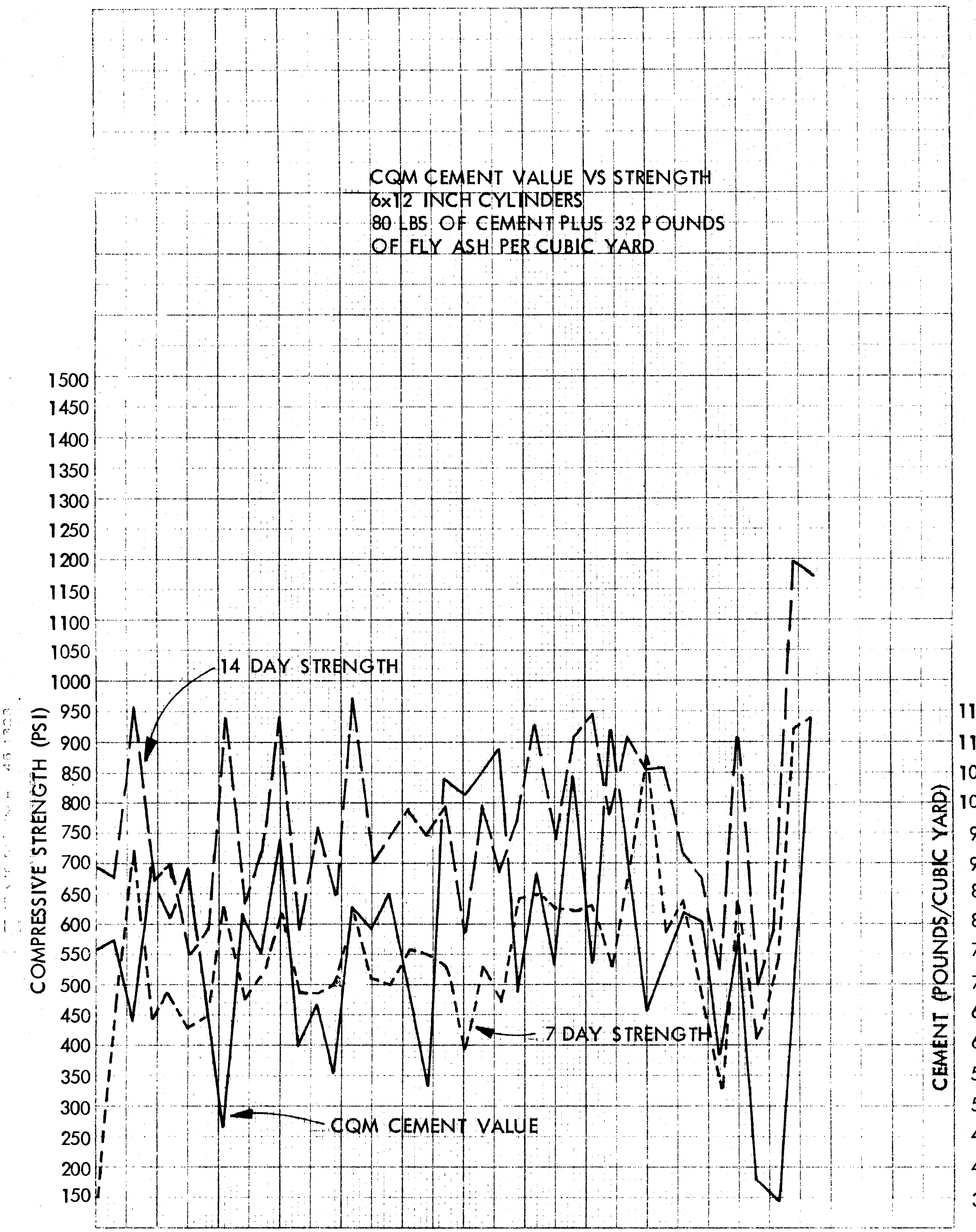

CQM CEMENT VALUE VS STRENGTH
6x12 INCH CYLINDERS
80 LBS OF CEMENT PLUS 32 POUNDS
OF FLY ASH PER CUBIC YARD
14 DAY STRENGTH
7 DAY STRENGTH
CQM CEMENT VALUE
COMPRESSIVE STRENGTH (PSI)
CEMENT (POUNDS/CUBIC YARD)
1500
1450
1400
1350
1300
1250
1200
1150
1100
1050
1000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35

PLATE 19.11

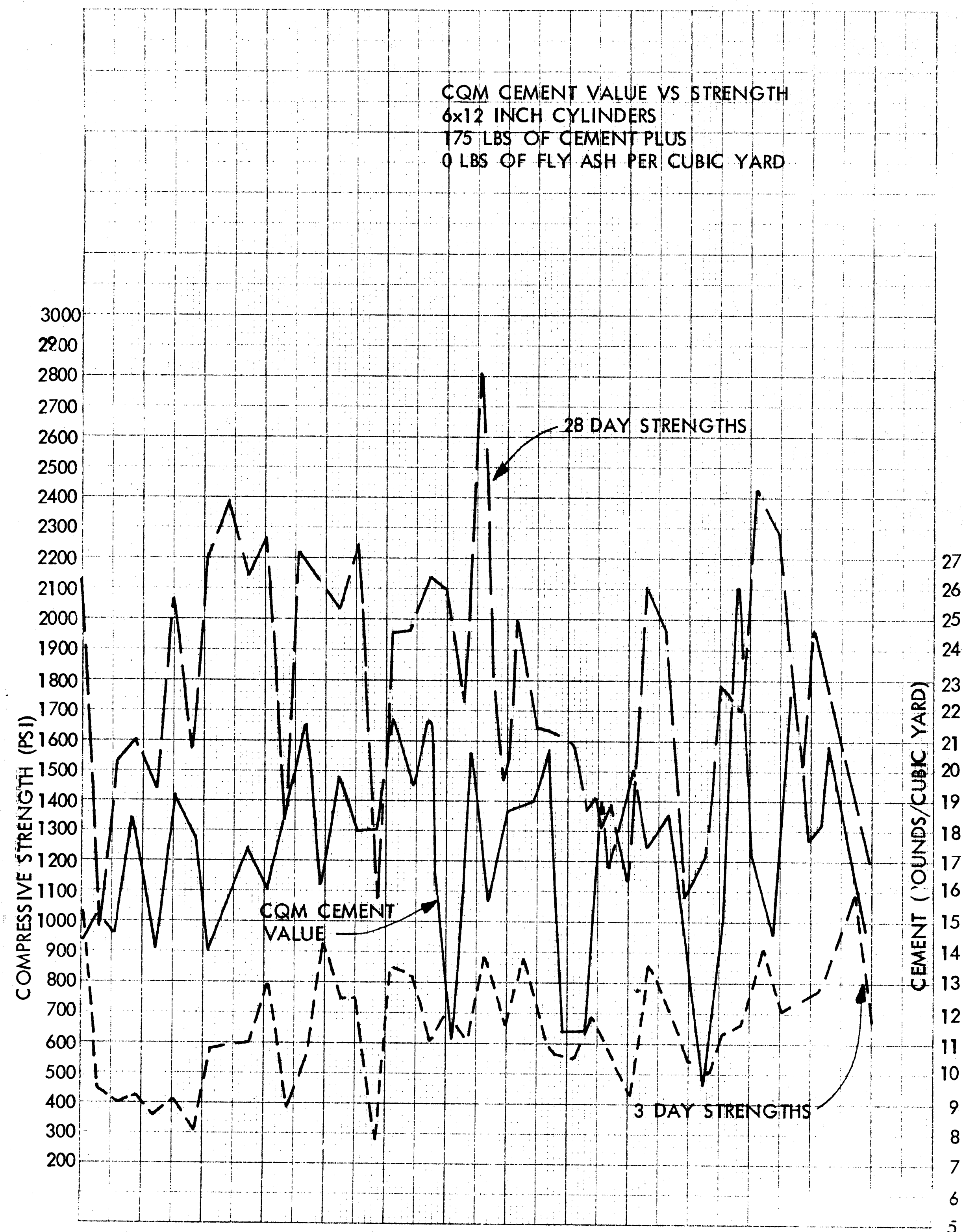
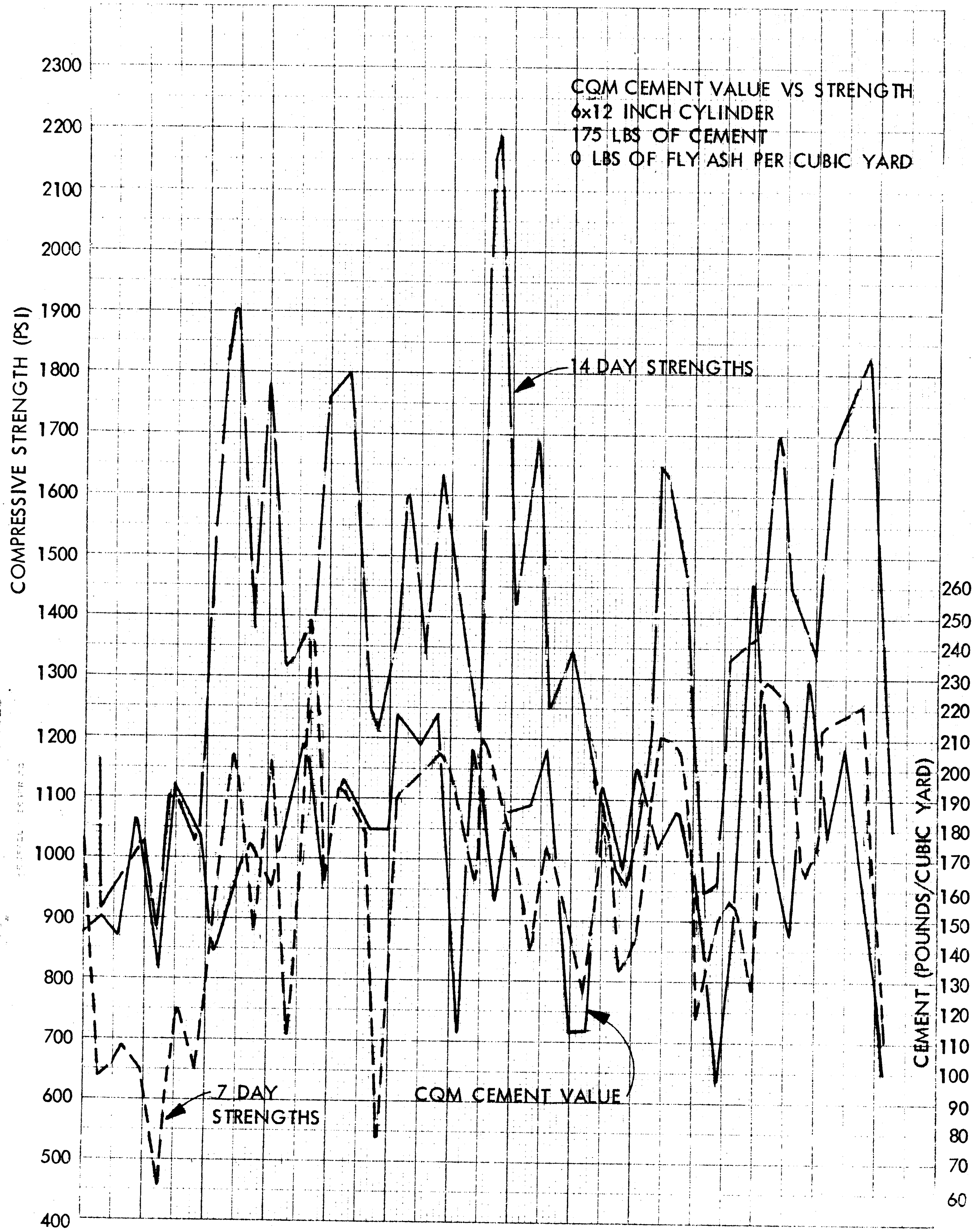
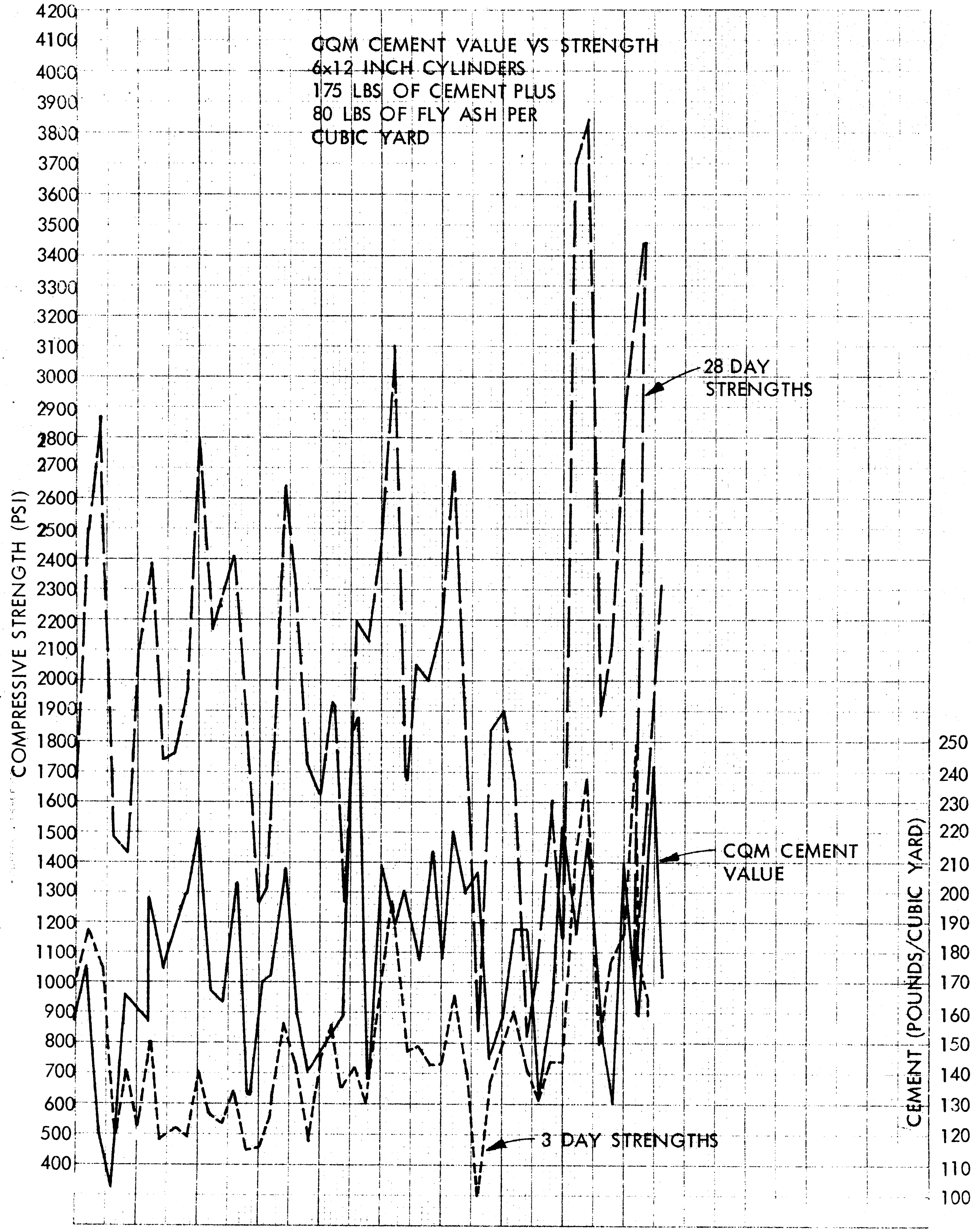

CQM CEMENT VALUE VS STRENGTH
6x12 INCH CYLINDERS
175 LBS OF CEMENT PLUS
0 LBS OF FLY ASH PER CUBIC YARD
28 DAY STRENGTHS
CQM CEMENT VALUE
3 DAY STRENGTHS
COMPRESSIVE STRENGTH (PSI)
CEMENT (POUNDS/CUBIC YARD)
3000
2900
2800
2700
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5

PLATE 19.12



CQM CEMENT VALUE VS STRENGTH
6x12 INCH CYLINDER
175 LBS OF CEMENT
0 LBS OF FLY ASH PER CUBIC YARD
14 DAY STRENGTHS
7 DAY STRENGTHS
CQM CEMENT VALUE
COMPRESSIVE STRENGTH (PSI)
CEMENT (POUNDS/CUBIC YARD)
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60

PLATE 19.13



CQM CEMENT VALUE VS STRENGTH
6x12 INCH CYLINDERS
175 LBS OF CEMENT PLUS
80 LBS OF FLY ASH PER
CUBIC YARD
COMPRESSIVE STRENGTH (PSI)
4200
4100
4000
3900
3800
3700
3600
3500
3400
3300
3200
3100
3000
2900
2800
2700
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
28 DAY STRENGTHS
CQM CEMENT VALUE
3 DAY STRENGTHS
CEMENT (POUNDS/CUBIC YARD)
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100

PLATE 19.14

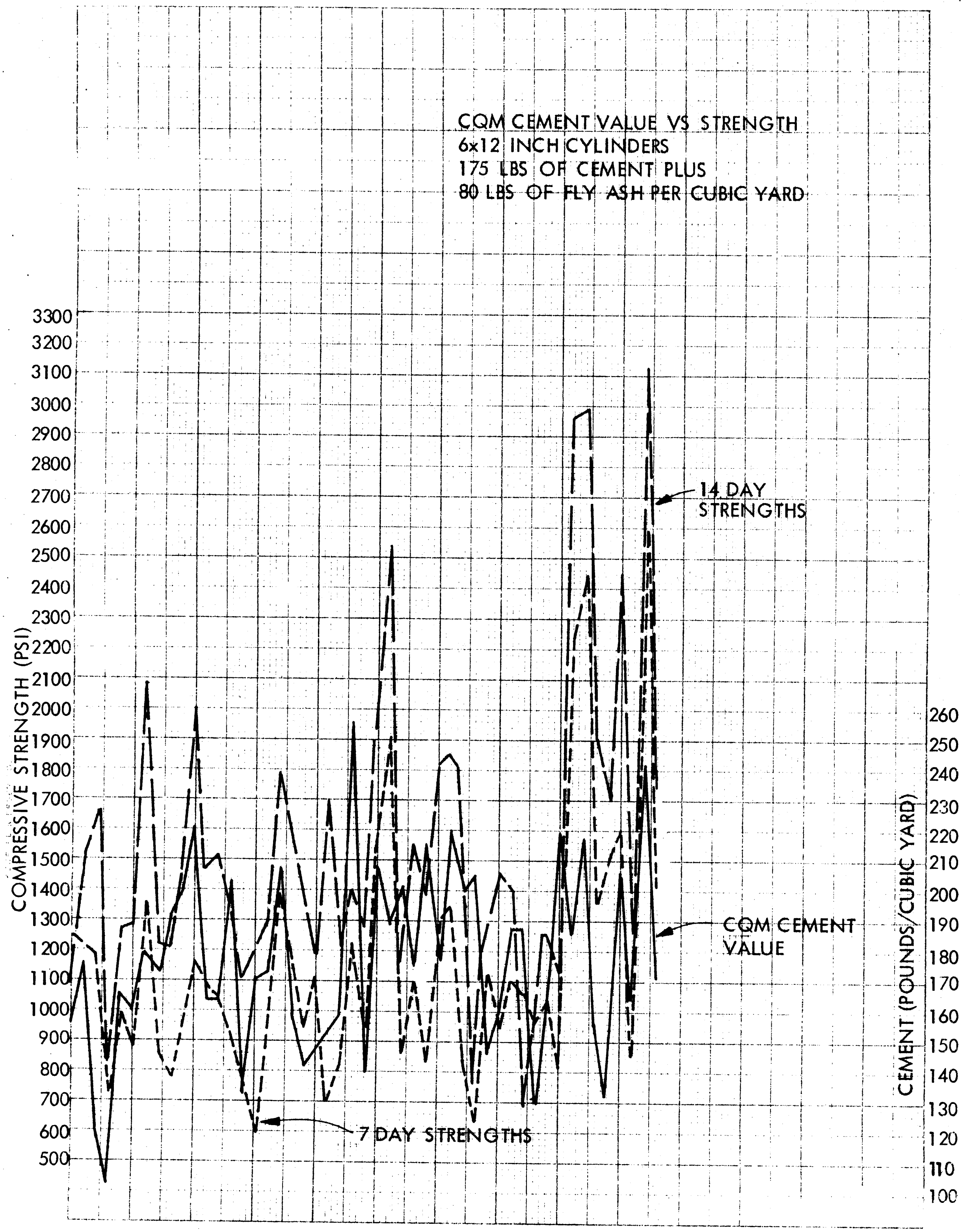

CQM CEMENT VALUE VS STRENGTH
6x12 INCH CYLINDERS
175 LBS OF CEMENT PLUS
80 LBS OF FLY ASH PER CUBIC YARD
COMPRESSIVE STRENGTH (PSI)
3300
3200
3100
3000
2900
2800
2700
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
14 DAY STRENGTHS
CQM CEMENT VALUE
7 DAY STRENGTHS
CEMENT (POUNDS/CUBIC YARD)
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100

PLATE 19.15

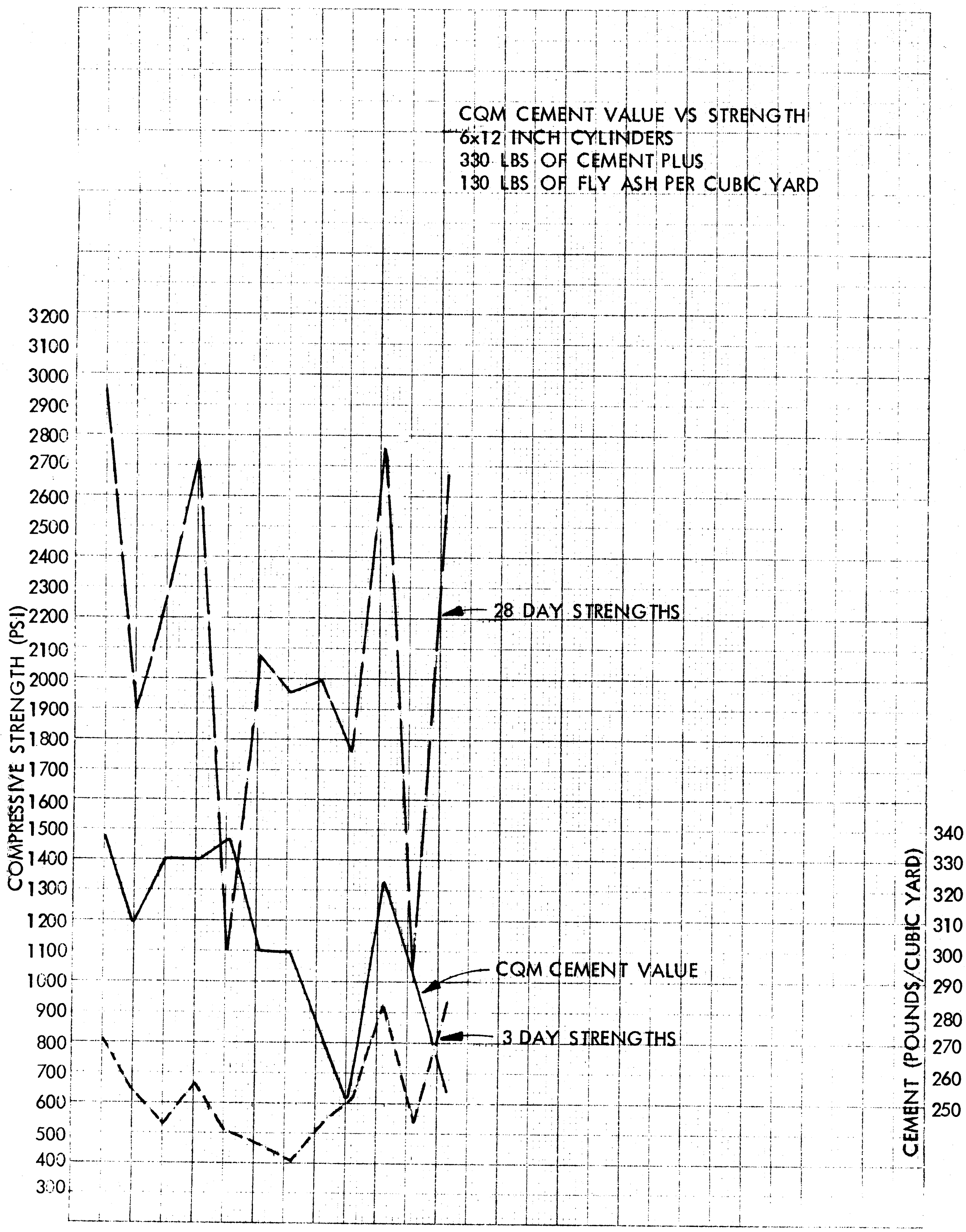

CQM CEMENT VALUE VS STRENGTH
6x12 INCH CYLINDERS
330 LBS OF CEMENT PLUS
130 LBS OF FLY ASH PER CUBIC YARD
COMPRESSIVE STRENGTH (PSI)
3200
3100
3000
2900
2800
2700
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
28 DAY STRENGTHS
CQM CEMENT VALUE
3 DAY STRENGTHS
CEMENT (POUNDS/CUBIC YARD)
340
330
320
310
300
290
280
270
260
250

PLATE 19.16

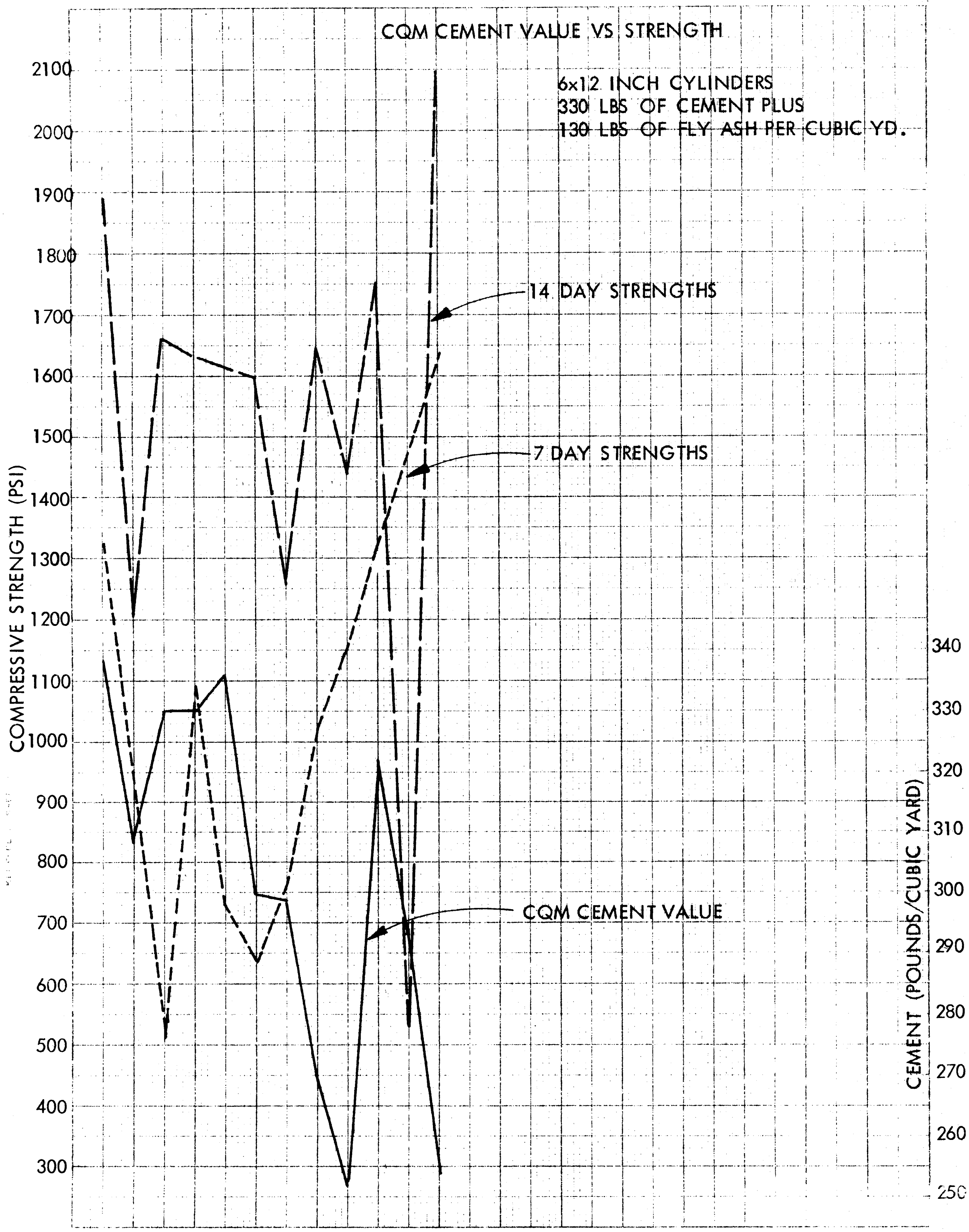
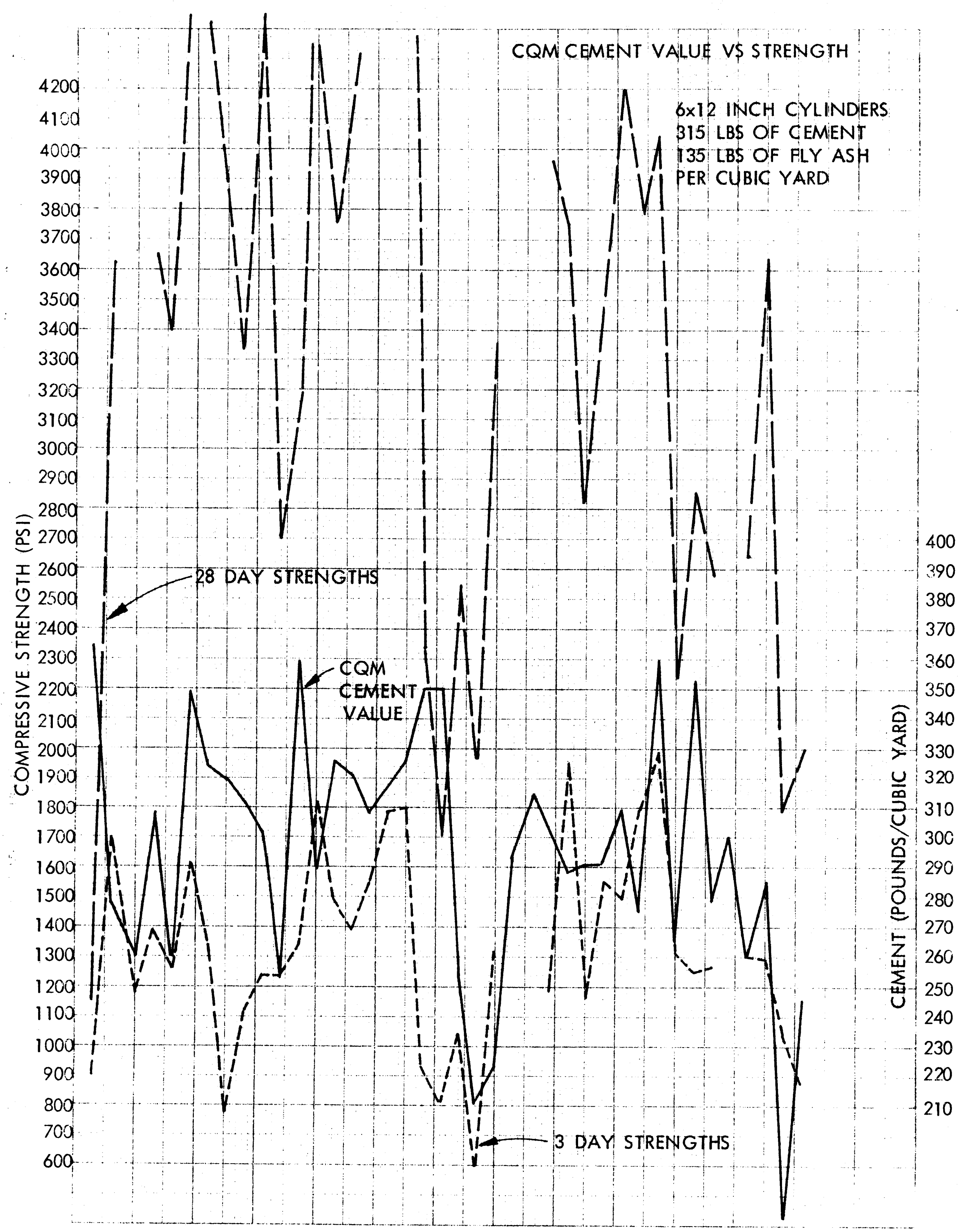

CQM CEMENT VALUE VS STRENGTH
6x12 INCH CYLINDERS
330 LBS OF CEMENT PLUS
130 LBS OF FLY ASH PER CUBIC YD.
14 DAY STRENGTHS
7 DAY STRENGTHS
CQM CEMENT VALUE
COMPRESSIVE STRENGTH (PSI)
CEMENT (POUNDS/CUBIC YARD)
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
340
330
320
310
300
290
280
270
260
250

PLATE 19.17



CQM CEMENT VALUE VS STRENGTH
6x12 INCH CYLINDERS
315 LBS OF CEMENT
135 LBS OF FLY ASH
PER CUBIC YARD
COMPRESSIVE STRENGTH (PSI)
CEMENT (POUNDS/CUBIC YARD)
28 DAY STRENGTHS
CQM CEMENT VALUE
3 DAY STRENGTHS
4200
4100
4000
3900
3800
3700
3600
3500
3400
3300
3200
3100
3000
2900
2800
2700
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
400
390
380
370
360
350
340
330
320
310
300
290
280
270
260
250
240
230
220
210

PLATE 19.18

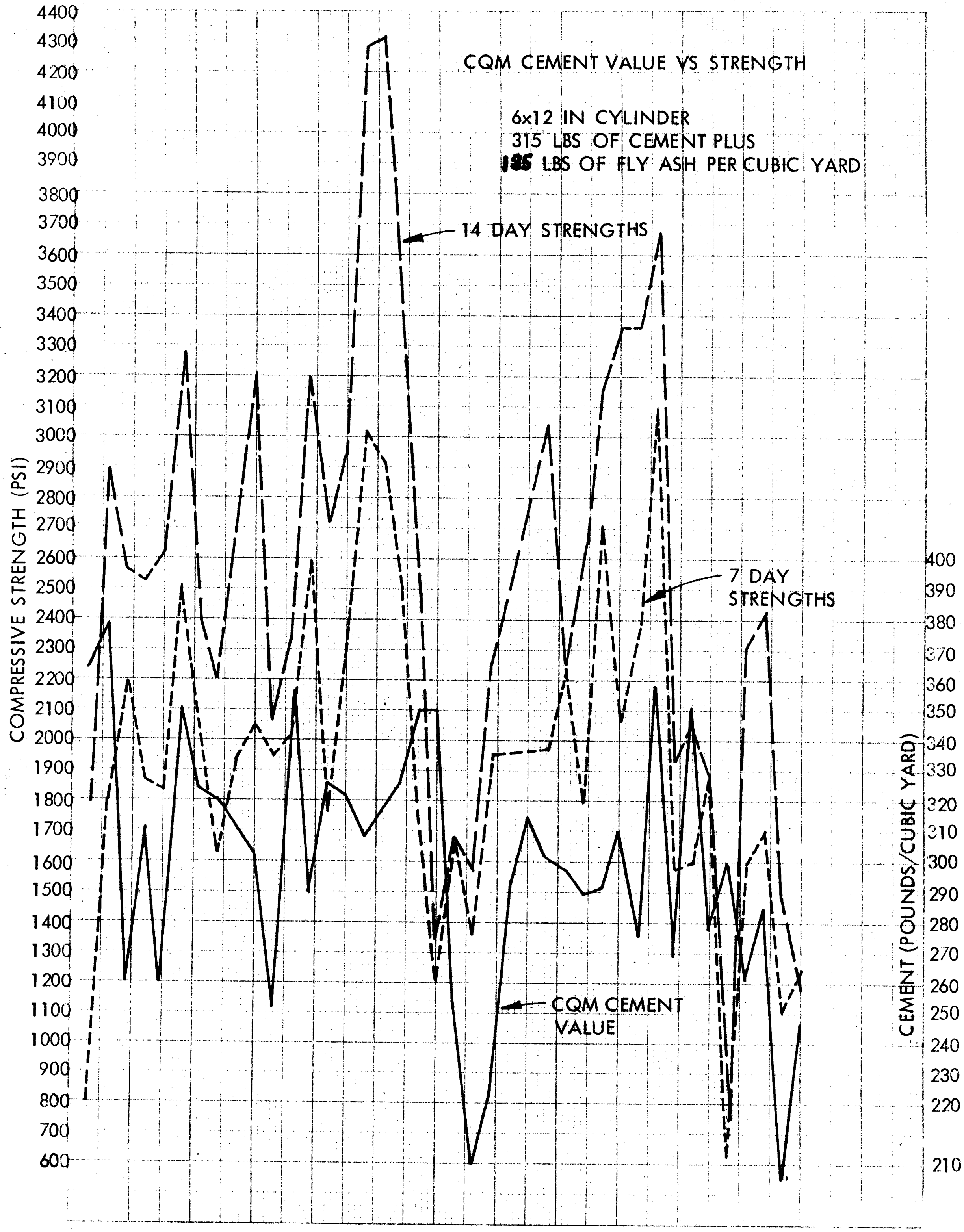

CQM CEMENT VALUE VS STRENGTH
6x12 IN CYLINDER
315 LBS OF CEMENT PLUS
135 LBS OF FLY ASH PER CUBIC YARD
14 DAY STRENGTHS
7 DAY STRENGTHS
CQM CEMENT VALUE
COMPRESSIVE STRENGTH (PSI)
CEMENT (POUNDS/CUBIC YARD)
4400
4300
4200
4100
4000
3900
3800
3700
3600
3500
3400
3300
3200
3100
3000
2900
2800
2700
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
400
390
380
370
360
350
340
330
320
310
300
290
280
270
260
250
240
230
220
210

PLATE 19.19

CHAPTER 20

UPSTREAM FACE PANELS AND SPILLWAY TRAINING WALLS

During design, a variety of ways of constructing the training walls and the upstream face was investigated. Of the various options, one (precast reinforced earth panels) was shown in the drawings and was to be the basis for bids, but specifications also described other systems and the basis under which they could be allowed. For example, a slip form (extruded curb) facing would have to bond to the RCC, provide for freeze-thaw and wet-dry resistance, have material properties similar to the RCC, etc. Also, the contractor would have been responsible to demonstrate the equipment, mix, and procedures in a test fill.

The reinforced earth panel system is an established procedure for retaining each fill. It uses precast interlocking panels (typically 25-square-foot surface area) attached to ribbed flat steel straps running between layers of backfill. The idea is that the straps provide increased shear strength to the embankment mass, resulting in a stable section. With RCC as the fill material, stability and a supported facing (actually just a form) are needed only until the cement hydrates to the point that the RCC mass is a self-supporting hardened mass.

The contractor submitted a value engineering proposal to utilize a different precast facing system. To simplify the proposal and also to gain experience with the original reinforced earth panel scheme, the stilling basin and spillway training walls were not included in the proposal. In the remarkably short period of time of only 6 weeks, the proposal went from initial submittal, through revision, test fill (Plate 20.1), negotiations, and the audit process to final approval and acceptance. The instant contract savings was $655,555 - a record amount in the Corps for a contractor-initiated value engineering proposal. In retrospect, with the work now complete, the savings really did develop, the resulting product is better aligned, and the system was safer to build.

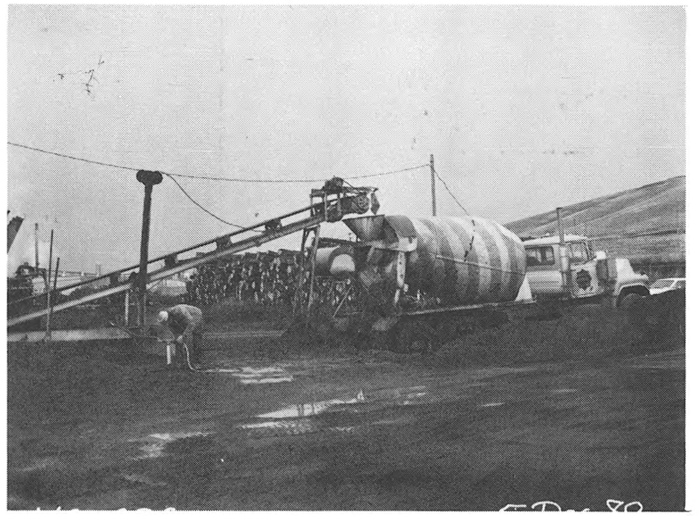
The reinforced earth panel system could probably be improved upon and be made more economical for RCC by using a thinner panel with a less complicated section, and by increasing the area of each panel so there are fewer of them to set in place. The number of tieback straps could also be reduced. The two main problems experienced with the standard panels were in maintaining their alignment, and simply the vast number of them that had to be set.

The contractor-developed facing system is shown on Plates 20.1 and 20.2. It consisted of tongue and groove precast panels 4 feet high by 16 feet long and 3-1/2 inches thick. Each panel had more than 2-1/2 times the area of the reinforced earth panel. They were anchored by two 5-foot-long, 3/4-inch-diameter coil rods located mid-height of the panel and 4 feet in from each end. Temperature steel consisting of No. 4 bars was placed near the center of the panel. A 3- x 3-inch steel plate was attached to the end of the coil rod with two nuts to help anchor it, but strain gages along the rod indicated that the load dissipated along it through bond before getting to the anchor plate.

The erection and support system can be understood more easily by referring to the photos on Plate 20.2. The top row of panels against which RCC was placed was supported by two "strongbacks" on the outside face of the panel. These were attached with temporary short bolts to the same insert into which the coil rods threaded from the opposite side. The strongbacks extended down the dam face and attached to the coil rod insert in the panel below. The load against the upper panel (as the RCC was placed against it) was transmitted to this insert and consequently to the coil rod threaded into it from the opposite side. This rod was embedded in previously placed and hardened RCC, and was temporarily loaded in tension. Another strongback extended from this panel down the upstream face to the row of panels below it and pushed against them with the compressive reaction force. As the next row of panels was placed, the bottom row of strongbacks was removed. All work was safely done with personnel working from the RCC surface on the downstream side of the panels. Soon after high production was underway, the contractor worked his panel crew (about five people) on the graveyard shift and placed RCC during the day and swing shifts.

Both the coil rods in the contractor's system and the flat straps in the reinforced panel system were instrumented with strain gages to determine the form pressure exerted by the RCC and how it developed. This was done both in test sections and during actual construction with the same results. Regardless of height of RCC, rate of placing, temperature, spreading equipment, and even the compaction equipment, the average form pressure was just less than 1 psi. Apparently, the aggregate interlocked during compaction and the mass became almost entirely self-supporting immediately upon being consolidated.

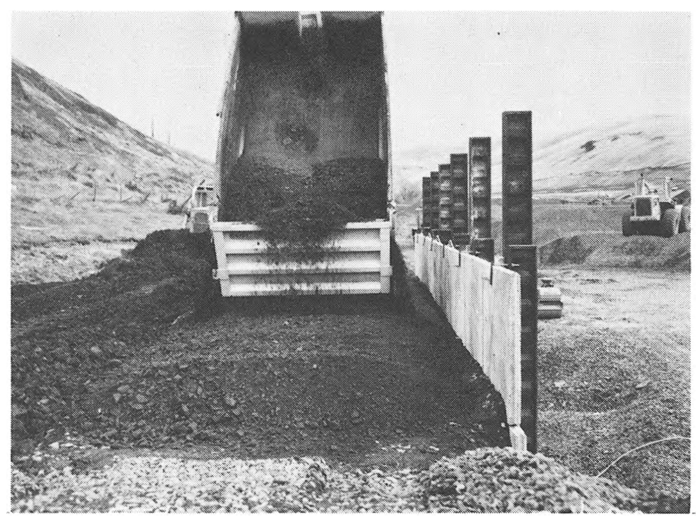
The precast panels were made of entirely different concrete than the RCC behind them. Even if they could have been bonded initially to the RCC, through differential movement and time they undoubtedly would have become unbonded. Rather than spend time and money trying to seal the panels to each other and to the RCC, the idea at Willow Creek was to provide a gap between the panels, mechanically anchor them with coil rods, and avoid any bedding and special compactive effort behind them. Water that gets behind them will drain back out, and ice will have a place to expand and extrude. It is important to remember that aside from aesthetics, the panels could actually fall off with no effect on the integrity, safety, or performance of the structure.



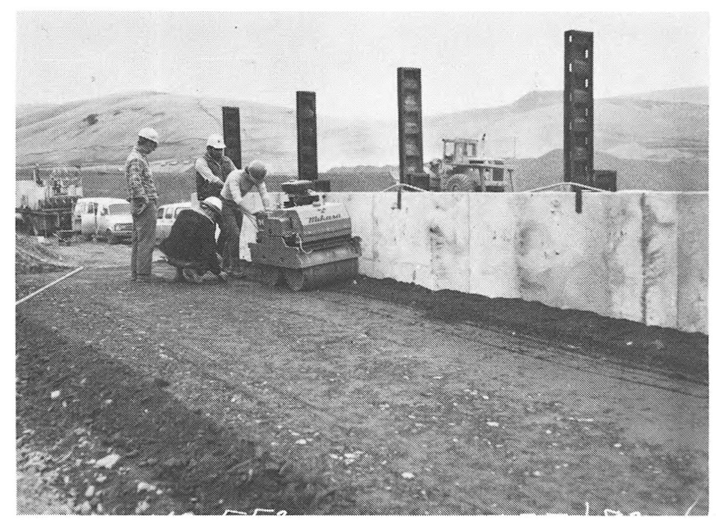
BATCHING RCC AT A LOCAL READY MIX PLANT. (MIXED IN TRUCK)

DISCHARGE FROM MIXER TRUCK INTO DUMP TRUCK.

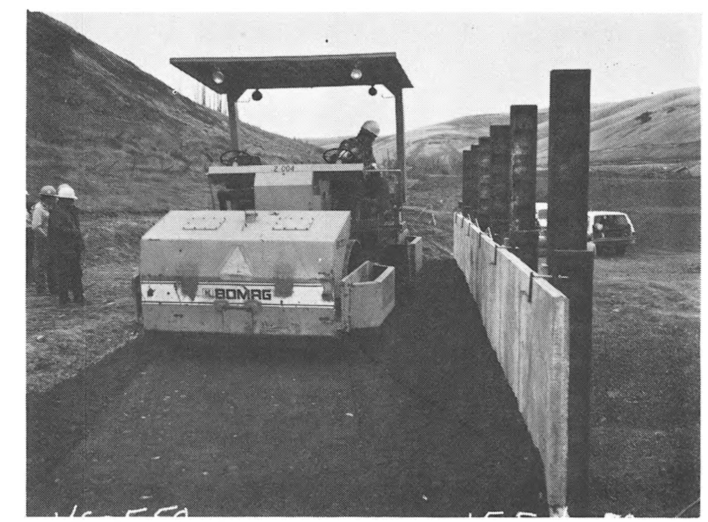
HAND WORKING RCC TO MINIMIZE SEGREGATION FROM THE READY MIX TRUCK.



DUMPING RCC.

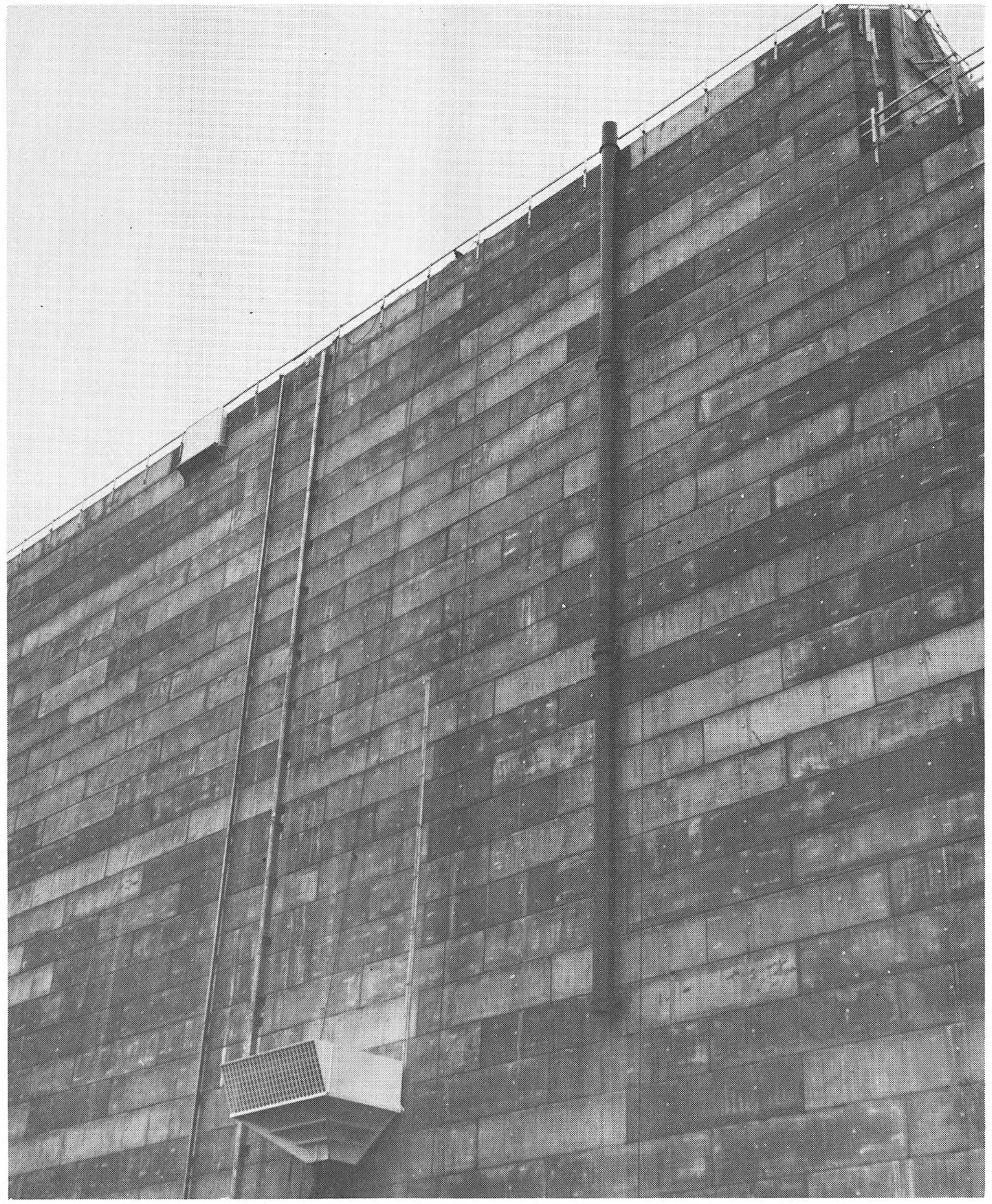


COMPACTION WITH FULL PRODUCTION EQUIPMENT.

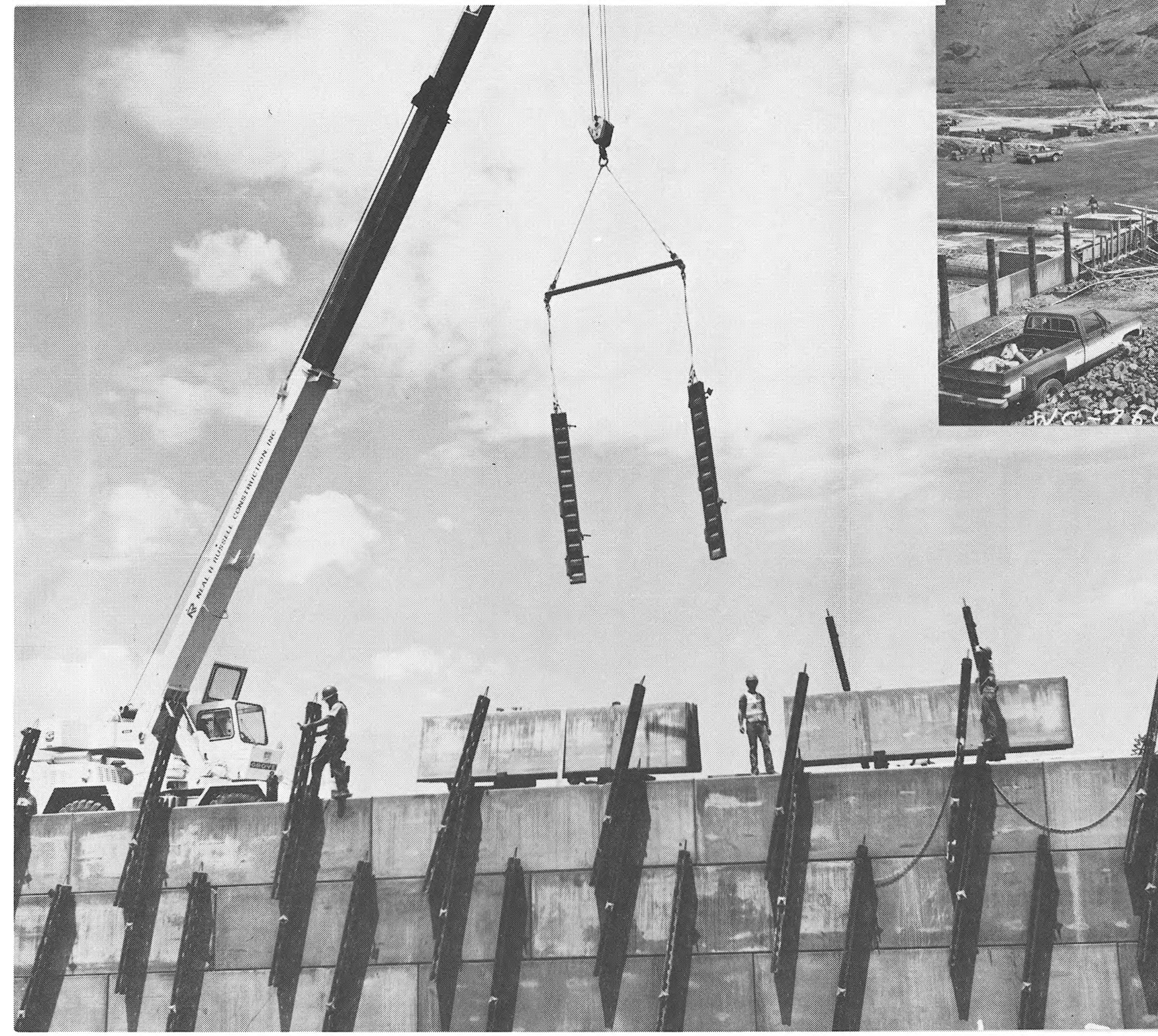


COMPACTION BEHIND PRECAST PANELS WITH WALK BEHIND ROLLER.

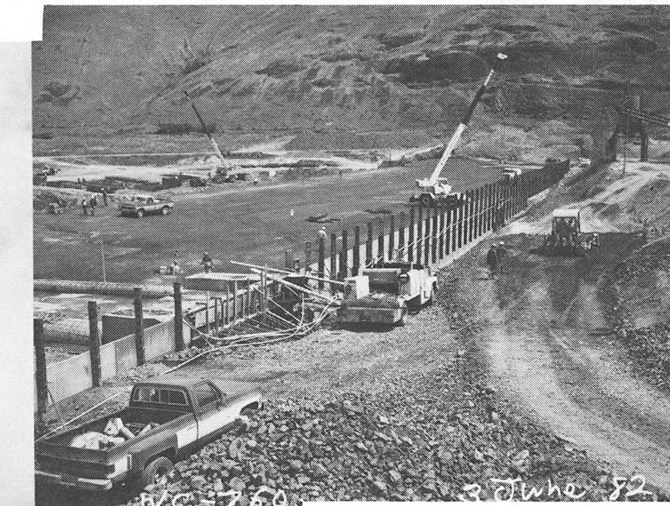
TEST FILL



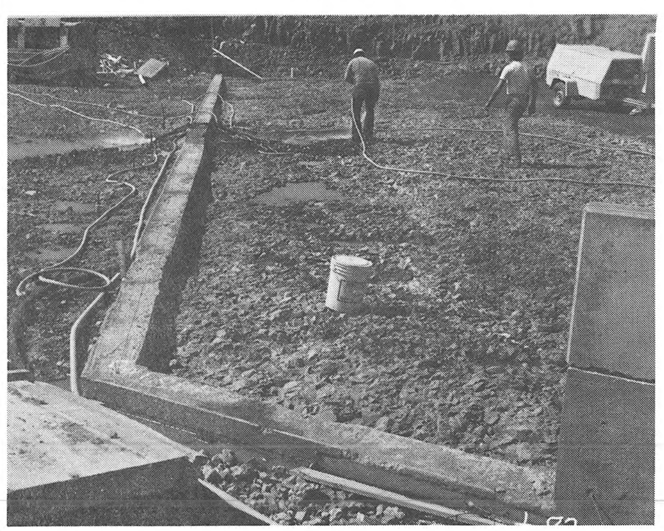
UPSTREAM FACE AT THE FLOATING INTAKE.



PANEL INSTALLATION.

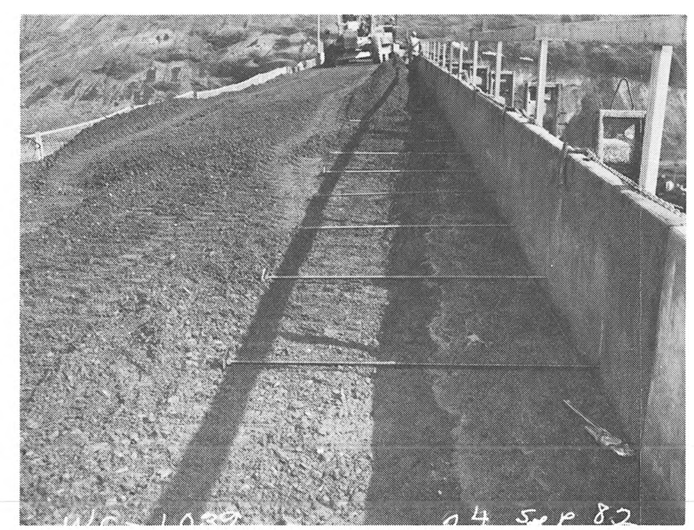


PANEL INSTALLATION.

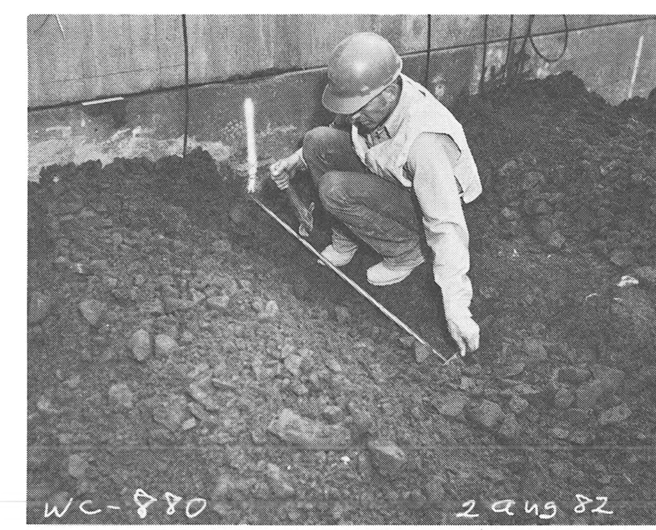


STARTER CURB/WALL FOR THE UPSTREAM PANELS.

HAND COMPACTION OF RCC ADJACENT TO THE PANELS.



ANCHOR RODS FOR THE UPSTREAM PANELS DURING PRODUCTION.



INSTALLATION OF ANCHOR ROD FOR THE TEST FILL.

UPSTREAM FACE PANELS
PLATE 20.2

CHAPTER 21

SPILLWAY OGEE (SHOTCRETE)

The original design called for a 2-foot-thick section of conventional concrete to be used at the spillway crest so that the parabolic ogee curve could be accurately shaped. The concrete cap starts at elevation 2109 of the upstream face, curves up and over the crest at elevation 2113.5, and curves down the downstream face to match the RCC spillway surface at elevation 2097. Plate 1.1 shows a typical section. The quantity involved was 1,000 cubic yards.

A change to use shotcrete (wet mix) was submitted as a value engineering proposal by the subcontractor (Hamilton) through the prime contractor (Eucon) to the Corps of Engineers. A shotcrete specialty firm (Johnson-Western) did the work. All parties worked together to develop a technically and administratively acceptable proposal.

Total savings for the change was $63,000 on what otherwise would have been about $250,000 work with conventional placing methods.

A major advantage to shotcreting and one of the prime reasons for seeking out alternate placing methods was improved safety.

Productivity was very good. The placement was separated into 11 sections butting each other with an upstream/downstream construction/contraction joint. Each placement used about 100 cubic yards of shotcrete. A single crew and nozzleman worked one shift per day to place and finish each section. One section was done each day.

The quality of concrete, workmanship, and tolerance was not relaxed. The typical strict tolerances for conventional concrete spillway surfaces were maintained. In addition, the crest elevation had to be within 1/2-inch of the design line across its full 380-foot width.

The recently published American Concrete Institute recommended method for certification of nozzlemen was used to qualify workers. This included a practical test with a demonstration panel for examination and evaluation, as well as written tests.

Cores from nozzlemen qualification test panels cured under field conditions showed 28-day strengths ranging from 3,810 to 4,230 psi with an average of 4,050 psi, indicating excellent quality and uniformity.

Companion cylinders cured in the lab yielded 4,145 psi strength. Minimum design strength requirements were 3,000 psi at 90 days. Because a practical shotcrete mix requires fairly high cement contents (in this case 600 pounds per cubic yard), the shotcrete method provided higher strength than would have been achieved with conventional placing.

The shotcrete has just been completed. Test data has not been fully compiled and evaluated but the indications are very good. The update to this report will include photographs and this data. It will contain the standard compressive strength results from normal laboratory tests, and also results of special tests. The strength of standard compressive cylinders of the truck-delivered mix versus strengths of companion cylinders made by shooting directly into the test molds will be compared. Air contents determined for the mix in the truck, as shot into the mold, and from physical traverse examination of hardened shotcrete sawn from the placement will also be compared.

CHAPTER 22

INSPECTION
(Quality Control and Quality Assurance)

Inspection was achieved through the contractor's quality control and the Government's quality assurance systems. The special provisions of the contract specifications outlined the quality control program in general (Section SP-30). The end of each technical provision section of the specifications pertinent to concrete detailed minimum specific contract requirements. (TP-3A "Concrete," TP-3B "Precast Concrete," and TP-3C "Roller Compacted Concrete.") The Engineering Division of the Walla Walla District provided detailed guidance for quality assurance to the Resident Office in a 44-page document entitled "Concrete Inspection, Quality Control, and Quality Assurance Testing." It contained recommendations for staffing, frequency and type of testing, inspection guidance, and both the reasons and criticality of various specification requirements.

The contractor hired a private testing firm to provide all quality control testing and field survey. This represented a significant portion of the contract price. In addition to the survey crew and a quality control chief, the day shift usually included two full-time inspection/testing personnel. Swing shift usually had one full-time man. A laboratory building with standard equipment was provided.

A unique aspect to the project was that the Corps' Engineering Division provided a full-time representative at the Resident Office during construction. The individual had the same grade as the Resident Engineer but was separate from the resident staff. He provided technical review/guidance to the Resident and was available to provide instant response or critique from Engineering Division when technical issues arose. The representative was the principal designer, specification writer and materials engineer, and the person who established the quality control/quality assurance guidelines. As adjustments in the testing frequency or method became appropriate, they received immediate attention from the engineering standpoint without untimely delays awaiting response from the District Office. Inspection personnel worked under the nominal chain of command within the Resident Engineer's organization, and the Resident Engineer maintained ultimate responsibility for implementing proper inspection and testing, but there was close interface with the engineering representative.

A very important part of the quality control and assurance programs was training and orientation of all personnel towards RCC concepts and requirements. The contractor had each foreman and supervisor attend a seminar and discussion early in the job before any RCC work was done. This was given by the Corps' engineering representative in the Resident Office. Prior RCC work was shown using 35mm slides, and specific important contract requirements pertinent to Willow Creek were explained. Unfortunately, resident staff and inspection personnel did not attend. Later in the job other orientations and review sessions were given that were available to all personnel. The sessions included slides showing workers and inspectors on the job, discussed what was being done right and wrong and what needed attention, reviewed the work to date, offered suggestions for the continuing work, and offered a chance for open discussion. These sessions were extremely helpful from a technical standpoint and for team morale. The contractor arranged facilities and a buffet for the sessions, and spouses were encouraged to attend. The Corps' District Engineer also attended one of the sessions. A feeling that the project was a true team effort developed. The principal speaker was the onsite engineering representative and principal designer for the Corps who pointed out the importance of each person's job from laborer and equipment operator to the foremen and superintendent. The sessions were held in both the afternoon and evening so that both shifts could attend. Literally every employee of the contractor attended at least one session. Unfortunately, some of the Corps' inspection personnel were not as enthusiastic. Senior inspectors did not attend these sessions so a continuity was lost resulting in workers becoming more familiar with the real reasons why and how things should be done than some of the inspectors. This was especially unfortunate where specification requirements left some latitude for interpretation.

A situation worth noting at Willow Creek with regard to inspection and laboratory personnel concerns the availability of qualified personnel and the staff required. Unlike most projects that gradually build up personnel requirements, RCC dam construction can suddenly place a tremendous demand on inspection. Once RCC started, the Willow Creek situation jumped to a full production two shifts per day, 6 days a week operation during which large areas of foundation were covered and overtime was commonplace. Other work for the upstream facing, cleanup, plant maintenance, maintaining a moist lift surface, etc., kept crews working Sundays and nights. Requirements for these needs must be anticipated and qualified personnel should be readily available at the start of future projects. It can be difficult to appreciate just how instant and important this need is. At Willow Creek it resulted in understaffing and significant overtime at the start of the job. The problem is compounded by the fact that although the main contract for an RCC dam may stretch out for 1 to 3 years, the RCC will usually be placed in about 2 to 8 months. After this, personnel are no longer needed. Obtaining quality personnel for a short duration can be difficult. At Willow Creek, personnel needs were met with two experienced inspectors and one experienced concrete laboratory technician during the day, and two experienced inspectors for the swing shift. Other personnel were mostly term appointments, engineer trainees, and some personnel on temporary duty assignments. Most inspectors and laboratory personnel had little or no experience, but they were required to immediately get into the work because the project was in full swing.

CHAPTER 23

RESERVOIR RAISE, SEEPAGE, AND GROUTING

RESERVOIR RAISE AND SEEPAGE

It is worth noting that flood protection was provided within about 1 year after the contract was awarded. Without RCC, protection probably would have been 2 or 3 years away. The early flood protection was utilized. On 4 and 5 March 1983, heavy rains and runoff swelled Willow Creek to the point of flooding. The dam backed up water raising the reservoir about 10 feet in 24 hours while simultaneously discharging maximum flows that still prevented downstream flooding.

In June 1983, the dam prevented what could have been another catastrophe. A large volume of strong chemical defoliant was accidentally spilled into the creek in an unrelated incident upstream of the dam. The chemical killed all vegetation, fish, and wildlife with which it came into direct contact. Because of the dam, it was trapped in the reservoir and the gates were temporarily closed down until the chemical was diluted to a tolerable level. Without the dam, the chemical would have continued downstream through the town and agricultural areas using the water for irrigation.

The diversion conduit was plugged on 16 February 1983. The reservoir rose to elevation 2000 (the permanent outlet works invert) within 2 days. The water level was raised again during the first week of March and was maintained at elevation 2018 until 5 June when the level was lowered to facilitate grouting from the upstream face. The history of reservoir levels is shown on Plates 23.1 and 23.2.

The normal reservoir elevation after project completion will be 2047. The spillway crest is 2113.5 and top of the upstream face is 2130. The lowest point of concrete is 1964. The exposed downstream toe is at elevation 2071. This resulted in an effective head to the downstream face of 47 feet after initial reservoir raise, 76 feet during normal future operation, and 159 feet at full flood conditions. The head to the bottom of the dam was 54 feet after initial reservoir raise, 83 feet during normal future operation, and 166 feet during full flood conditions.

During design and test fill evaluations it was apparent that obtaining a near perfect watertight contact between each RCC layer would be difficult and expensive to achieve. At Willow Creek Dam it was also not necessary and it was appropriately decided not to include them in the design. Controls were established and followed to insure sufficient joint integrity for structural stability with normal factors of safety. Practical measures that would not significantly increase cost were included to help minimize seepage. Design documents indicated that without special efforts some seepage could be expected. Permeability values of 0.0013 ft/min (the result of seepage along joints) were used in design.

Based on 172 pressure tests of the in-place concrete, the average permeability is 0.0008 ft/min (better than thought during design). When the reservoir was raised, an expected damp appearance became evident at the downstream face. There was no way to collect and measure this seepage which was distributed across the downstream face of the structure, but calculations showed it should be less than 100 gpm. Near the outlet works where placing became difficult, isolated seepage paths also appeared which produced a collected total flow of less than 100 gpm.

Drain holes drilled for the stilling basin and spillway face as a part of design to relieve uplift pressures contributed the most to water collected in that area. Some of these drains produced water from other sources even before the reservoir was raised.

Original design concepts did not include a gallery. One of the reasons was that the resulting short seepage path from the upstream face to it would allow significant leakage, especially because the continuity of placement in this zone would be disrupted. Because of the unprecedented nature of the dam and the desirability of inspecting the interior of the RCC, the gallery was included and, in fact, significant leakage to it developed as anticipated. The gallery collected about 1,800 gpm total after initial reservoir raise to elevation 2018, of which about 1,500 gpm was from joint leakage and 300 gpm was from foundation drains in the reservoir.

Chapter 6, "Transporting and Spreading RCC," discusses inspection difficulties and concerns over joint tightness which became apparent during the start of RCC hauling, placing, and spreading. A few weeks after placing was underway, it became apparent that the situation would not improve. To help block seepage along the layer-to-layer interface, the practice was started of placing a strip of conventional bedding mix between each layer of RCC near the upstream face as shown on Plate 17.1. The reservoir has not reached the elevation where this practice started so its effectiveness has not yet been demonstrated.

OBSERVATIONS AND CONCLUSIONS BASED ON INITIAL SEEPAGE HISTORY

Seepage was evident at the downstream face of the dam very soon after the reservoir was raised. Seepage into the gallery was seen almost immediately after the reservoir reached its elevation. The general opinion of those who frequently, closely, and periodically made a visual inspection of the downstream face was that it visually decreased with time.

Plates 23.1 and 23.2 graphically show the initial history of seepage. The graph includes the following pertinent data:

(1) important elevations of the structure and reservoir;

(2) reservoir elevation versus date;

(3) gallery total flow versus date;

(4) stilling basin total flow versus date; and

(5) gallery drain flow as a percent of gallery flow.

Several things worth noting are:

(1) During the time that the gallery drains were being drilled (prior to reservoir raise until 30 March 1983), the gallery flow was affected by two things: first, as more drains were completed, they provided more water; secondly, the drillers occasionally forgot to turn off their drill water pumped into the gallery. This resulted in a change in the outflow with no change in seepage.

(2) A very significant decrease in seepage as collected in the stilling basin occurred through a general trend from 25 April to 15 May. This occurred naturally - that is, by doing nothing to the structure. The reduction over the 3-week period was about 28 percent. The gallery flow has been more erratic, with periods of increasing and decreasing flow. Overall there has been more decrease than increase. During one 2-week period from 6 May to 20 May, the flow dropped 35 percent by doing nothing to the structure or operation.

(3) The stilling basin flow includes runoff from the downstream face of the dam, an area downstream of the stilling basin, and the general area downstream of the right abutment. Some of the flow into the basin and some (if not much) of the variation is attributed to runoff

from local rains. At times, water has been seen flowing over an estimated 30 to 60 percent of the basin end sill from the area downstream of the dam. This has been seen for as long as a full day after a rain.

(4) The stilling basin drains were making water during construction and before there was any water in the reservoir. This amount was probably on the order of 50 to 150 gpm.

(5) During the day that chemical grouting from the upstream face was done with concentrations and quantities that would theoretically be effective, there was no significant noted reduction of flow into the gallery. However, as shown on the graph, the gallery flow was distinctly and significantly less during the following day. Without continuing the operation, uncontrolled flow at the sides of the effectively grouted zone apparently then caused it to wash out.

(6) The data used to develop Plates 23.1 and 23.2 were essentially obtained by the same person reading the same instruments at the same time of day. Other readings obtained individually at different times of the day in a less systematic method may not agree entirely with this data.

In addition to the seepage shown in the graph, a separate measure was made of water collected near and at the outlet works control building. This essentially stayed constant, but raw data may initially give an indication of increasing seepage. The collection location was changed and moved downstream to allow better collection of all sources of seeps in the area. As water from more sources was picked up, the flow reading increased accordingly. Total flow at the collection location now at the downstream end of the left training wall for the outlet works stilling basin stayed fairly steady at about 100 gpm.

GROUTING (SEEPAGE CONTROL AND FOUNDATION)

Soon after the reservoir was raised above elevation 2000, it was evident that seepage into the gallery was considerable and that it could be expected to increase substantially if the reservoir suddenly filled for flood control purposes (Plate 23.3). Because of this and a very conservative concern of the slight possibility that erosion along the joint lines might occur, a program to attempt to slow or stop the seepage by chemically grouting from the upstream face was initiated.

The original plan was to set a temporary containment vessel (say 18 feet high by 30 feet wide by 3/4-inch deep) against the upstream face in the area of the gallery and inject concentrated chemical grout mix into it. The grout was to also contain a maximum practical cement content to provide rigidity to the otherwise gelatinous filler. By allowing water to be drawn into the containment panel from the reservoir through small holes drilled through it, the idea was that the chemical solution would be drawn into the joints through the natural seepage paths where it would gel.

After strong suggestions by the specialty grouting contractor (Gelco) and field personnel and because of the simpler and more economical procedure, it was decided to start with a different procedure that was to let the chemical grout flow from a wand held at individual points and later traversed back and forth around the perimeter of joints in the upstream face panels. This procedure was not effective.

A variation of the original plan was then attempted. As suggested by the grouting firm, this used a vinyl curtain weighted at the bottom as the "containment vessel." The top was held against the dam. It is estimated from feeling with a probe that some of the curtain drifted as much as 6 to 12 inches out from the dam face (probably near the solid panel surface) and at other places it was tight to the dam (probably at the joint where water was being drawn into the leaky joints). The chemical grout was flooded into the area behind the curtain, but the procedure was unsuccessful. Apparently the grout diluted too much in the reservoir behind the curtain and/or more probably sunk past the curtain to the bottom of the reservoir before being drawn into the dam. Dye included with the mix was faintly seen in drain holes at the general vicinity. Because of the desire to provide "body" to the gel, the cement content of the grout was fairly high, resulting in a specific gravity of 1.5 and sink velocity of 1 to 2 inches per second.

The next attempt used the same curtain and flooding technique, but holes were cut in the curtain so that water from the reservoir could pass through it and carry the grout into the dam. As had happened previously, the flexible membrane apparently was sucked up tightly to the dam at the joints between panels so the grout never was pulled into the structure and the attempt was not successful.

The final attempt was to go back to the original plan with a rigid wooden panel having small holes to the reservoir and flood it with chemical grout. This was only done effectively for 1 day, found to be very expensive, and did not show any immediate significant decrease in seepage. Consequently, further chemical grout attempts were disbanded. However, as shown on Plate 23.2 there was a significant reduction in seepage which did not show up until 1 or 2 days later. Apparently because the grout pattern was not continued, the material in the effectively grouted zone eroded out (probably due to seepage all around it) and the gallery flows subsequently increased again. The main problem with this technique was that because of the volume of the containment vessel, very high concentrations (and expensive quantities) of chemical had to be used to account for dilution. The original depth of the containment vessel of 3/4-inch had to be doubled to 1-1/2 inches so that it would clear the washers and bolts threaded into the precast panel tieback inserts at the face.

A side benefit from the chemical grout program came from dye testing. The conclusion is that there is not just a straight flow path from the upstream face to the gallery and that if only an isolated area at the upstream face is sealed off, seepage can still migrate around and continue exiting into the gallery directly downstream of this zone.

Migration can follow paths roughly ranging from say 20 feet (directly upstream to the gallery downstream) to a roundabout path of maybe 100 feet. Another observation is that velocity through the joints is much slower than originally thought might be occurring, i.e., about 0.03 fps.

After initial attempts failed to slow seepage by injecting chemical grout into the reservoir upstream of the gallery area and allowing it to be drawn into the seepage paths, a $171,000 modification has been issued to Eucon to drill holes into the zone of RCC upstream of the gallery and grout through them. With this method, a cement grout should be successful. The holes will be drilled on 8-foot centers at an angle from a work barge at the upstream face.

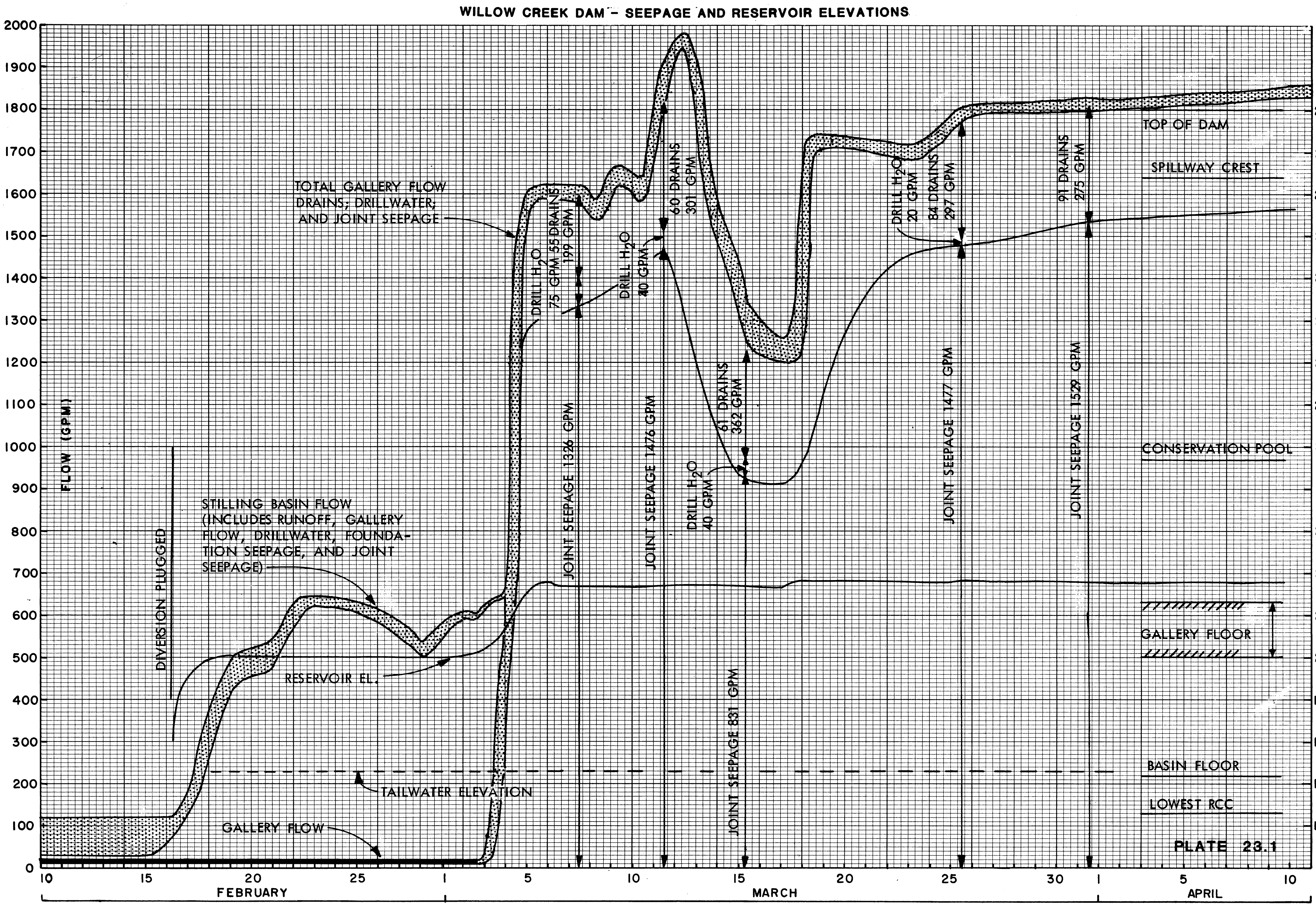
Exploratory drilling for design showed that a foundation grout curtain would not be needed for stability - at least not at the start of project operation. Rather than simply following convention and putting in a full-cost grout curtain "because it's always done" or because at some later date one might be desired, the Corps took the approach of building a safe structure without the grout curtain, evaluating initial seepage and the foundation as it was exposed during construction, and then following up with a subsequent contract for only that grouting which was prudent. This approach has resulted in the determination to grout only the upper 25 feet of foundation rock with a single line of holes.

The grouting contract will include obtaining eight 9-inch-diameter cores for the full height of the dam as discussed in Chapter 24, "Future Evaluations and Testing." They will be located to intercept zones where different compaction methods and equipment were deliberately used and where different joint treatments were employed during construction.

The dam itself will also be drilled and grouted under this contract to help seal joint seepage. Although there is no structural need for it and some seepage is tolerable, long-term performance may require remedial measures. Contingency funds set aside as a part of the original project cost for such work must be used by October 1984. The management decision has therefore been made to include the work now with the foundation drilling and grouting contract. A 150-foot segment of the dam will not be grouted so that its long performance without treatment can also be evaluated.

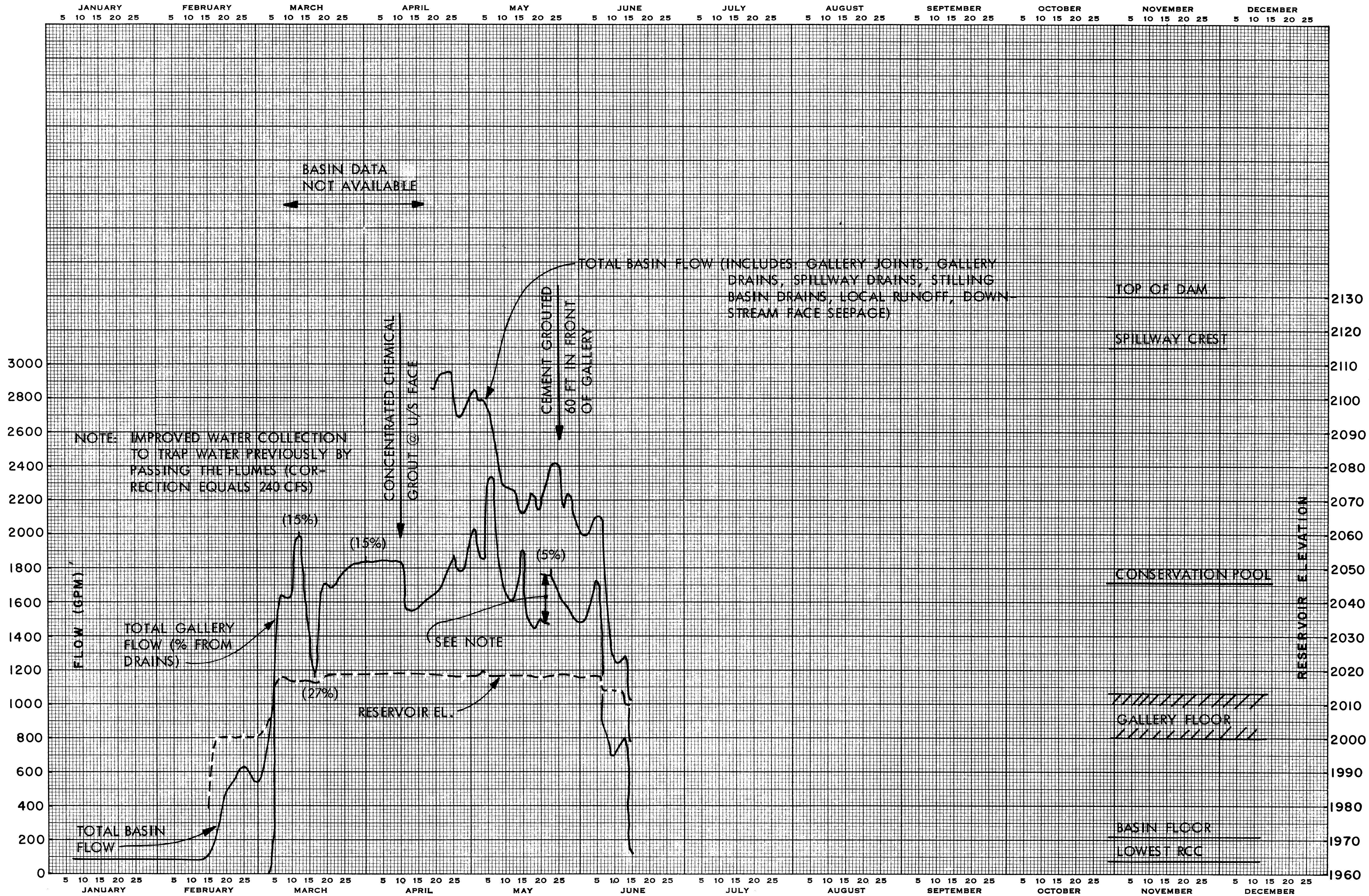
Total cost of the contract including the foundation and abutment grout curtain, redrilling drain holes, obtaining the full-height large-diameter cores, and grouting the dam itself is $1 million.

There has been considerable discussion and published comment about seepage at Willow Creek and what might be expected in RCC dams in general for future work. Unfortunately, much of it is incomplete or inaccurate. For the circumstances at Willow Creek (including the need to acquire performance knowledge), the no-frills initial approach with followup after reservoir raising was appropriate. For strict flood control projects without permanent reservoirs, there may be no reason to spend time, effort, or money to control joint seepage. Other projects may require watertight conditions. A variety of practical methods can be used to control joint seepage and watertightness. These range from collection systems to special bedding mixes in select zones, to chemical grout self-sealing or post-sealing systems built into each layer near the upstream face, to implementing a conventional concrete poured-in-place facing that acts as a cutoff wall to impervious membranes. As a rough value, providing watertightness may add $100,000 to $600,000 to the cost of an RCC dam on the order of 200,000 to 800,000 cubic yards.



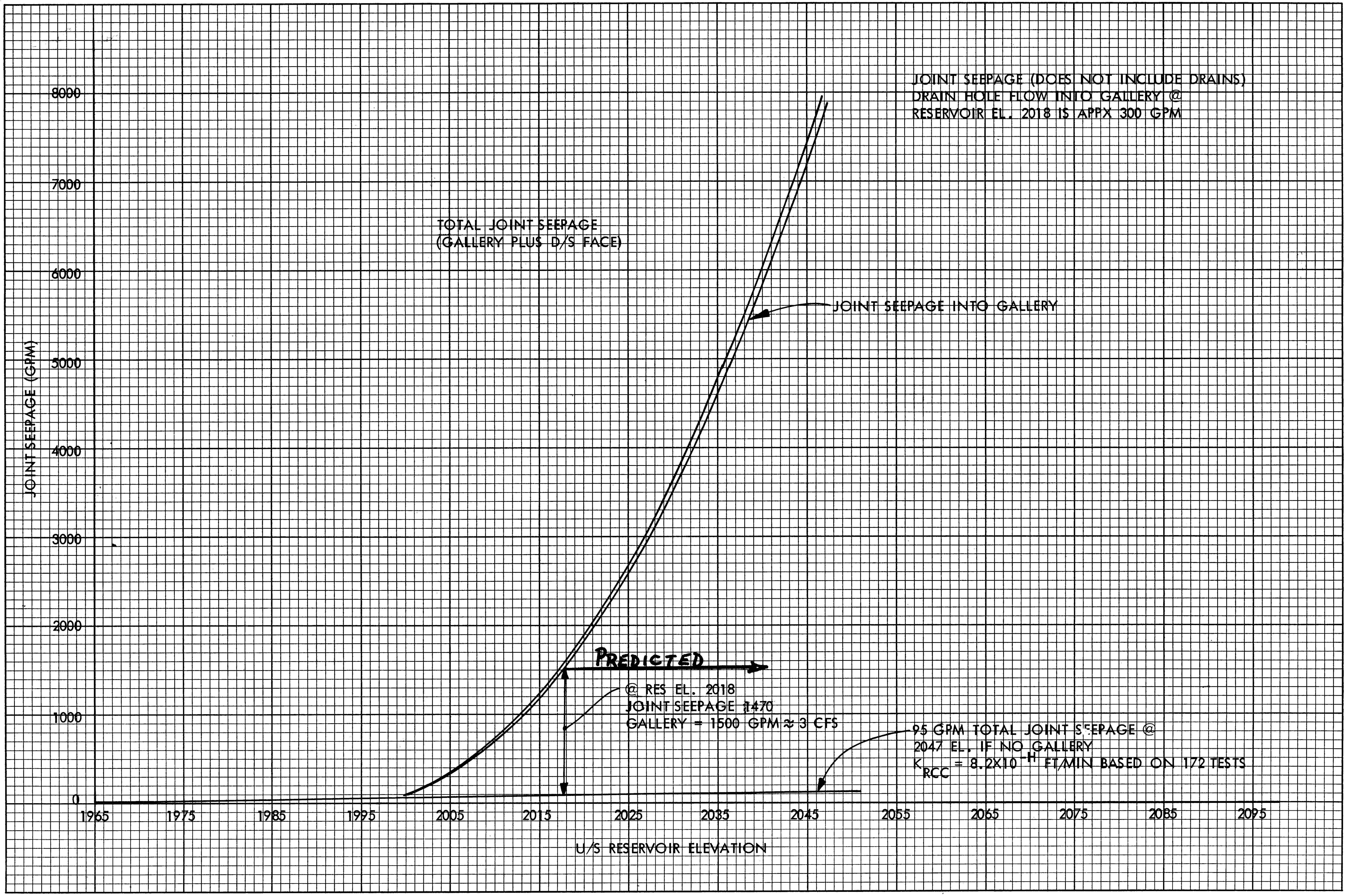
WILLOW CREEK DAM - SEEPAGE AND RESERVOIR ELEVATIONS
FLOW (GPM)
TOTAL GALLERY FLOW DRAINS; DRILLWATER; AND JOINT SEEPAGE
STILLING BASIN FLOW (INCLUDES RUNOFF, GALLERY FLOW, DRILLWATER, FOUNDATION SEEPAGE, AND JOINT SEEPAGE)
RESERVOIR EL.
TAILWATER ELEVATION
GALLERY FLOW
DIVERSION PLUGGED
DRILL H2O
75 GPM 55 DRAINS 199 GPM
DRILL H2O 40 GPM
60 DRAINS 301 GPM
61 DRAINS 362 GPM
DRILL H2O 40 GPM
DRILL H2O 20 GPM
84 DRAINS 297 GPM
91 DRAINS 275 GPM
JOINT SEEPAGE 1326 GPM
JOINT SEEPAGE 1476 GPM
JOINT SEEPAGE 831 GPM
JOINT SEEPAGE 1477 GPM
JOINT SEEPAGE 1529 GPM
TOP OF DAM
SPILLWAY CREST
CONSERVATION POOL
GALLERY FLOOR
BASIN FLOOR
LOWEST RCC
FEBRUARY
MARCH
APRIL

PLATE 23.1



WILLOW CREEK DAM — SEEPAGE AND RESERVOIR ELEVATIONS

PLATE 23.2



WILLOW CREEK DAM – SEEPAGE RESULTING FROM THE GALLERY **PLATE 23.3**

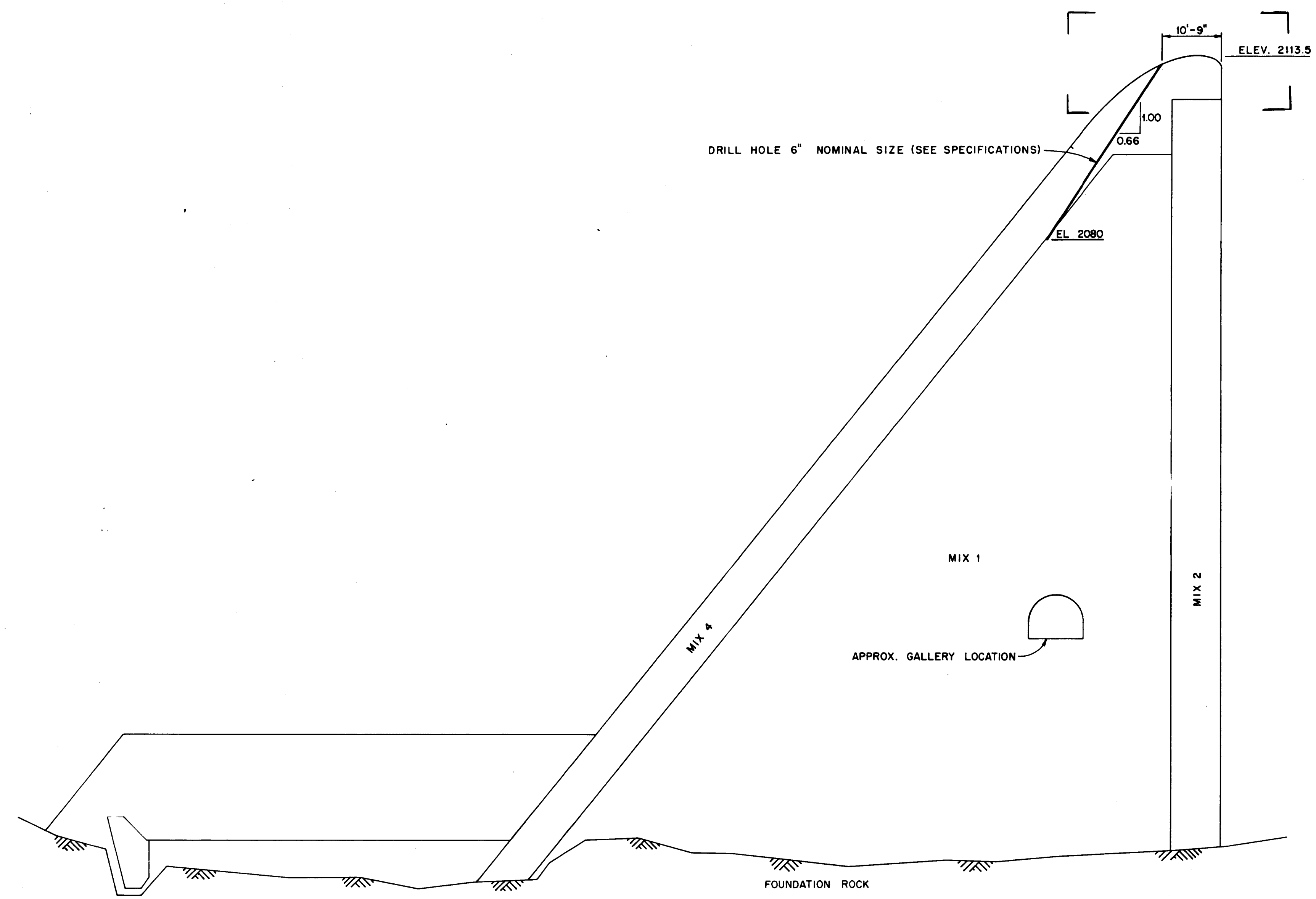
CHAPTER 24

FUTURE EVALUATIONS AND TESTING

A major core drilling and testing program is scheduled for the summer of 1983. Large diameter cores (6-inch nominal diameter for 1-1/2-inch RCC and 9-inch nominal diameter for 3-inch RCC) will be taken from the dam at specified locations. Each mix will be cored from the top of the dam down to 2 feet into bedrock, and each mix will be drilled in at least two locations. One of the locations will be through concrete placed under contract specification requirements with no modifications. One hole will be drilled through areas where modifications to the standard specifications were incorporated to see what effect they would have. These variations included different compaction equipment and methods, different joint treatments, and different bedding mixes at the foundation contact. Plates 24.1 through 24.5 show the locations and depths of the planned holes. They also show the locations where modified placing procedures were used and what they were.

The cores will be weighed, photographed, and sent to the Division laboratory for testing which will include unit weight, compressive strength, modulus of elasticity, shear strength across joints, direct tension, and strain capacity. In addition, each hole will be pressure tested every 4 feet as it is being drilled to determine permeability values.

In general, the goals of the drilling and evaluation program are to determine properties of in-place RCC, compare it to laboratory data and design requirements, and provide guidance for future RCC projects based on experience at Willow Creek Dam. Specific goals are: (1) to determine hardened material properties of the various RCC mixes in the dam (density, strength, modulus, etc.); (2) to compare in-place properties to those determined for laboratory samples prepared by various methods, and to provide recommendations as to the most appropriate method of preparing laboratory samples; (3) to evaluate various methods of joint treatment; (4) to look at the effect of the age of the RCC layers when covered with the next RCC layer; (5) to look at the achieved quality of foundation to RCC contact for each mix used and for both types of bedding tried; (6) to determine the overall unit weight of RCC in each mix used, including at joints and in the layer mass; (7) to determine typical permeability values of joints prepared by different methods; and (8) to look at trends that may have developed in material properties and how they correlate with trends in weather, production rate, gradation, etc., as recorded during construction.



STATION 112+00

SCALE IN FEET
10 0 10 20

REVISION	DATE	DESCRIPTION	BY
A	83 APR 15	Removed line	

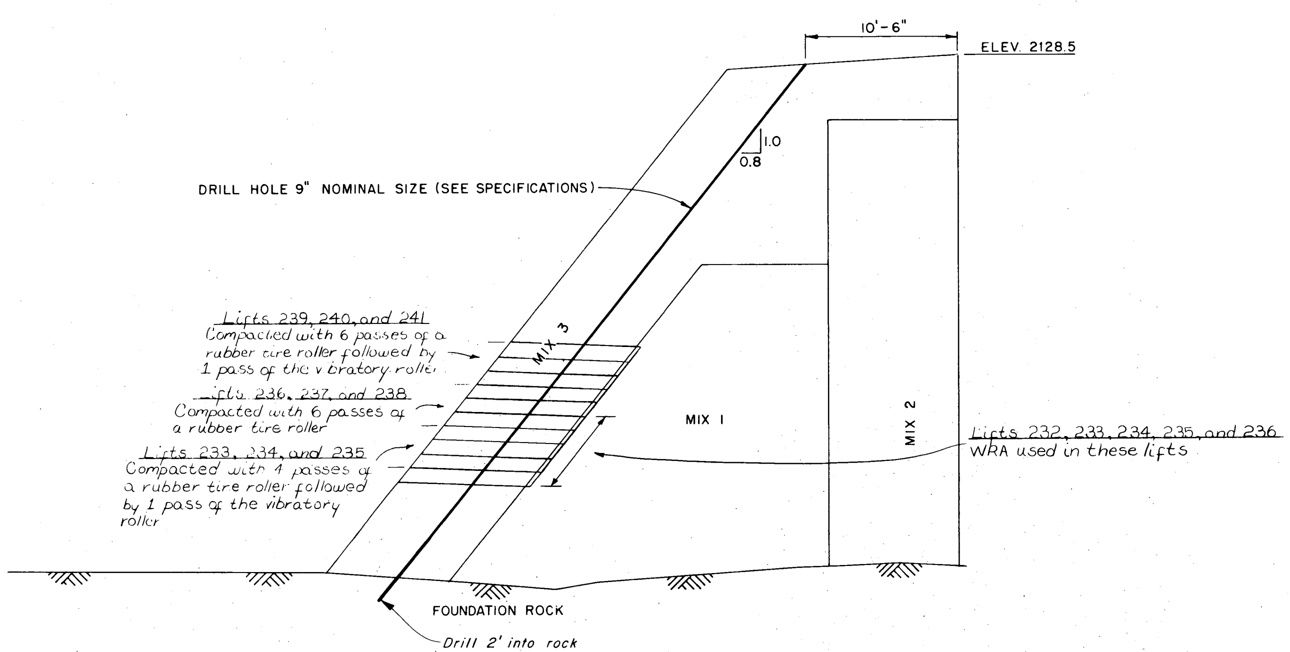
U. S. ARMY ENGINEER DISTRICT
WALLA WALLA, WASHINGTON

DESIGNED: E. Schrader
DRAWN: G.D.P.S.
CHECKED: S. Tatro
SUPERVISED:
CHIEF, MATL'S. SEC.

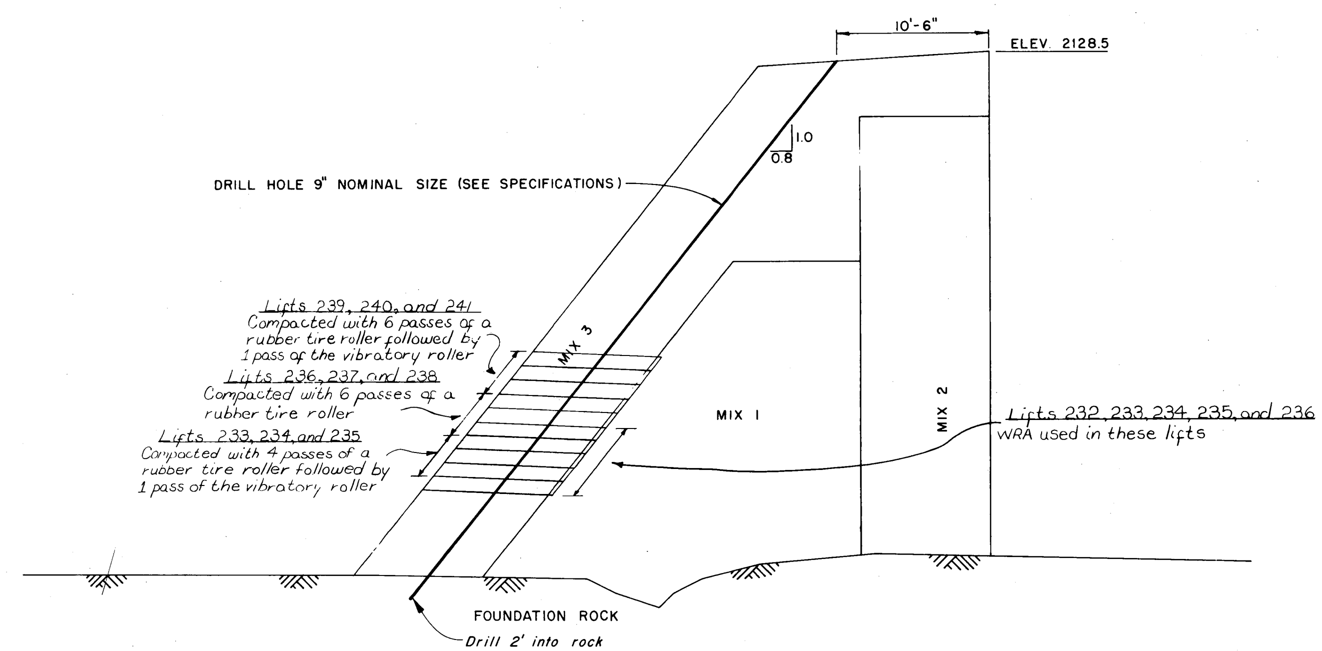
WILLOW CREEK LAKE
HEPPNER, OREGON
CONCRETE CORE SAMPLING
LOCATIONS I

SUBMITTED:
CHIEF, FOUNDATIONS AND MATERIALS BRANCH

DATE 83 MAR 15
SCALE AS SHOWN
INV. NO. 83-B-37
FILE NO.
SHEET 12 WC-1-11/12



STATION 105+20



STATION 105+30

SCALE IN FEET
5 0 5 10

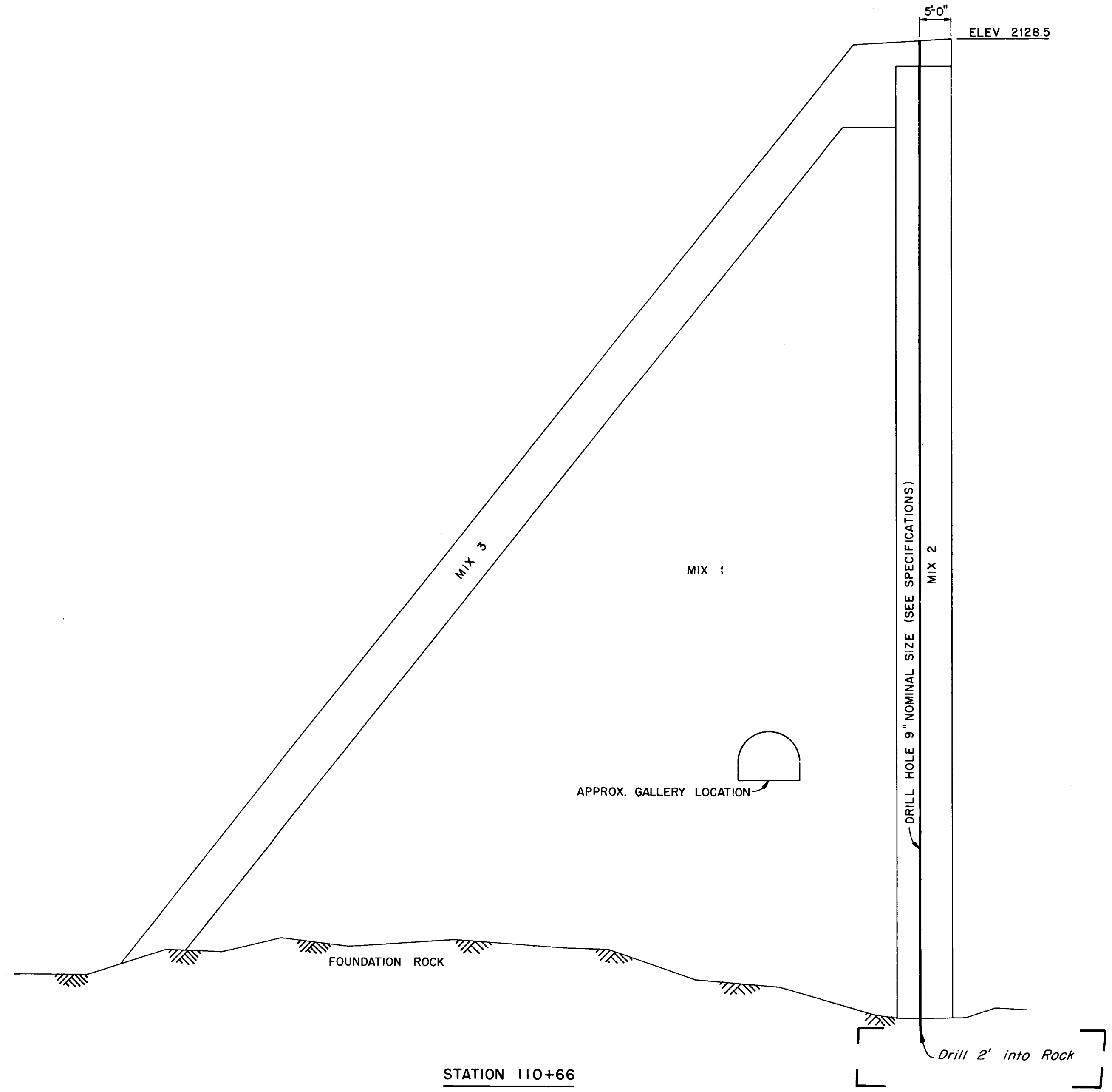
REVISION	DATE	DESCRIPTION	BY

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA, WASHINGTON

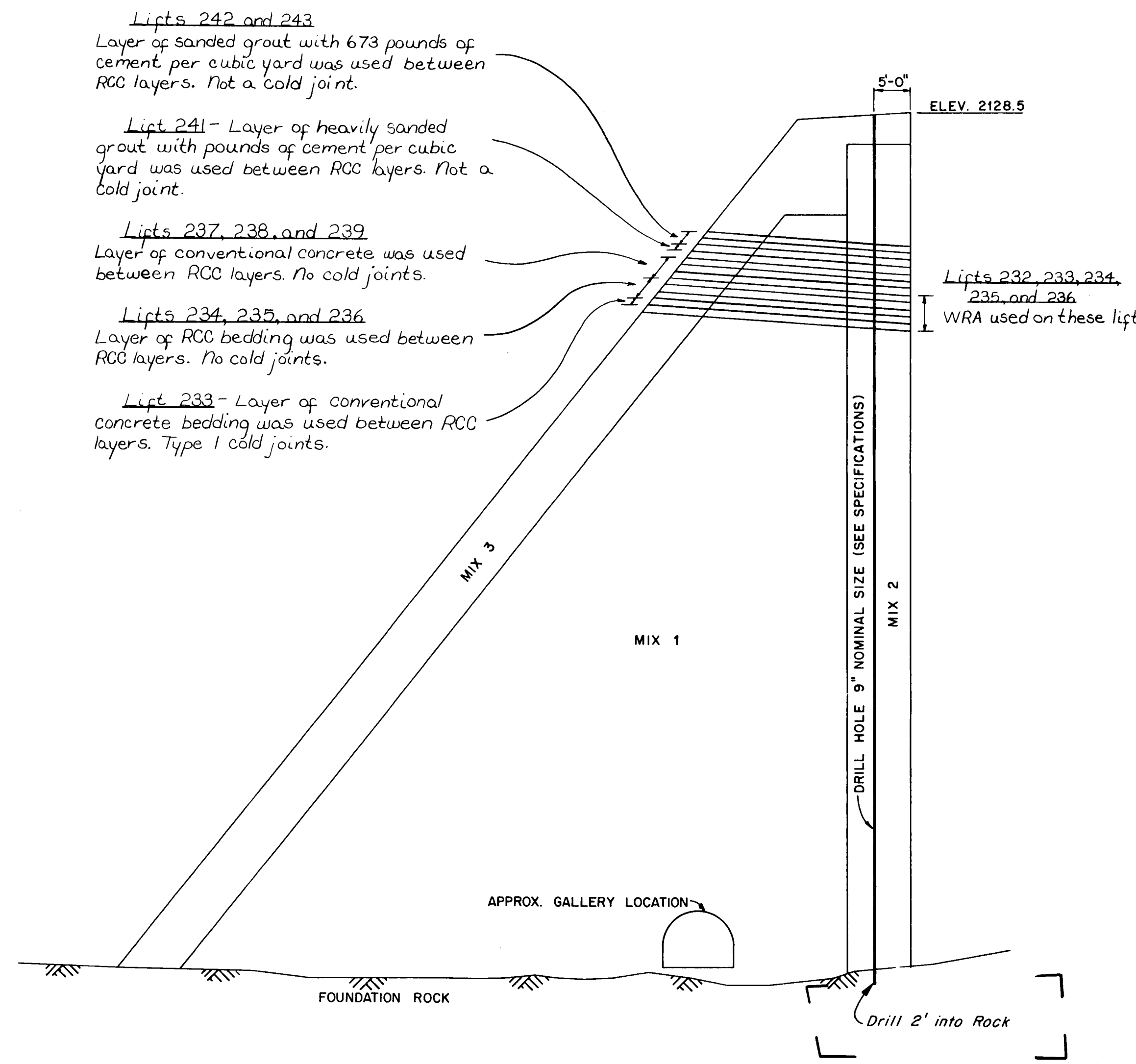
DESIGNED: E. Schrader
DRAWN: GDPS
CHECKED: S. Tatro
SUPERVISED: CHIEF, MATL'S. SEC.
SUBMITTED: CHIEF, FOUNDATIONS AND MATERIALS BRANCH

WILLOW CREEK LAKE
HEPPNER, OREGON
CONCRETE CORE SAMPLING
LOCATIONS II

DATE 83 MAR 15
SCALE AS SHOWN
INV. NO. 83-B-37
FILE NO. WC-1-11/13
SHEET 13



STATION 110+66



STATION 107+16

SCALE IN FEET
10 0 10 20

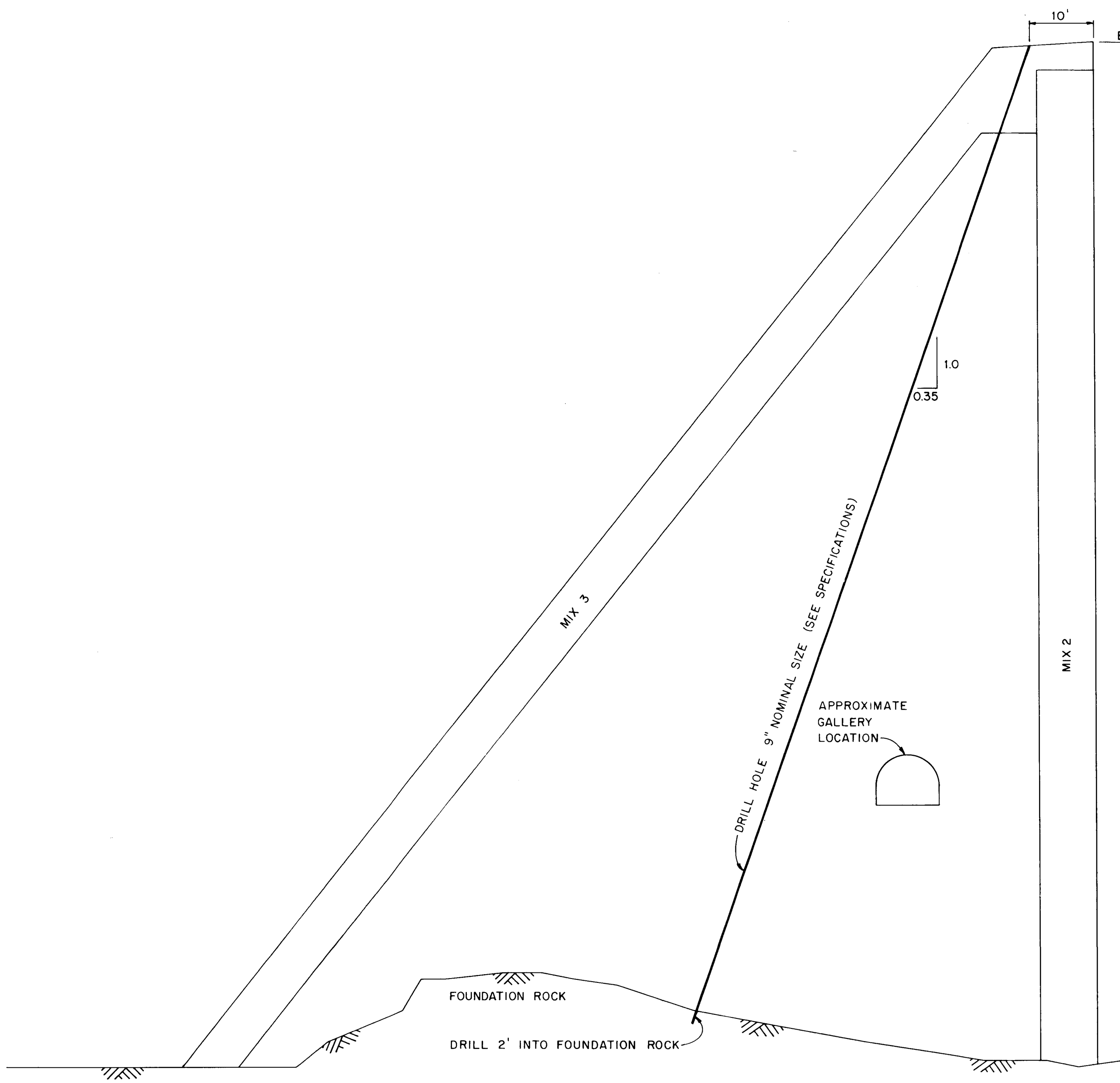
REVISION	DATE	DESCRIPTION	BY
A	83 APR 15	Added notes	[illegible]

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA, WASHINGTON

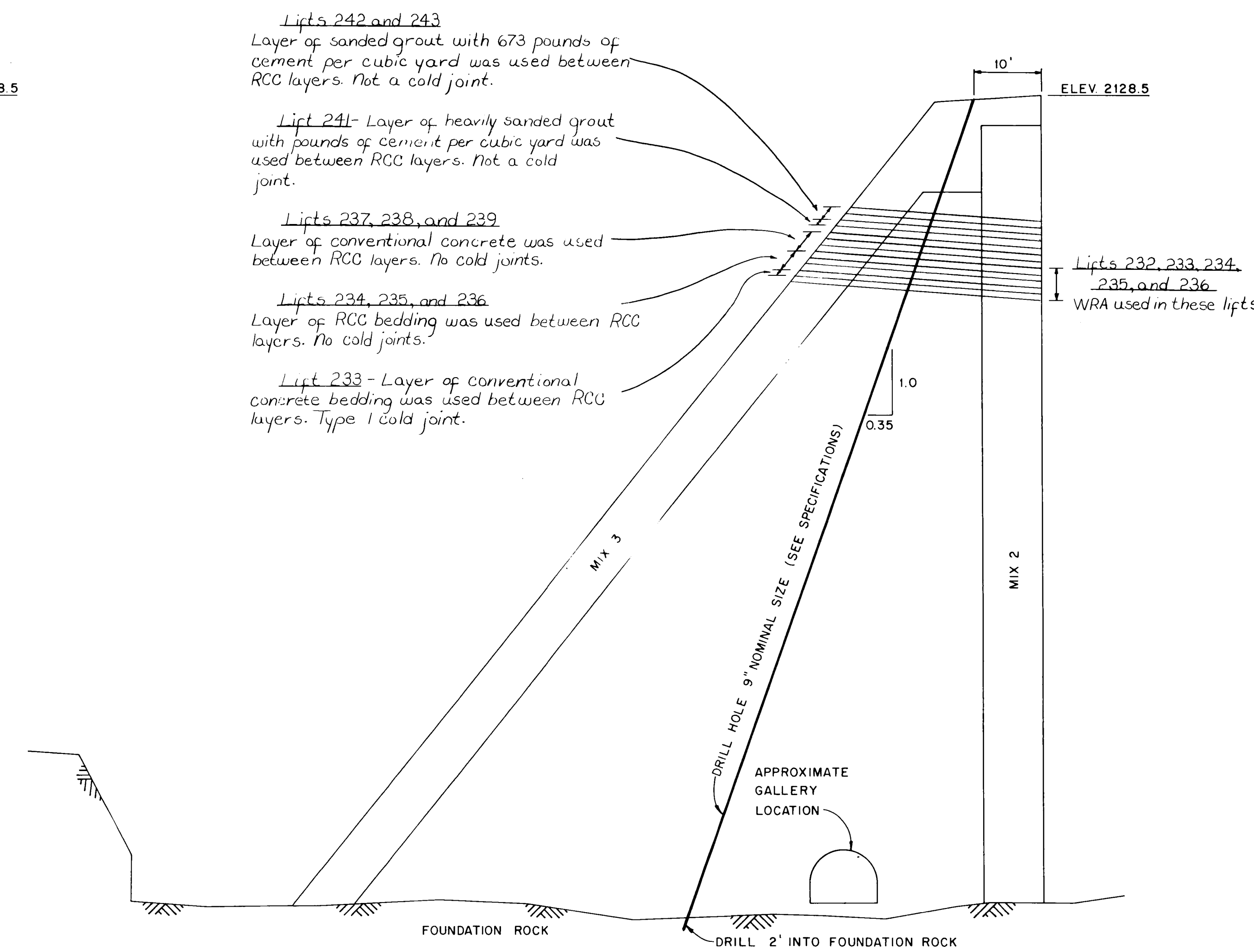
DESIGNED: E. Schrader
DRAWN: GDPS
CHECKED: S. Tatro
SUPERVISED: [illegible]
CHIEF, MAT'LS. SEC.
SUBMITTED:
CHIEF, FOUNDATIONS AND MATERIALS BRANCH

WILLOW CREEK LAKE
HEPPNER, OREGON
CONCRETE CORE SAMPLING
LOCATIONS III

DATE 83 MAR 15
SCALE AS SHOWN INV. NO. 83-B-37
SHEET 14 FILE NO. WC-1-11/14



STATION 110+76



STATION 107+25

SCALE IN FEET

10 0 10 20

REVISION	DATE	DESCRIPTION	BY

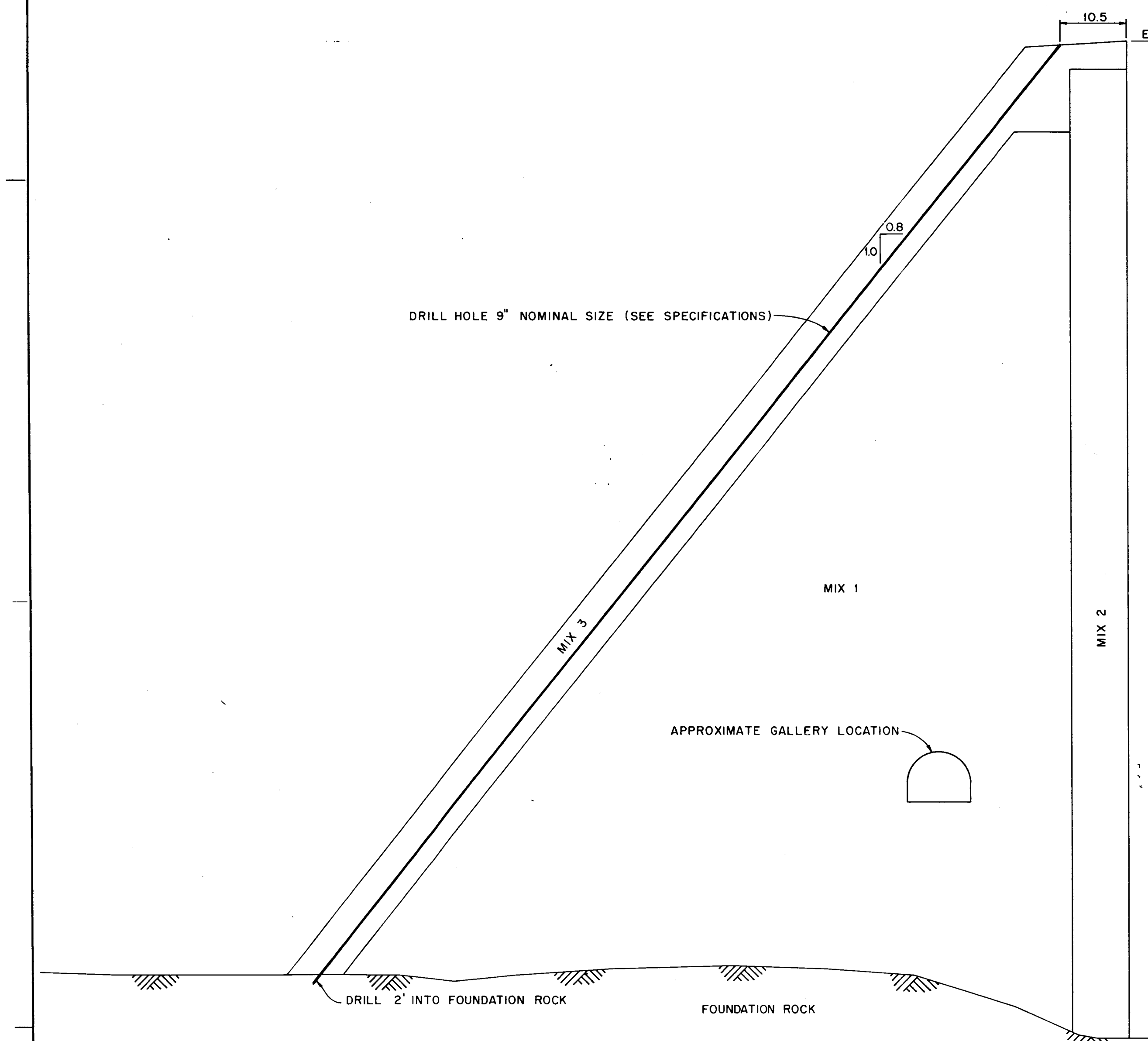
U. S. ARMY ENGINEER DISTRICT
WALLA WALLA, WASHINGTON

DESIGNED: E. Schrader
DRAWN: GDPS
CHECKED: S. Tatro
SUPERVISED: [signature]
CHIEF, MATL'S. SEC.

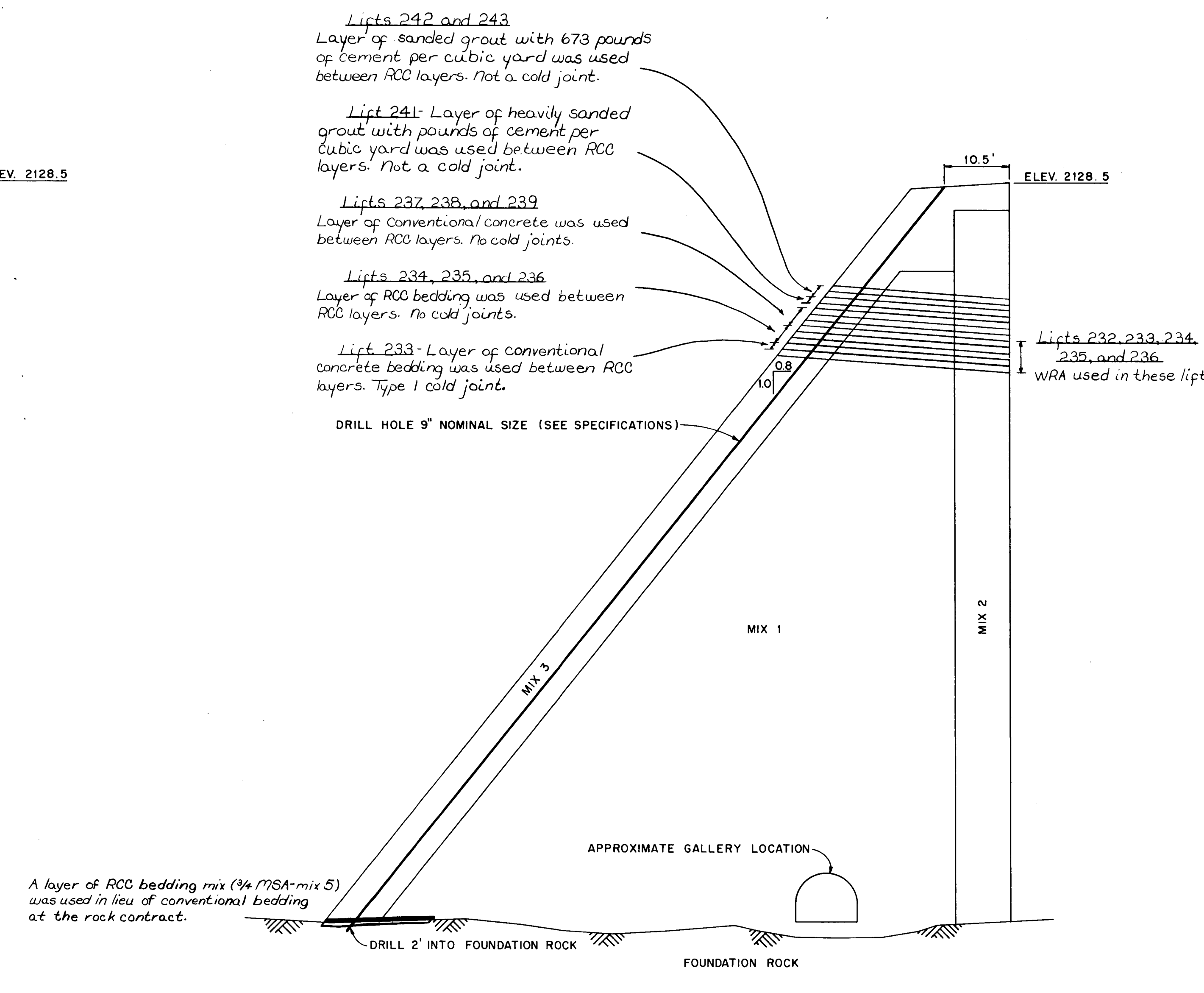
WILLOW CREEK LAKE
HEPPNER, OREGON
CONCRETE CORE SAMPLING
LOCATIONS IV

SUBMITTED:
CHIEF, FOUNDATIONS AND MATERIALS BRANCH

DATE 83 MAR 15
SCALE AS SHOWN
INV. NO. 83-B-37
FILE NO.
SHEET 15 WC-1-11/15



STATION 110+60



STATION 107+34

SCALE IN FEET
10 0 10 20

REVISION	DATE	DESCRIPTION	BY

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA, WASHINGTON

DESIGNED: E. Schrader
DRAWN: GDPS
CHECKED: S. Tatro
SUPERVISED: [illegible signature]
CHIEF, MATL'S SEC.

WILLOW CREEK LAKE
HEPPNER, OREGON
CONCRETE CORE SAMPLING
LOCATIONS V

SUBMITTED:
CHIEF, FOUNDATIONS AND MATERIALS BRANCH

DATE 83 MAR 15
SCALE AS SHOWN
INV. NO. 83-B-37
FILE NO.
SHEET 16 WC-1-11/16

CHAPTER 25

CONTRACTOR'S COMMENTS

The prime contractor, Eucon Corporation, has participated in several seminars on roller-compacted concrete and has given public talks concerning their view towards bidding and construction of Willow Creek Dam. Their comments have been prepared by the project manager who also prepared the bid and then ran the project. Because of the value of this information, it is included here as provided to public seminar audiences.

EXHIBIT 25.1

CONTRACTOR'S COMMENTS

NOTE: This exhibit is the unedited text of a presentation that the contractor's project manager, Rick McKinnon, prepared for "The World of Concrete" Seminar on Roller-Compacted Concrete, January 1982, in Las Vegas, Nevada.

US Army Corps
of Engineers
Walla Walla District

Willow Creek Lake
Heppner, Oregon

Main Dam Contract

EUCON CORPORATION
RICK McKINNON
Vice President

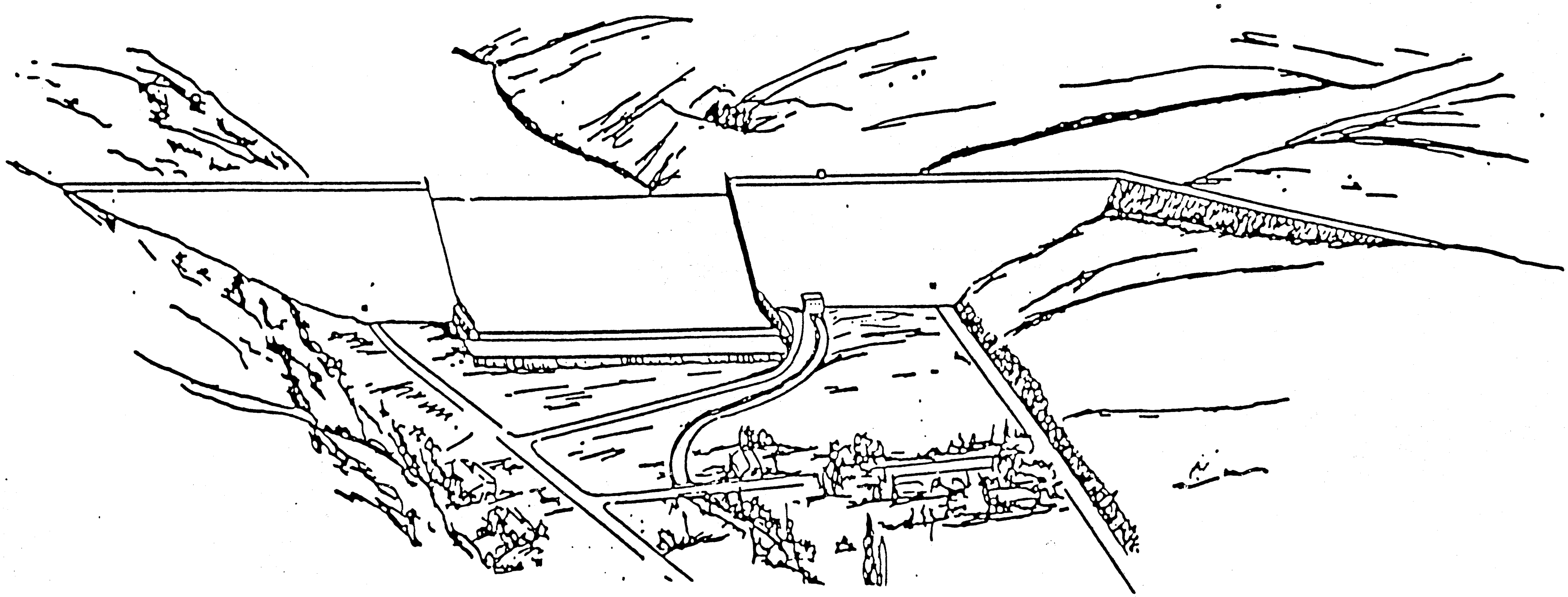


EXHIBIT 25.1
Sheet 1 of 18

WORLD OF CONCRETE PROGRAM
Session 1-06, Roller Compacted Concrete
February 26, 1983 2:00 - 5:00 P.M.

1. About the Prime Contractor

Eucon Corporation has been in existence since 1 January 1979, and came into existence as a result of a merger between several corporations. The major ones were: L. W. Vail Company, Inc. of Pasco, Washington, whose specialty was essentially asphalt paving and crushing; Steelman-Duff, Inc. of Clarkston, Washington, whose major field of expertise was heavy earth moving, primarily in heavy highway and railroad construction; and DeAtley Corporation of Lewiston, Idaho, whose primary emphasis was on aggregate production and handling. The resulting company then had the financial resources and expertise to handle most highway and railroad construction projects with the exception of structural work, and certain specialty items that are normally subcontracted out.

11. Preparation of the Willow Creek Bid

Since dam construction is beyond our normal realm of endeavors, we originally ordered plans out of curiosity and with the thought of perhaps quoting some of the work as a subcontractor. After some review of the contract requirements, the plans, and the construction site, it became evident that we had most of the equipment available within our company to construct the project as prime contractor.

We lacked somewhat in personnel for the main dam construction. We did have, in-house, all of the personnel and expertise required for most of the preliminary work, so, after a little further analysis, we decided to bid the project with the assumption that, if we were successful, I would take over the duties as Project Manager and we would employ the necessary staff to construct the project.

Since our estimating department at Eucon Corporation consisted of two people, myself and a secretary, we worked quite diligently on the estimate preparation for several weeks. The method I used for estimating any project was to essentially construct it in my mind. This required from time to time, several visits to the project to make sure there wasn't some physical limitation that would influence methods of construction.

Since this was a relatively new procedure, and there was very little historical information that could be obtained, I used the plans and specifications as a guide and attempted to visualize what the designer had in mind as I put together the various crews necessary to perform the work.

The project was scheduled during the bidding process and allowed 121 days of work in the original estimate and we actually used 124 work days

In the estimate, I used the same conventional batch plant that we ultimately purchased, which was a Noble 600 Low Profile plant with two eight (8) yard mixers and utilized a conveyor system from the batch plant to the placement area where we discharged into holding hoppers and hauled away with scrapers. I used the placing spread of two scrapers, one track-type tractor, one motor grader, two vibratory rollers full time, three laborers and a grade checker.

We will very shortly get into the differences between the estimates and actual construction methods.

In conversations with some of the Corps' personnel, our approach to the job at bid time was very similar to theirs, and our production rates very closely paralled theirs, except for the upper twenty feet or so of the dam, where our actual and anticipated schedule was much more rapid than that of the Corps.

111. What Really Happened?

For the most part, what really happened is about what we allowed for in the estimate. The excavation work went pretty much as expected, using about the same equipment and crew sizes. The rock was a little more closely fractured than we had expected and there was a little more dirt in some of the seams than we had expected.

The crushing operation was slightly more difficult than we had anticipated. Production rates were about

10% less than we had allowed in the estimate.

The main area of dispute and surprise, was in the area of foundation preparation. Our interpretation of the specifications, and indications we had from prebid conversations, indicated that the foundation preparation for Willow Creek Dam was not going to be as stringent as had been experienced on conventional concrete dams. The indication in the specifications was that most of the foundation preparation could be handled with high volume, low pressure water. That did not prove to be the case. High pressure air/water jetting was necessary to cut the dirt that was overlying the rock and those same forces eroded the rock itself, so we had to employ substantially more expensive techniques than we had anticipated. We have a claim pending to resolve those differences.

After a couple of weeks' experimentation, we finally located and leased a large, truck-mounted vacuum unit. The vacuum itself was powered by a 671 jimmy diesel and it could easily pick up a six inch diameter rock. That machine facilitated our foundation cleanup efforts, since it would pick up loose surface rocks and dirt, as well as water that collected in the lower areas of the foundation.

As far as the actual placement of Roller Compacted Concrete was concerned, we used the Noble batch plant that we used in the estimate. We fed it with two 980 front end loaders.

We abandoned the conveyor system for several reasons, of which were the initial capital outlay required for a system, the timeliness in which this system could be constructed and delivered to the site, and difficulties in maintaining and moving the system.

After a considerable amount of analysis, we decided to maintain haul roads onto the dam and haul directly from the batch plant to the placement area with scrapers.

As far as the crew size on the placement area, it was just as in the estimate, one crawler tractor, one motor grader, two vibratory rollers, three laborers, and a grade checker, plus a placing foreman, 2-3/4 scrapers, and of course, a water truck twenty four hours a day, seven days a week.

The only major changes we made on this project were in the upstream facing panel system. The original design called for utilization of precast panels of the Reinforced Earth Company's system. We submitted a Value Engineering Proposal for a precast panel system of our own design, designed primarily by my Project Engineer, Kenneth Hunziker. (See Appendix #1). That Value Engineering Change Proposal was ultimately accepted by the Corps and resulted in an approximate savings of $700,000. The basic panel system is four foot by sixteen foot by three and one half inch panels (4' x 16' x 3½"), exteriorly supported by a strongback system, and ultimately tied back into the Roller Compacted Concrete with a three inch by five foot (3" x 5') threaded coil rod which screwed into an insert in the facing panels and was further secured by a four inch square washer on the end of the rod.

The exteriorly supported system proved to be very beneficial as far as maintaining alignment of the panels was concerned. We had a considerable amount of trouble holding the alignment of the Reinforced Earth Panels that we used in the training wall area. The main problem we encountered with the Reinforced Earth Panels was that we were attempting to achieve one hundred fifty (150) pounds per cubic foot density in the Roller Compcted Concrete immediately adjacent to the Reinforced Earth Panels. The Corps' preliminary tests had indicated that they would give sufficient support with a five foot long tieback strap instead of the fourteen foot long strap that is ordinarily used in the Reinforced Earth's system. That is true, after the concrete has taken its initial set but in the placing and compacting stages, prior to initial set, the five foot long strap doesn't develop enough friction to restrain movement in the panels. In future considerations, I would say that either a longer tieback strap or an exterior strongback system should be considered for the Reinforced Earth system.

We have applied for a patent for the system developed at Willow Creek Dam.

One area that proved to be a little more difficult than anticipated was maintaining the eight-tenths to one (8/10 to 1) slope on the downstream face of the dam. While the Roller Compacted Concrete would easily stand on that steep of a slope, its more natural tendency was to attempt to stand on about a one-to-one (1-1) slope, so it was necessary to place the outside edge of each lift with a motor grader and wheel walk the outer edge of each lift in order to achieve the 8/10 to 1. This had a tendency to cause the downstream face of the dam to appear to be corrugated, with the corrugations running horizontally rather than a smooth, uniform plane.

The gallery was formed by placing non-cemented aggregate in the gallery area as we placed each lift of Roller Compacted Concrete and ultimately mining that non-cemented aggregate out with conventional mining equipment. The system worked well. The execution was a little sloppy, causing the walls of the gallery to be somewhat more irregular than would have been anticipated.

IV. Selection and Training of Personnel

On most construction projects, when a person begins to select his crew, he selects from the available work force; leaning heavily towards personnel with experience in whatever type of work he is about to perform. In this particular instance, we were embarking on a process that was essentially new to the construction industry, hence, there were no people with experience. I advertised in several of the trade publications for staff. I called upon people whom I knew from past experience could adapt to a new process and ultimately ended up with what I considered to be a good crew.

My Project Engineer was a Resident Engineer with the State of Washington. I had dealt with him for quite some time in the past and he was curious to see what a construction project looked like from the contractor's point of view and also was very eager to be involved in the world's first Roller Compacted Concrete structure. Ken Hunziker took a year's leave of absence from the Highway Department and joined us at Willow Creek Dam.

Our Quality Control and Survey staff was selected after several interviews. We availed ourselves of the services of Century West Engineering out of Bend, Oregon, because they had the depth to supply all of the various types of personnel we needed for all of our testing and quality control activities.

Our General Superintendent moved from one of our other companies. He had quite a bit of experience in dam construction, especially conventional concrete dams.

We eventually signed Union agreements which gave the Unions exclusive preferral rights. Prior to doing that, I personally selected the majority of the crew that we would use during the Roller Compacted Concrete placement. Most of the crew were fellows that I had known in the past. A few were new to me but seemed to have the temperament and desire to make this project work. The people who were selected prior to the signing of any Union agreements, stayed with us through the entire project. We had to hire some personnel through the hiring halls after we signed agreements. We did have to terminate several of those fellows before we finally found people who fit into our scheme of things.

Before we started any Roller Compacted Concrete placement, we got together with the Corps of Engineers and Ernie Schrader put on a slide presentation for the supervisors and for the inspection staff at the Resident's office. Then, a week or so later, we rented the local Elks' hall and had another slide presentation. I gave a little pep talk for the entire crew. Once again, the Corps' personnel were invited.

What we were attempting to accomplish was to point out to each individual, whether he was a Laborer, Operator or Teamster, how important his job was to the structural integrity of the dam and also have the inspection staff hear the same words that the crew was hearing, to help alleviate any misunderstandings.

About midway through the project, we repeated that process because some of the people had become a little more familiar with what they were doing and consequently, a little sloppy.

There was one problem that I had not anticipated. Very simply stated, we were placing concrete with excavation type equipment and consequently with people who were primarily geared toward excavation work. The Roller

Compacted Concrete, both in the scrapers and as it was dumped, looked very much like embankment material. Historically, dirt people don't understand concrete and don't care for concrete. I'm not sure that we ever convinced some of our personnel that they were handling concrete and that things had to be done in a certain manner and within certain time constraints to avoid jeopardizing the project. For the most part, the people were adaptable and very cooperative in that regard.

Of course, our preliminary meetings were not only to point out the importance of each job but to make the people understand <u>why</u> certain things had to be done.

On the other side of the coin, a great number of the Corps' inspection staff had a good deal of experience in conventional concrete structures and it was necessary for them to "unlearn" some of the things that they had been previously taught, since some of the characteristics and methods involved in Roller Compacted Concrete construction are different than those involved in conventional concrete construction.

For the most part, the Corps' inspection staff did not choose to avail themselves of our educational sessions and were not very receptive to learning new methods and techniques.

I feel that Ernie and I understood what we were trying to accomplish and we established a fairly good working relationship. However, there were very frequent disagreements between the Contractor's personnel and the Corps' inspection staff that probably would have worked themselves out with no intervention on most projects. This project, being a new construction technique and being on a very tight schedule, did not permit us the luxury of letting these problems resolve themselves, so, on a number of occasions, it was necessary for both Ernie and I to intercede in order to keep the project moving on schedule. This intervention caused a number of hard feelings on both the side of the Contractor and the Corps.

Until we have managed to complete the educational cycle so that we have personnel on both sides who are experienced in this kind of construction, in my opinion, it is going to require a person on the project who has a strong will and a strong desire to see that things are accomplished as they should be.

Ernie's presence on this project was a little different than is normally the case on a Corps of Engineers project, a representative from the Engineering Department on site as an adviser to the Resident. Had Ernie not been present on this project, I don't believe it would have been completed in one season, because we would have, on a number of occasions, had to stop construction while we were getting an interpretation through normal channels. With Ernie on site, those interpretations could be obtained almost on a moment's notice so that construction could continue with no interruptions.

V. Scheduling

Willow Creek Dam bid on October 23, 1981. The contract award and notice to proceed were issued on November 6, 1981. We had the pre-job conference in the Corps' office in Walla Walla on November 16th and began setting up our job site office on the same day.

We started some excavation operations on December 3rd. We started drilling and blasting in the outlet works channel on December 10th, with the first shot on December 14th. We made the first shot in the quarry on December 11th. Our initial goal was to get all the excavation work done in the main dam area so that we could begin placement of Roller Compacted Concrete on April 1st. We thought by getting started at that early date, we could have the dam topped out before August 20th, which was the date at which we had to begin placing insulation.

The excavation work proceeded much as it should have, with few delays. However, our mechanical subcontractor suffered some delays in procurement of the diversion conduit.

Our first completion date on this project was April 1st, which is the date when temporary diversion of Willow Creek had to be made. We accomplished that diversion on April 1st, which was about a month later than we had hoped for.

We then began the remaining excavation work in the stilling basin. That could not be accomplished until after diversion and we started foundation cleanup in earnest, with a three shift a day operation, six days a week. The foundation cleanup didn't go as rapidly as we had hoped either so the result was that we placed the first Roller Compacted Concrete on April 29th.

As I have previously mentioned, it took almost exactly the number of days that we had anticipated in the estimate.

50% of the aggregate for the Roller Compacted Concrete had to be in stockpile by May 1. We crushed the first aggregate on the project on December 30th, due to several delays in mobilizing the plant. Not the least of which, was the cooperation of the local power company. It took them five weeks after they started work to get power into the project.

In order to accomplish the May 1st deadline, we mobilized a second crushing plant towards the end of March and ran two crushers through about mid-June. We finished crushing on 23 October 1982.

I made arrangements with Peter Kiewit Sons' in mid-December to purchase a used Noble model 600 concrete plant from them. The plant was fairly complete, except that we had to add one weigh batcher and add some electronics. This plant had two 8 yard Erie Strayer mixers. We began moving the plant from Kiewit's Pleasanton, California yard to our shop in Lewiston, Idaho on January 4th. The plant began arriving on the project on March 2nd and was operational on March 25th, 1982. The computer unit we installed in the batch plant was an Alkon Compu/key 20-CRT with a printer for a little more positive record keeping and inventory control.

Most of the other equipment for the project was scheduled in from our various divisions, with deliveries to fit our needs.

The flyash for this project was originally to come from Centralia, Washington and a portion of it from Boardman, Oregon. However, with heavy spring runoffs, there was so much hydro electricity available in the northwest that both of these coal fired plants were down. So flyash ultimately came from the Jim Bridger coal fired plant in Wyoming. It came from Jim Bridger to Heppner by rail and then by truck from the transfer point, about three miles from the job site, to the project. Pozzolanic Northwest kept one truck and two drivers at all times, delivering flyash, with standby units about fifty miles away.

The Portland Cement came from Lehigh's plant in Metalline Falls, Washington, by rail to Pasco, Washington and then by truck the last eighty five miles from Pasco to the job site. Lehigh kept three trucks and drivers full time, with the fourth full time standby and other standby units within about two hours time. We had about one hundred eighty five (185) tons of cement storage on the job site, between our horizontal silo that came with the plant and a guppy that was supplied by the cement company, and about eighty five (85) tons of flyash storage. We had practically no problems with delivery of either flyash or cement.

We had originally planned to work a double eight hour shift, six days a week on this project, in order to achieve one of our deadlines, which was Elevation 1990, by May 21st. We did work a double ten hour shift, six days a week. However, that left so little time for equipment maintenance that we experienced an extraordinary amount of down time. As soon as we achieved Elevation 1990, we went back to a double eight hour shift, six days a week, with a graveyard and a Sunday maintenance crew. We still suffered some down time on equipment but at least it was manageable. The concrete plant required four to five people, ten to twelve hours every Sunday during peak production, in order to keep it workwise. The graveyard crew, during the week, could take care of minor items, but anything of any major consequence, had to wait until Sunday.

VI. Owner - Contractor Relationships

For the most part, relationships between the owner and contractor on this project were better than on most Corps of Engineers' projects that I have been around. The basic reason for a better than average relationship was that both the Corps and the contractor were committed to prove that a structure of this magnitude could be constructed in one season.

In order to accomplish this goal, it required that both sides exercise control and reason in arriving at an answer to the day-to-day problems that were to arise. And, for the most part, both sides lived up to that commitment fairly well.

I feel that the relations between the Corps and the contractor could be improved somewhat if they were to adopt a policy more closely akin to some of the other governmental agencies. One point that has for some time concerned me, is the Corps' policy towards a contractor's Quality Control organization. There are few owners that require such an organization so consequently, few contractors who keep quality control personnel on staff. On a project such as this one, that is of relatively short duration, it is very difficult for a contractor to locate and employ a quality control staff that is really fully qualified. It seems as though the Corps keeps about as many inspectors on the project as they would if they had sole responsibility for quality control. There is a substantial duplication in costs that could be eliminated and probably ease an on-going argument about whether the owners' sampling and testing techniques are superior to those of the contractor.

I also feel that, in many instances, I'll speak now in generalities, the Corps' requirements towards submittals and their handling of submittals should be updated and refined.

VII. Other Applications for Roller Compacted Concrete

I know there has been some work and study done on other applications of Roller Compacted Concrete besides dam construction. Basically, the techniques and equipment that were utilized on this project would be about the same if Roller Compacted Concrete was used as a foundation fill or in a gravity retaining wall, as with our upstream facing system.

For paving applications, a plant similar to ours, or a continuous mix plant, would be appropriate. The hauling units would most likely be flowboys or some other rear discharge semi units and an asphalt paving machine.

The compacting equipment, even for paving operations, would be the same as on this project.

In closing, as you have probably already detected, from the standpoint of my company and myself, we found this opportunity to be involved in the first major structure in the world to be constructed with this somewhat revolutionary method, to be both rewarding and exciting.

Thank you for your attention.

CHAPTER 26

CONVENTIONAL CONCRETE

Included in the main dam contract were approximately 8,000 cubic yards of conventional concrete, either as separate payment items or incidental to the work. The vast majority of it was used in dental fill and bedding mixes. Plate 26.1 shows typical uses of the conventional concrete. The classes of conventional concrete (90-day compressive strengths) and the location of their use are shown below:

<u>2,000 psi</u>

Bedding for precast items and for RCC construction.

<u>2,500 psi</u>

Concrete for encasement of diversion piping and the outlet piping within the RCC dam structure.
Dental concrete.
Leveling pad for prefabricated wall facing units.

<u>3,000 psi</u>

General concrete construction.
Diversion conduit plug.
Control building and gage well building concrete.
Spillway crest concrete.

<u>4,000 psi</u>

Diversion conduit intake structure.
Dam spillway end sill concrete.
Outlet works stilling basin, outlet works spillway, and outlet works structure concrete.

In addition, about 400 cubic yards of conventional concrete were used for the precast training wall and upstream face panels. The precast panels were made offsite, primarily at a small private facility in Kennewick, Washington, about 60 miles from the site. This concrete was a 4,000-psi steam-cured mix containing 3/4-inch maximum size aggregates from a local supplier using a natural gravel source.

The conventional concrete plant for the project was a satellite facility of the Umatilla Readymix Company, a major supplier whose central facility was located in Hermiston, Oregon, about 50 miles from the jobsite. The plant was a Model 100 Ross plant with batching capability only. Mixing was done in transit trucks. The facility had been at the same site just outside of Heppner, about 5 miles from the jobsite prior to dam construction. It had been used sporadically for local supply and for earlier relocation and miscellaneous highway construction requirements. Plate 26.2 shows the plant and typical aggregate stockpiles.

Aggregates were supplied by Jones-Scott from their gravel pit and processing facility in Umatilla, Oregon, about 50 miles away. Aggregate was delivered by truck and kept in relatively small stockpiles at the plant. The quality, source, processing method, grading, etc., are discussed in the project design memorandum. During peak construction, typically 500 cubic yards of each size (1-1/2-inch, 3/4-inch, and fine aggregate) were on hand. Near the start of the project, aggregates were frequently found to fail gradation requirements. About 500 cubic yards of material were rejected. Investigations showed that equipment at the main processing facility needed maintenance, replacement, or rebuilding. When this was taken care of, gradations were consistently supplied within specification limits.

Cement storage consisted of 69,000 pounds in the main silo and another 74,000 pounds in an additional storage silo. Type I-II cement from the Oregon Portland Cement Company was used for all concrete from this plant.

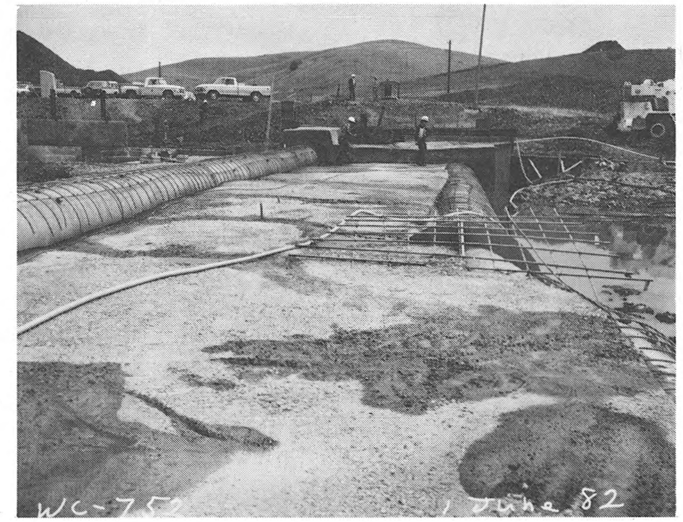
Haul from the plant to the jobsite required travel through Heppner and different approaches on access roads depending on where the mix was used. The resulting haul time varied from about 10 to 20 minutes. Radio communication was maintained between the plant and jobsite. About 5 minutes were required from the time a mix was ordered until it was on the road and going to the job.

From March through November, hot water was normally used to maintain required minimum temperatures of the mix. There was no capability for ice or chilled water during the summer, but by sprinkling stockpiles and placing concrete during the cooler times of the day, mix temperatures were typically kept below 85 degrees F during the summer.

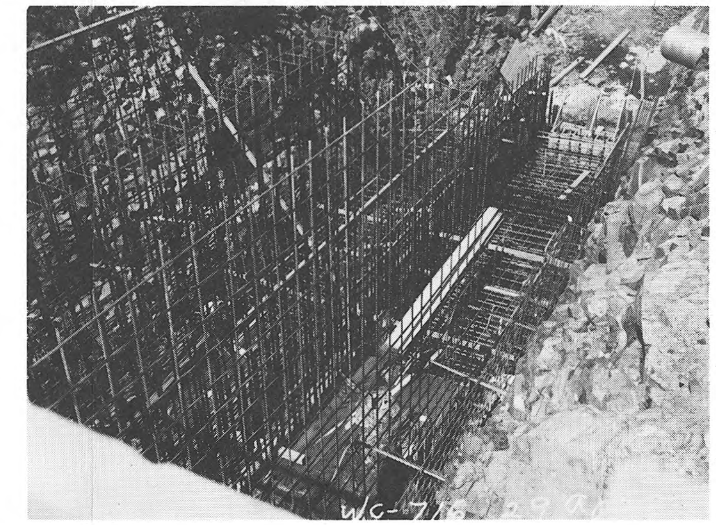
The admixture used was almost exclusively MBAE10 for air entrainment, with water-reducing admixture used only in the spillway cap for the wet mix shotcrete. Soon after warm weather arrived, it was evident that the conventional bedding mix would require a high degree of retardation if reasonable quantities were to be batched and delivered. The bedding was typically needed onsite in a ready status, but not discharged all at one time. This mix was then modified to include a high dosage of retarder.

Contractor quality control and Government inspection/testing for quality assurance followed the specification requirements and written guidelines provided to the Resident Office at the start of construction. With very few exceptions, conventional concrete was well controlled, consistent, and very seldom rejected. Mix designs prepared by the contractor through a testing laboratory hired by his supplier were well developed and proved out on the job from placing and strength standpoints.

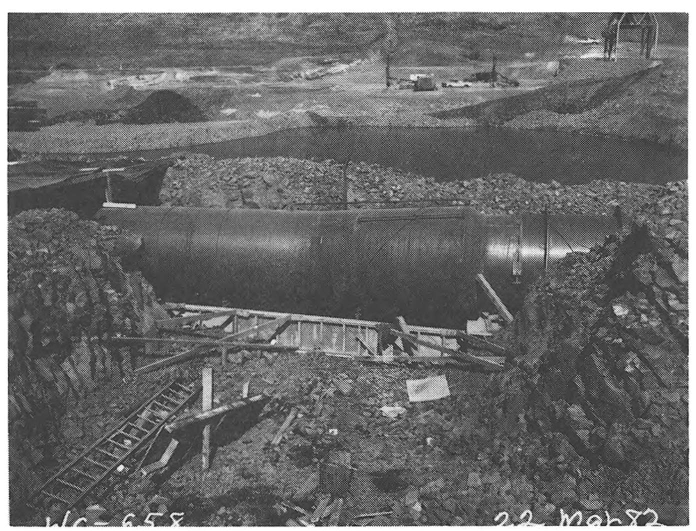
DIVERSION PIPE ENCASED IN CONCRETE TO THE RIGHT. EXCAVATION FOR PERMANENT OUTLET TO THE LEFT.



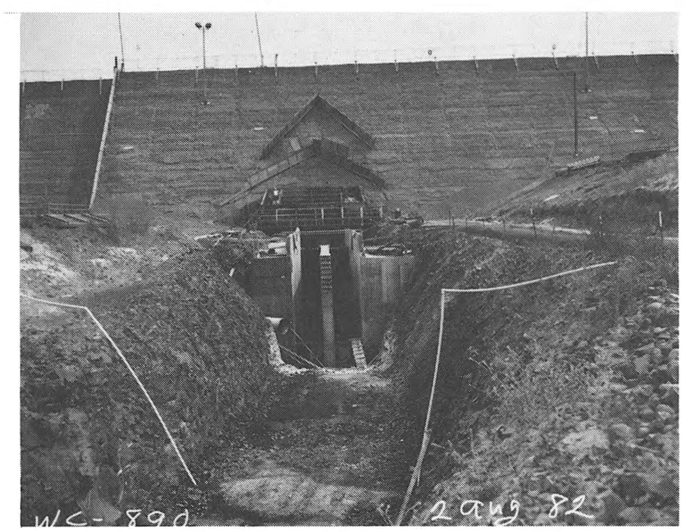
CONVENTIONAL FILL CONCRETE BETWEEN THE OUTLET PIPES.



TYPICAL REINFORCING STEEL FOR THE OUTLET WORKS.



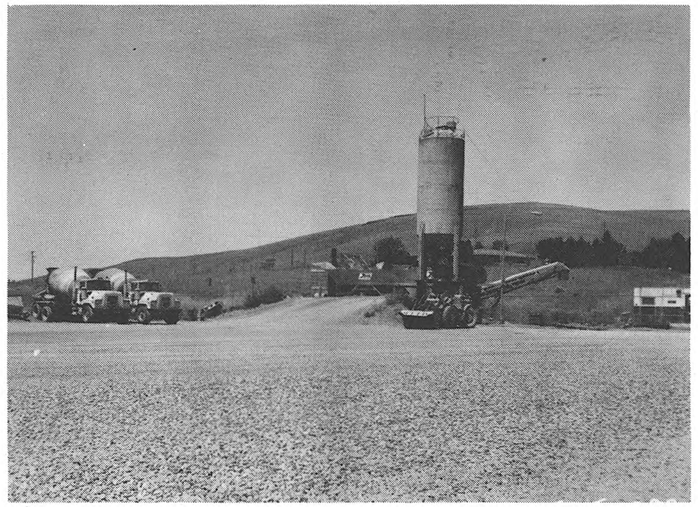
GROUT PLUG IN THE DIVERSION CONDUIT.



OUTLET WORKS TRAINING WALLS.

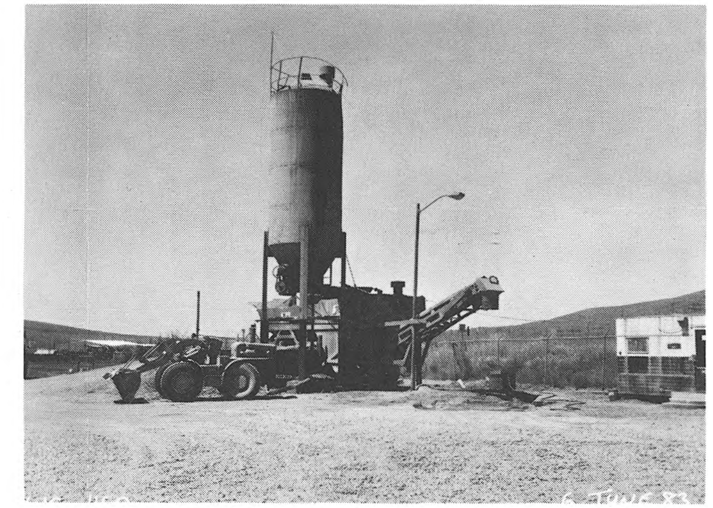
PLACING CONVENTIONAL CONCRETE IN THE OUTLET WORKS BY PUMP.

CONVENTIONAL CONCRETE OUTLET WORKS AND DIVERSION PIPE AREA

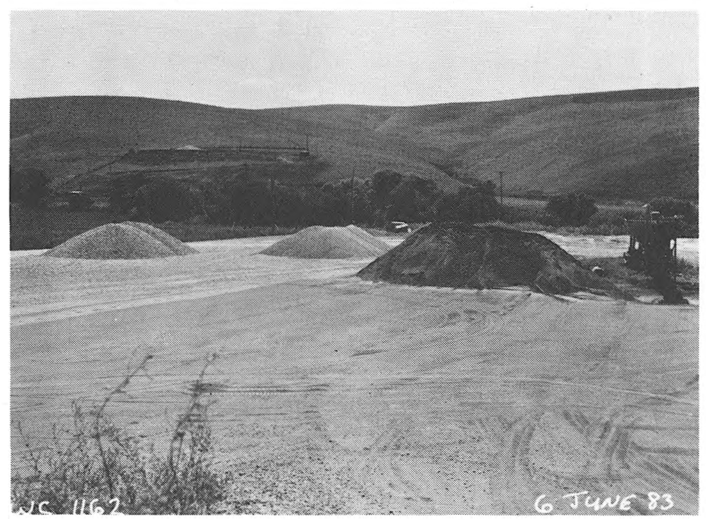


CONCRETE PLANT AND TRUCK

AGGREGATE BINS



CEMENT SILO AND CHARGING BELT FROM WEIGH BINS TO MIXER TRUCKS.



AGGREGATE STOCKPILES

AGGREGATE STOCKPILES

CONVENTIONAL CONCRETE PLANT

PLATE 26.2