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Engineering & Construction

Rocky Mountain Arsenal
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Commerce City, Colorado

INTERIM REPORT

**DIKE STABILITY ANALYSIS
BASIN F
ROCKY MOUNTAIN ARSENAL
DENVER, COLORADO**

June 1978

by

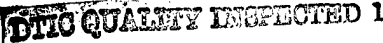
G. B. Mitchell, Yu-Shih Jeng

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1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE 13 Jun 78		3. REPORT TYPE AND DATES COVERED Interim 9 Nov 77 - 23 May 78
4. TITLE AND SUBTITLE Dike Stability Analysis, Basin F, Rocky Mountain Arsenal, Denver, Colorado			5. FUNDING NUMBERS	
6. AUTHOR(S) G. B. Mitchell Yu-Shih Jeng				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Engineer Waterways Experiment Station 3909 Halls Ferry Road Vicksburg, MS 39180			8. PERFORMING ORGANIZATION REPORT NUMBER 81266R44	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSORING / MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION / AVAILABILITY STATEMENT APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) This report presents the findings of the U. S. Army Engineer Waterways Experiment Station in compliance with the appropriate portions of Task 1.05.62. The work to be performed under Task 1.05.62 is defined as; Quantitative Feasibility Evaluation for Full Depth Containment of Basin F, and states, in part, that "Any hazards to the existing dikes due to age or construction should be identified" and "Assess the current physical condition of the Basin for determination of need for immediate structural repair."				
14. SUBJECT TERMS Treatment, Disposal, Liners			15. NUMBER OF PAGES 91	
			16. PRICE CODE	
			17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	
18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED		19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED		20. LIMITATION OF ABSTRACT UL

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13 June 1978

DIKE STABILITY ANALYSIS, BASIN F
ROCKY MOUNTAIN ARSENAL
DENVER, CO

1. This analysis was performed during the period 9 November 1977 - 23 May 1978. The study was authorized by Intra-Army Order for Reimbursable Services (IAO) No. RM 56-78 dated 9 November 1977. A Work Statement attached to that IAO defines the work to be performed under Task 1.05.62, Quantitative Feasibility Evaluation for Full-Depth Containment of Basin F, and states, in part, that "Any hazards to the existing dikes due to age or construction should be identified" and "Assess the current physical condition of the Basin for determination of need for immediate structural repair." This report presents the findings of the U. S. Army Engineer Waterways Experiment Station (WES) in compliance with the appropriate portions of Task 1.05.62.

2. A visual on-site inspection was made of the dike, and four boring locations were selected. A plan view of Basin F, along with the boring locations, is shown in Figure 1. The initial borings were made by a WES drill crew operating a drill rig belonging to Rocky Mountain Arsenal (RMA). The rig was not equipped to obtain satisfactory undisturbed samples, and in order to expedite the investigation, the borings were made utilizing Standard Penetration Tests (SPT). Jar samples were obtained and tested in the WES Soil Testing Facility for moisture content, Atterberg limits, grain-size distribution, and specific gravity. The laboratory test results are presented in Figures 2-41. The graphic boring logs and results of the SPT tests are presented in Figures 42-45.

3. From the SPT and laboratory test results, shear strength and unit weight parameters were estimated. The soils were considered to be either cohesive (in which case no angle of internal friction was assigned) or cohesionless (in which case no cohesion was assigned).

These estimated values are presented in Figures 42-45. Stability analyses were performed by using the Wedge Method in the WES Computer Program SSW028.

4. It appeared from the calculated factors of safety (0.87 to 1.25) that a critical condition existed in the outside, or downstream, slope when the reservoir was at full pool (2 ft below the crest) and when a steady seepage state with an assumed phreatic line occurred through the dike. Since the reservoir has been at full pool and the dike has not failed, it was felt that either the estimated strength values were not valid or the asphaltic membrane liner on the upstream slope had been effective in preventing a steady seepage state from occurring and the conditions necessary to reduce strength to that for saturated drained conditions have not yet developed. (The laboratory tests indicate that the embankment zone below the assumed phreatic line is not saturated.) Since the possibility exists that the liner could become ineffective at some point at any time, and since the low factors of safety were calculated from estimated soil parameters, it was felt that additional borings to obtain undisturbed soil samples for more accurate laboratory testing were necessary.

5. Four additional borings were made within 5 ft of the initial borings by a WES drill crew using a WES drill rig. Undisturbed Shelby-tube samples, 5 in. in diameter, were obtained. Where the soil possessed sufficient cohesion, Q triaxial tests were performed; where the soil possessed low cohesion, S direct shear tests were performed. All test results are presented in Figures 46-79. A comparison of the initial estimated values and the measured laboratory values indicates that the estimated values were only slightly in error. Since several samples were tested from each zone, and since the values within a zone varied slightly, it was necessary to make statistical selections of values for use in the analyses. The selected soil parameters for respective zones are shown, along with the initial graphic borings logs and estimated values, in Figures 42-45. Stability analyses were performed

utilizing the selected values and the Modified Swedish Method in the CORPS Computer Program I0009. Only the downstream slope was evaluated. Again, pool level was assumed to be 2 ft below the crest. Analyses were also performed with a pseudo-seismic (earthquake) loading of 0.05 g. The analyses are presented in Figures 80-83.

6. The analyses revealed that the factors of safety are highly dependent upon the degree of cohesion. Figure 84 graphically depicts this sensitivity. Corps of Engineers (CE) criteria, however, dictate that the SS case be analyzed using the drained strength (S test), which in this case is without cohesion. On this basis, factors of safety of 0.79 to 1.11 were obtained. Because of the sensitivity of the factors of safety to cohesion, analyses were also performed using the undrained strength (Q test) which includes cohesion and represents the unsaturated "as is" condition of the dike. Factors of safety for this condition range from 4.43 to 9.80. A summary of all factors of safety is presented in Figure 85.

7. Because of the low factors of safety indicated for the SS case, further analyses were performed with the reservoir pool lowered by 2-ft increments to determine if a lower head would increase the factor of safety to 1.5 as required by CE criteria for the SS case. (We understand that the reservoir pool elevation is decreasing due to reduction and possible complete cessation of fluid discharge into the basin.) Boring 482 was selected as being representative and only this location was subjected to the additional analyses which were performed using both S and Q strengths and with and without earthquake loadings. The results are shown graphically in Figure 86. Increases in factors of safety were only slight.

8. A summary of all analyses indicates that in order to comply with current CE criteria of a factor of safety of 1.5 for the SS condition, the downstream dike slope must be altered from its present 1:1 to a flatter 1:2.5. It is estimated that the dike comprises approximately one-half of the total periphery of the basin; consequently,

approximately 3600 lin ft of dike must be altered. The alteration will require approximately 16,000 cu yd of soil. The operation should be fairly simple and can be accomplished by stripping soil from around the periphery with a bulldozer and shoving it up onto the existing slope. The absence of significant vegetation in the surrounding topsoil and on the dike slope should expedite the operation. The peripheral fence must be removed and replaced along the length of dike addressed.

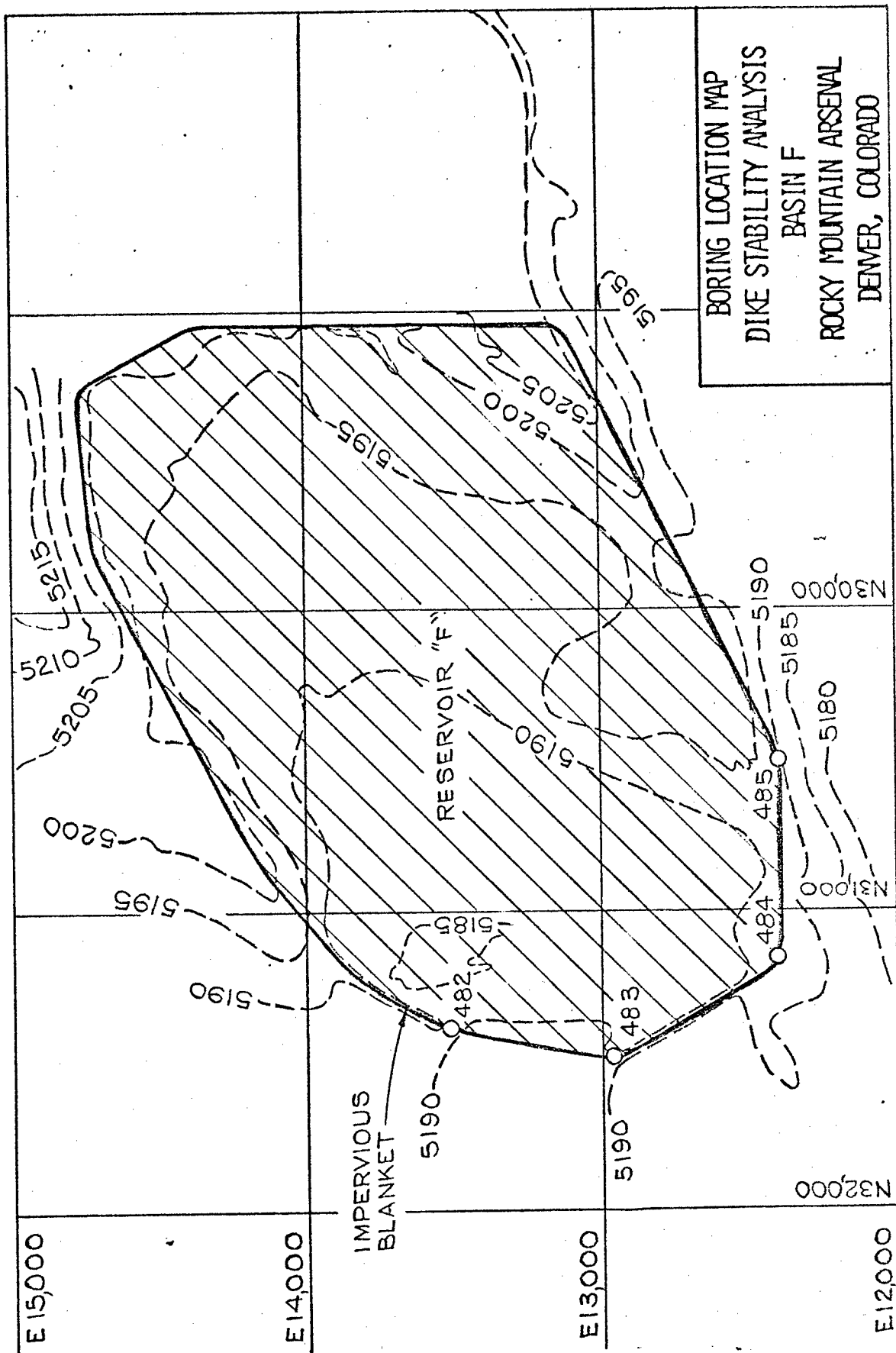
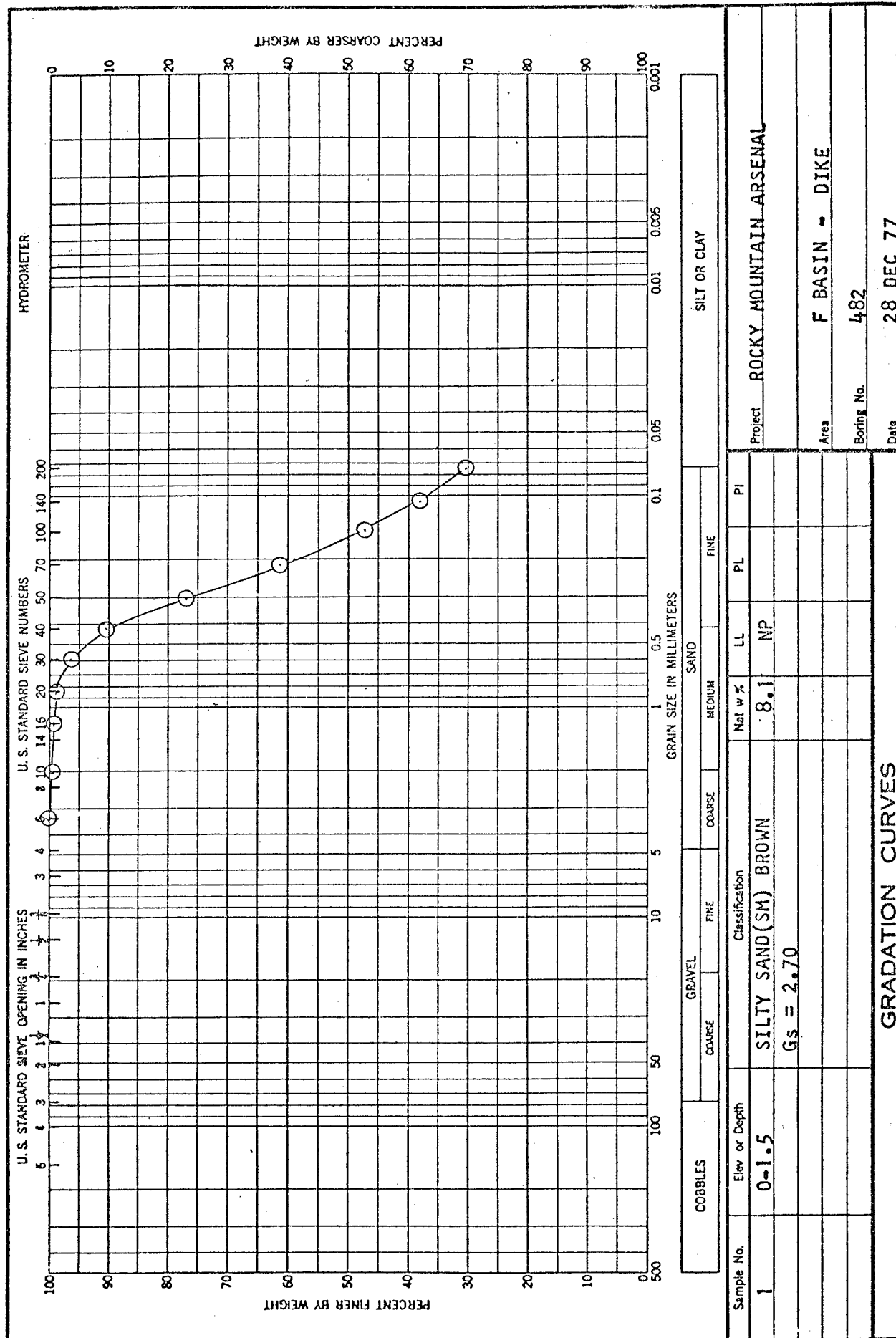


Figure 1



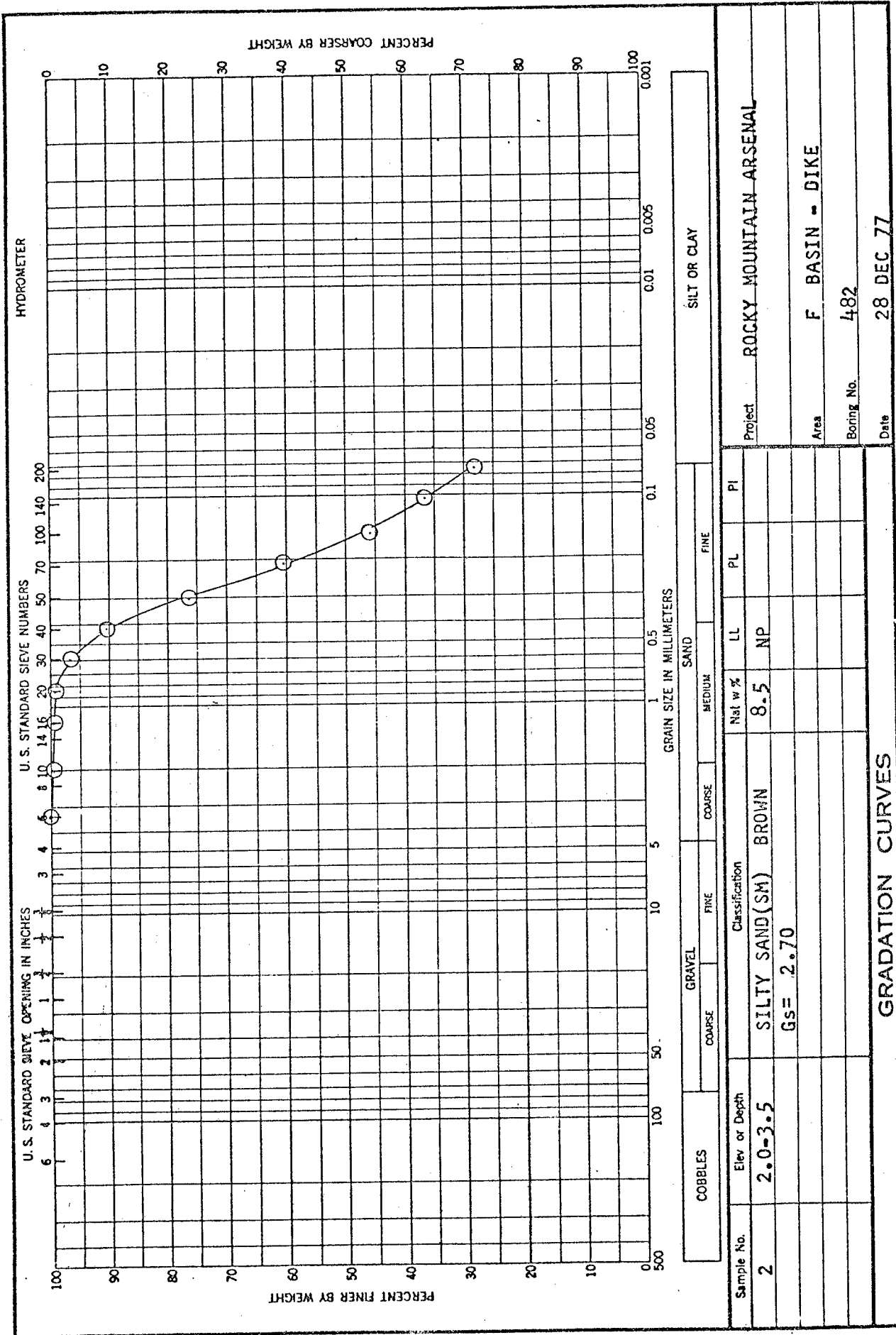


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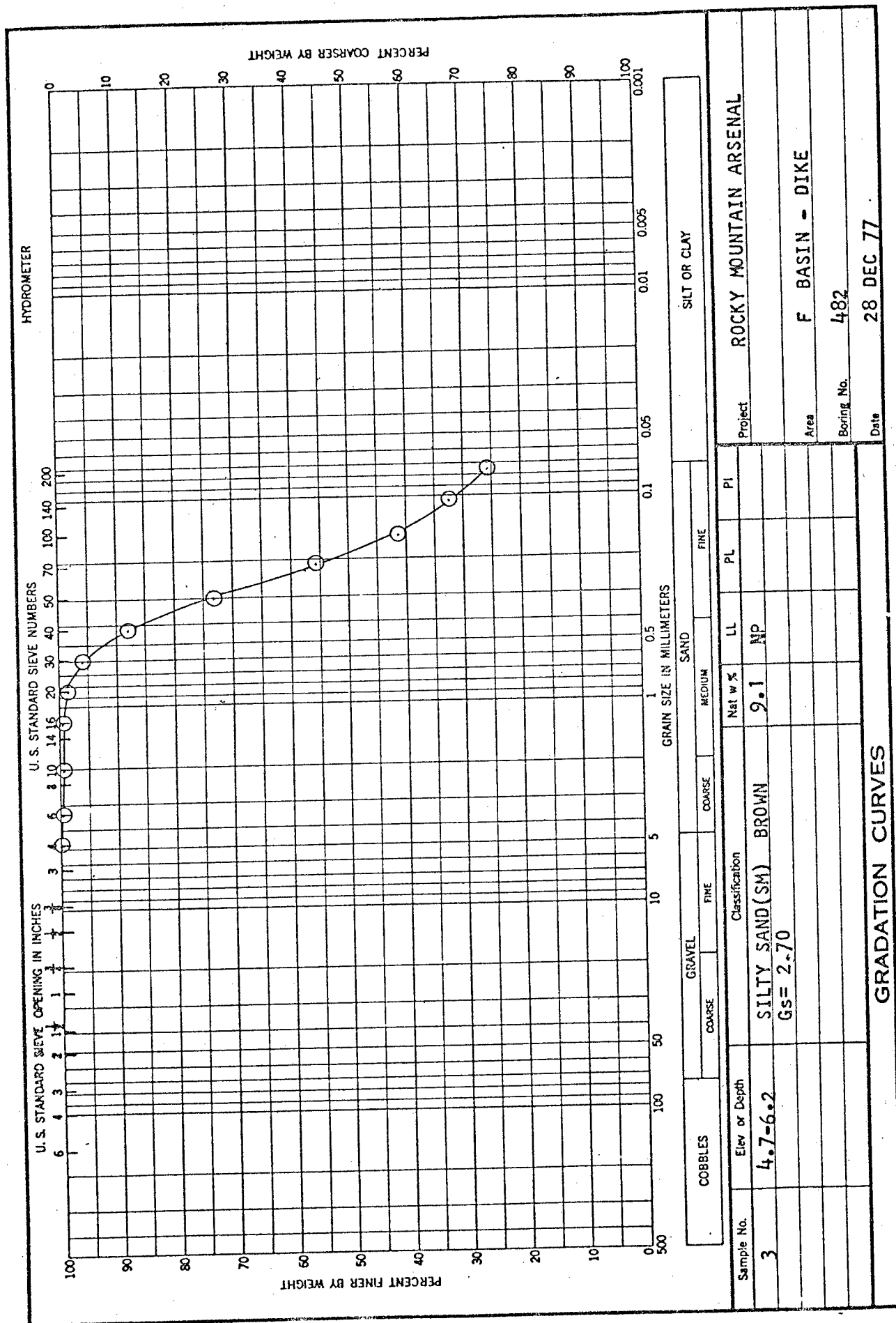
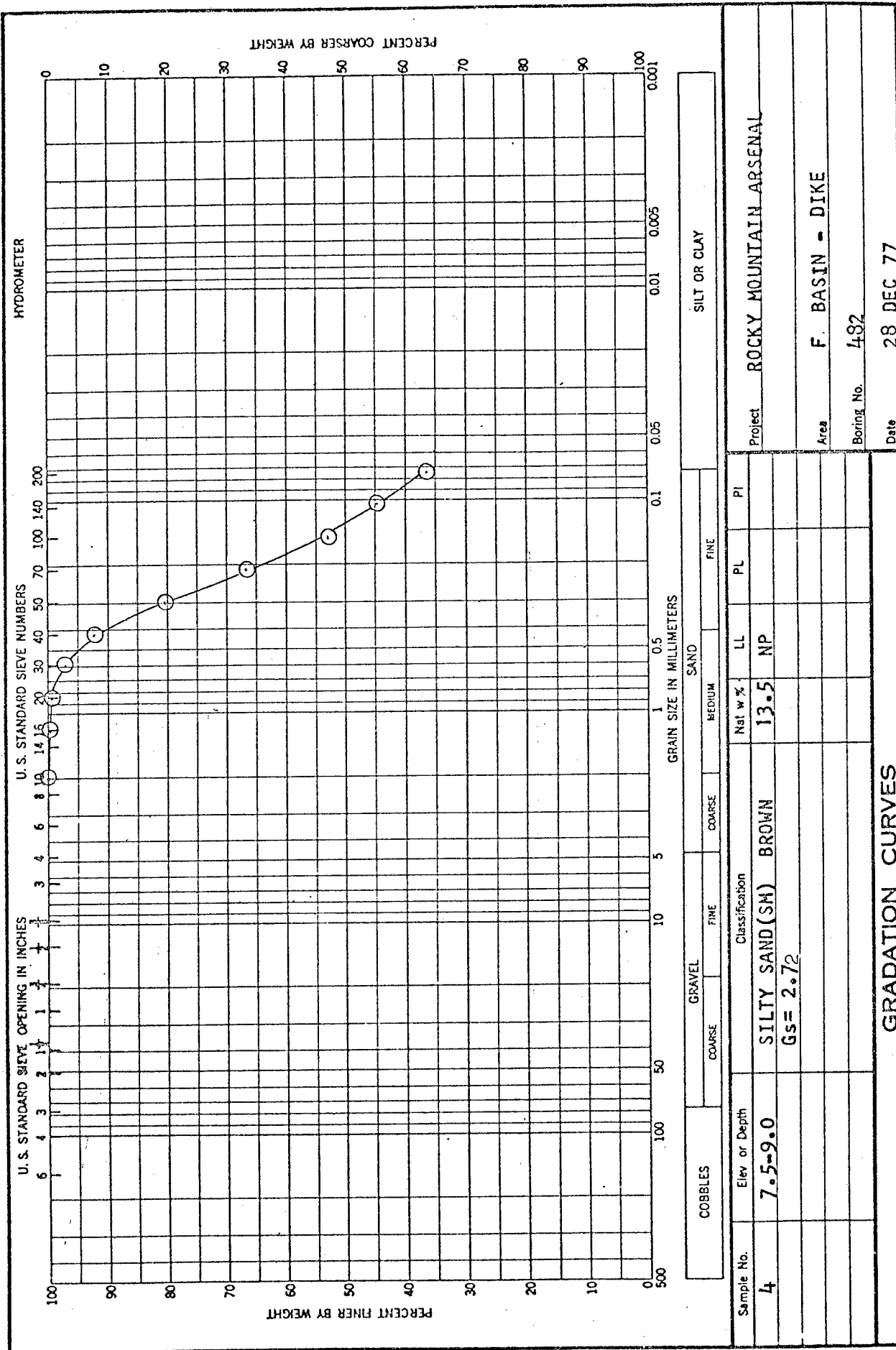
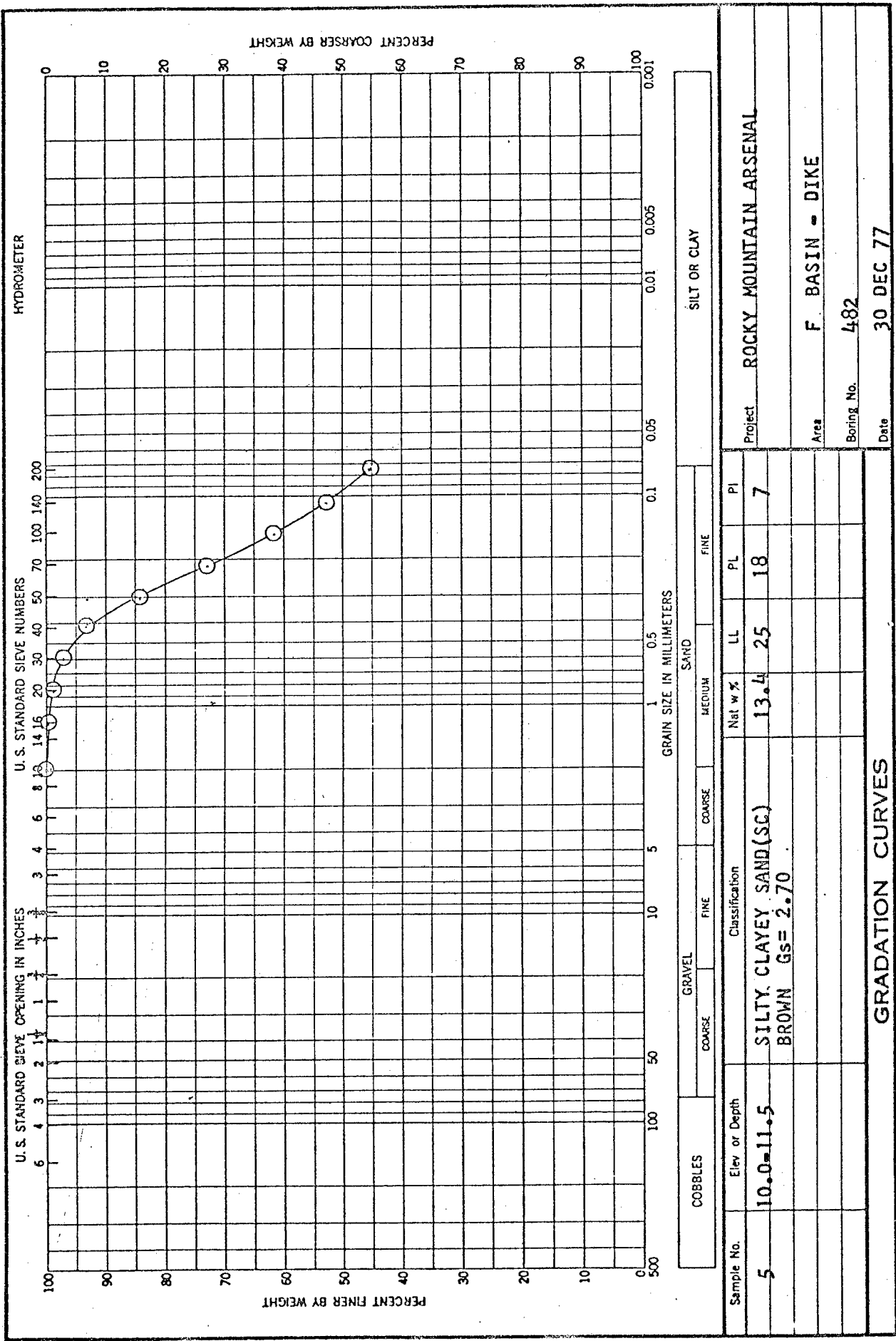


Figure 4



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Figure 5



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Figure 6

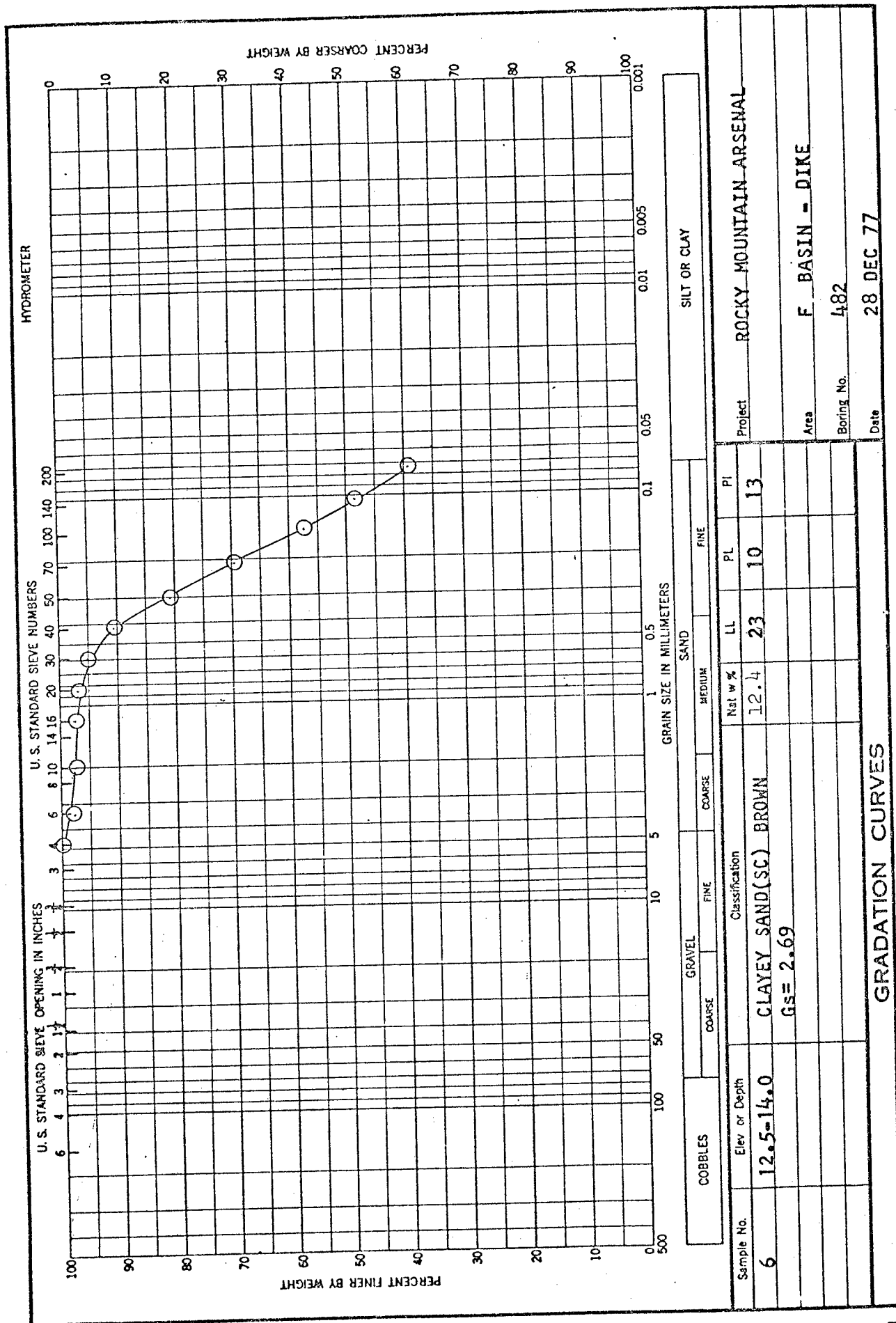
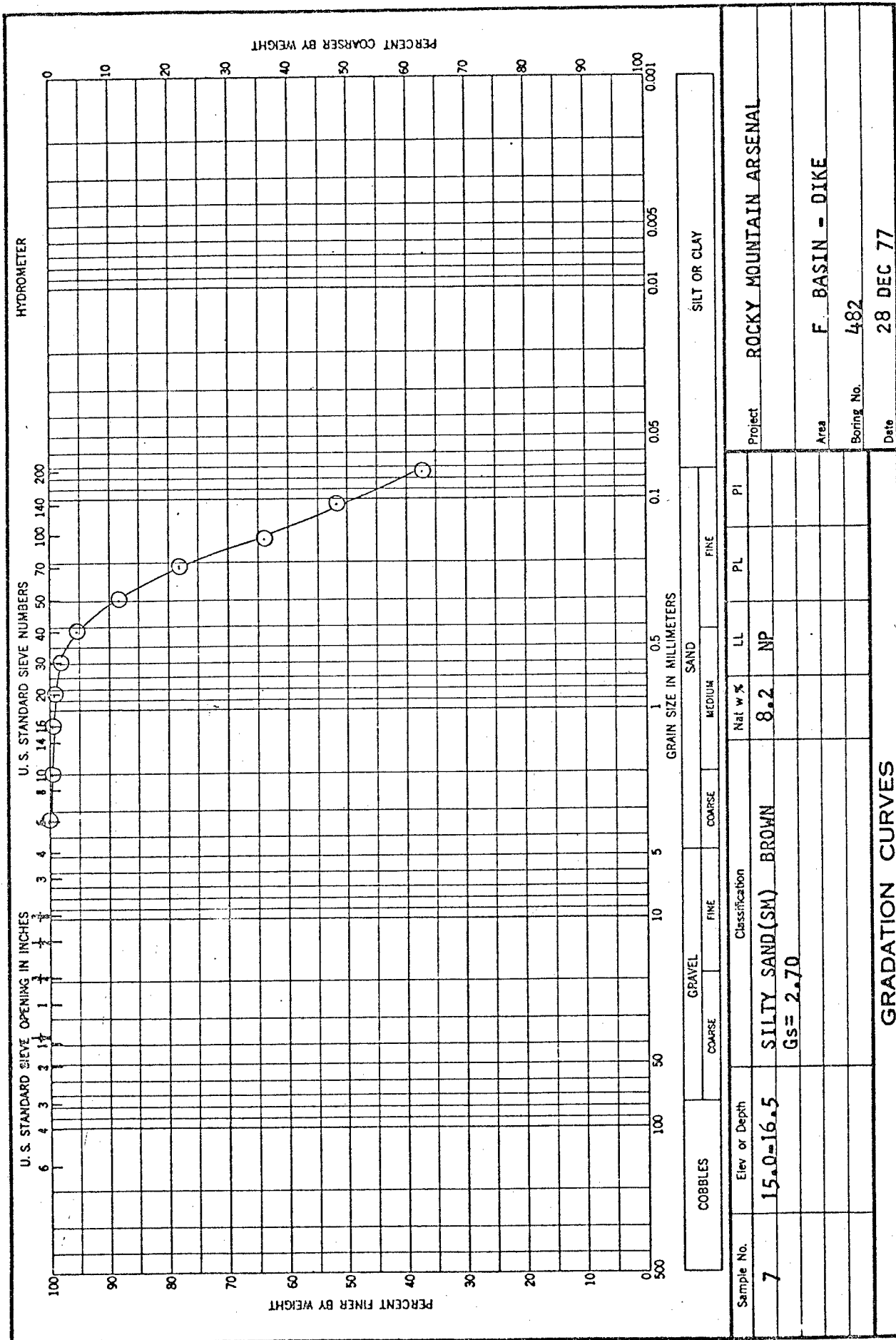
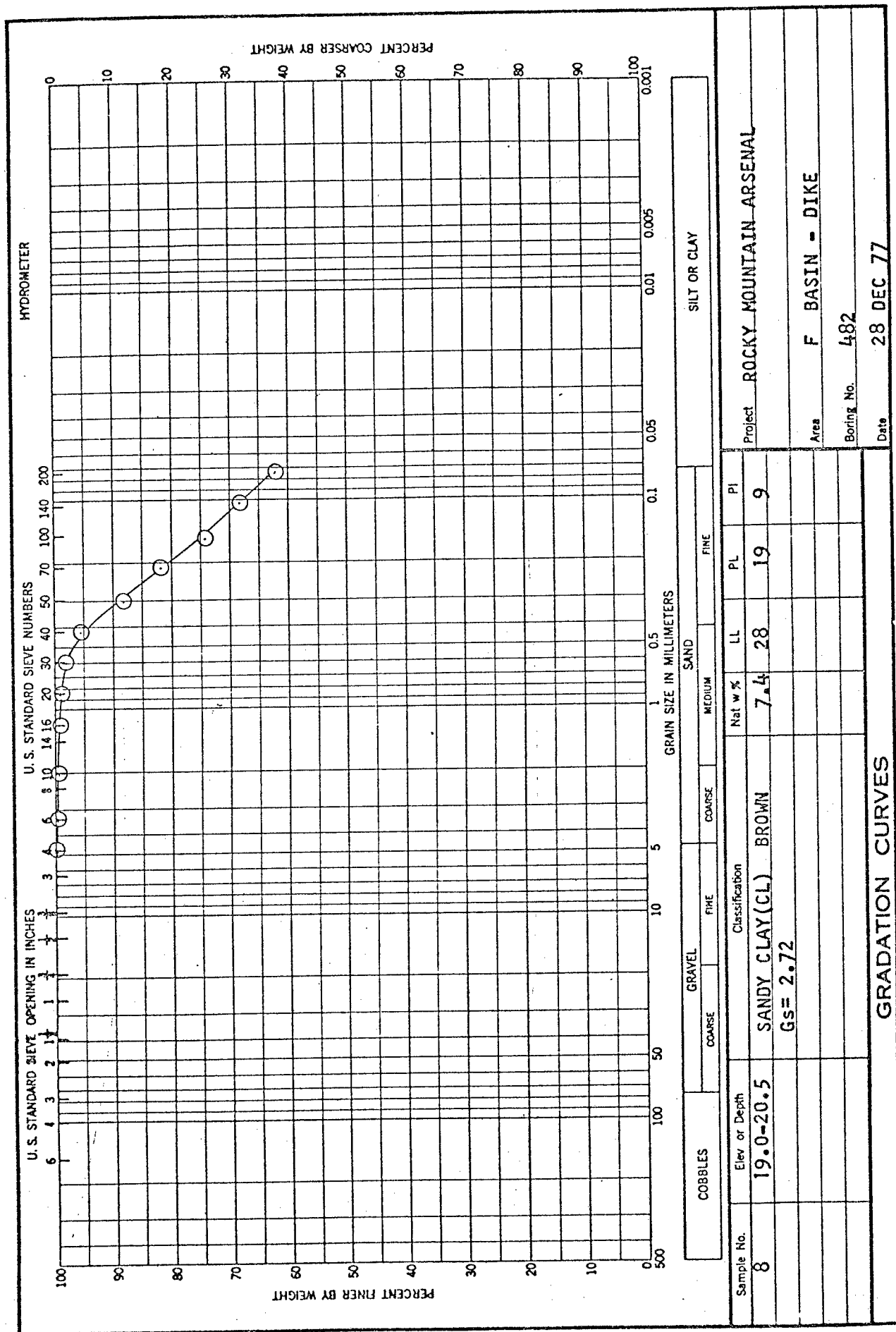


Figure 7





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Figure 9

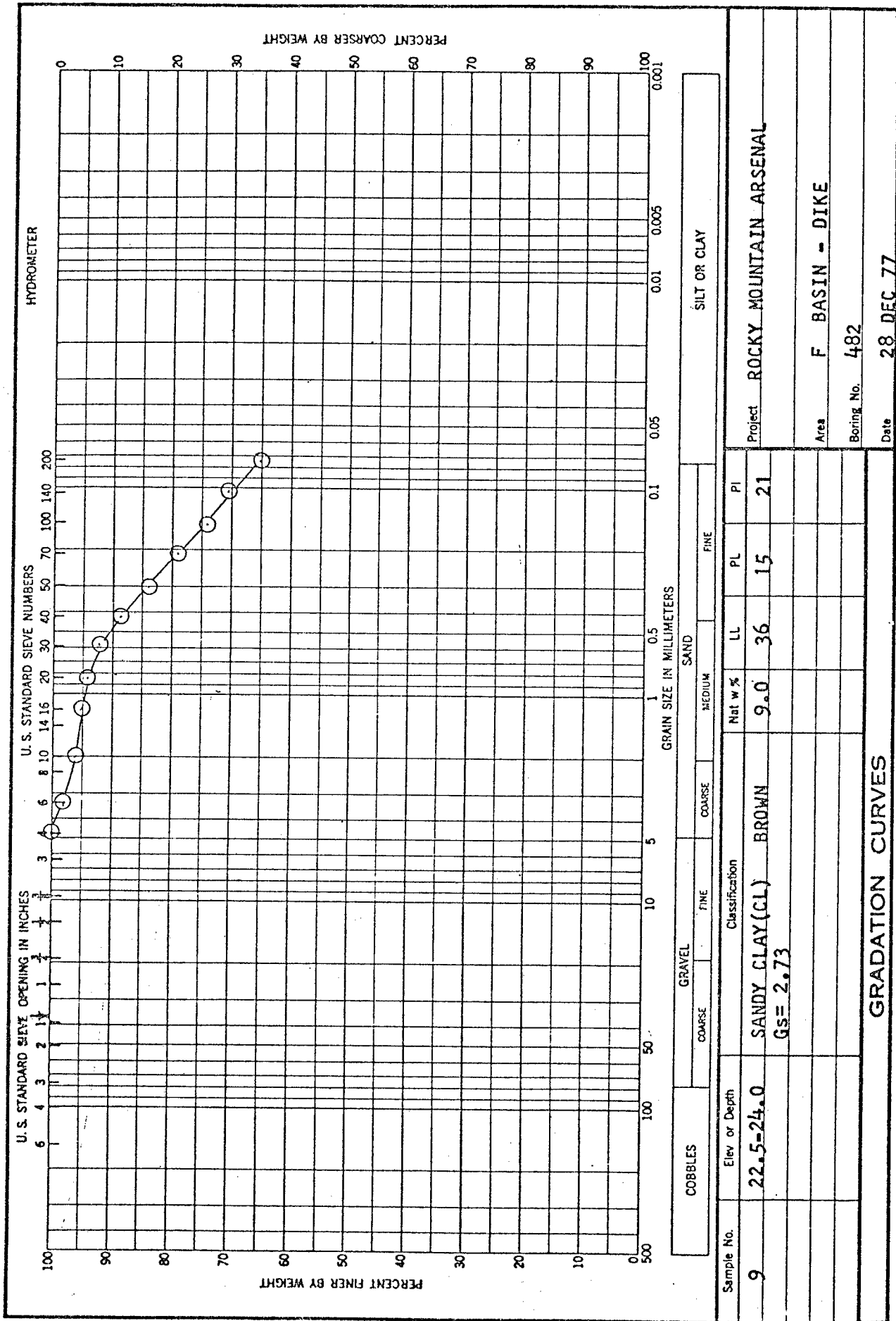


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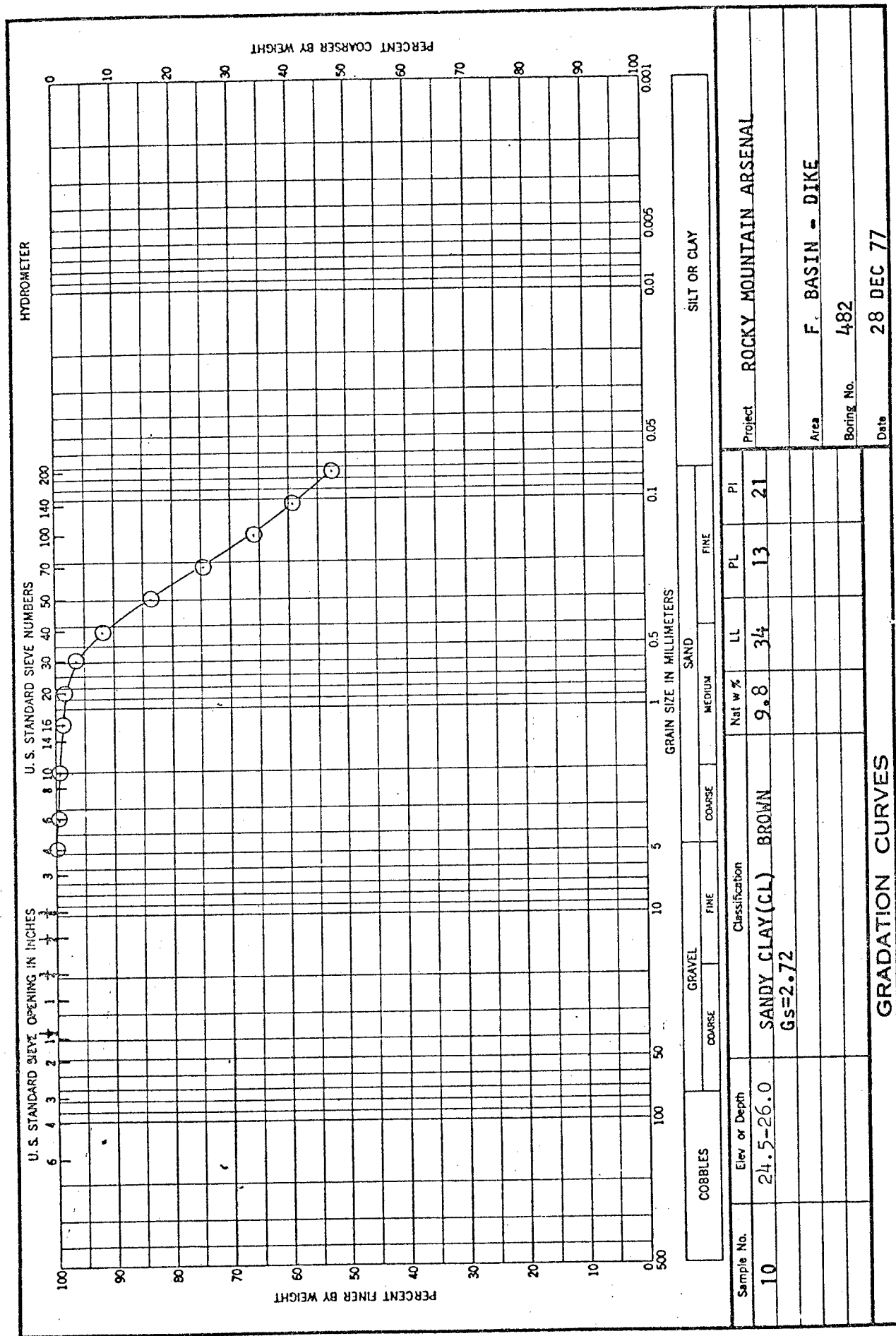


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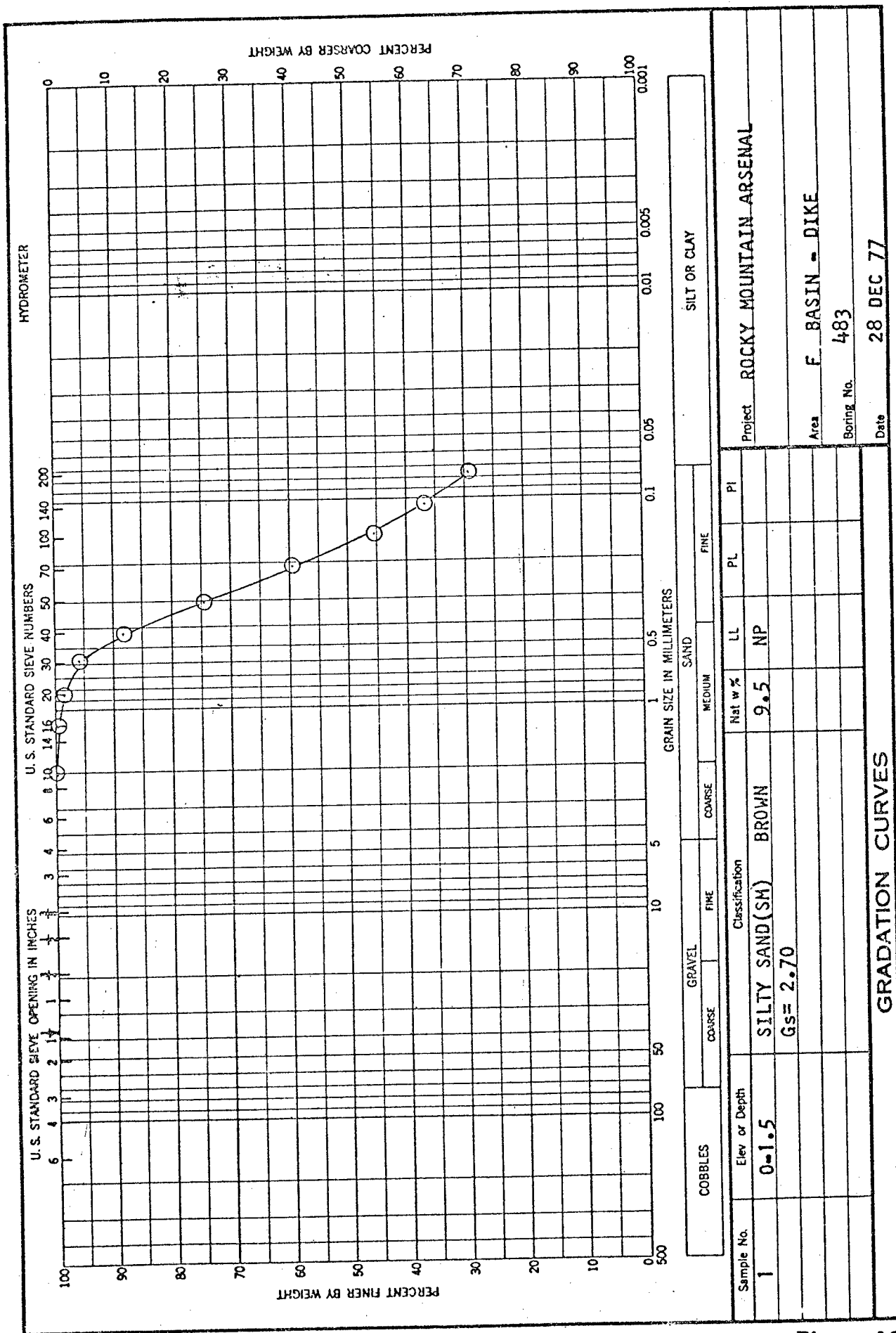


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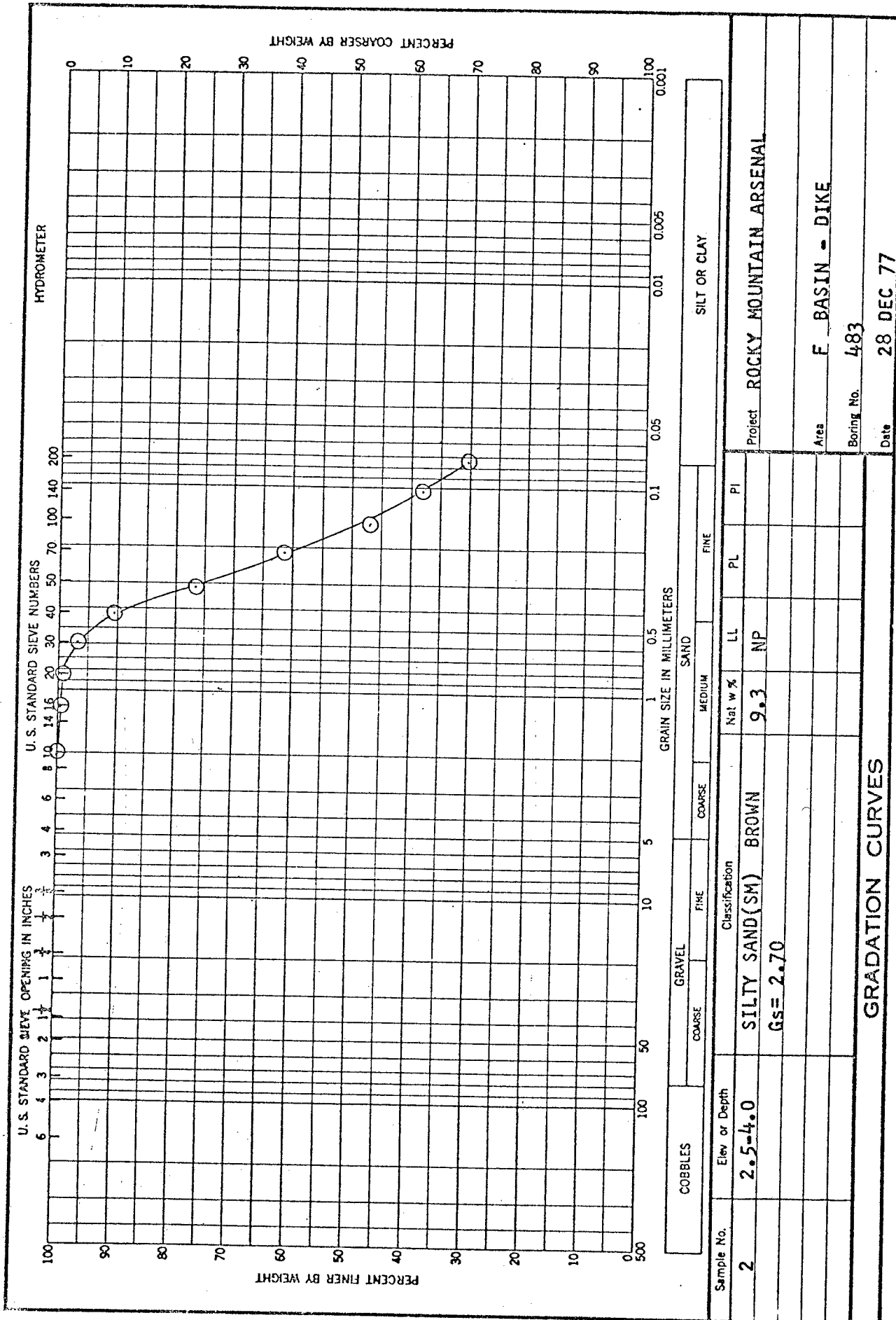
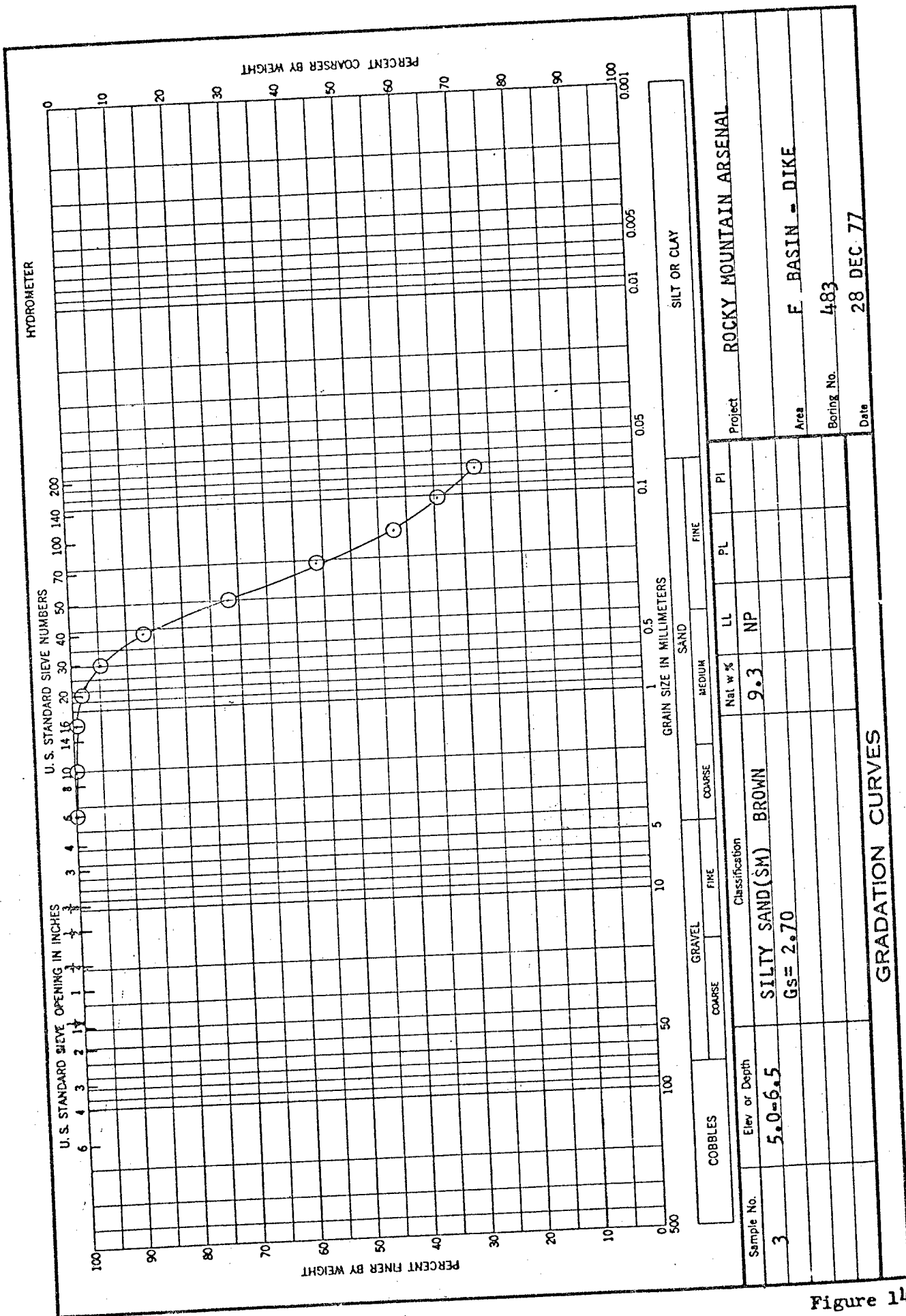
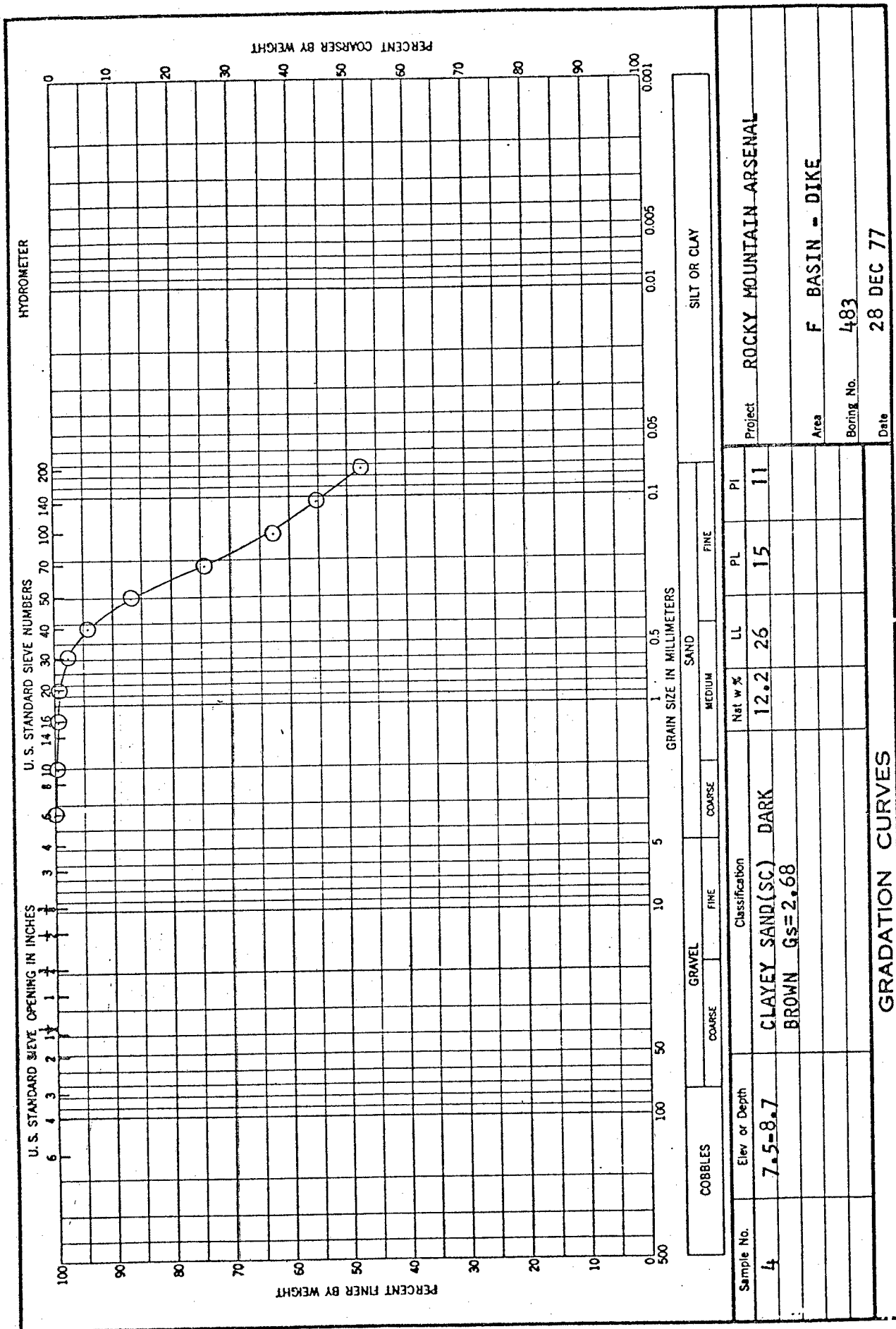


Figure 13





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Figure 15

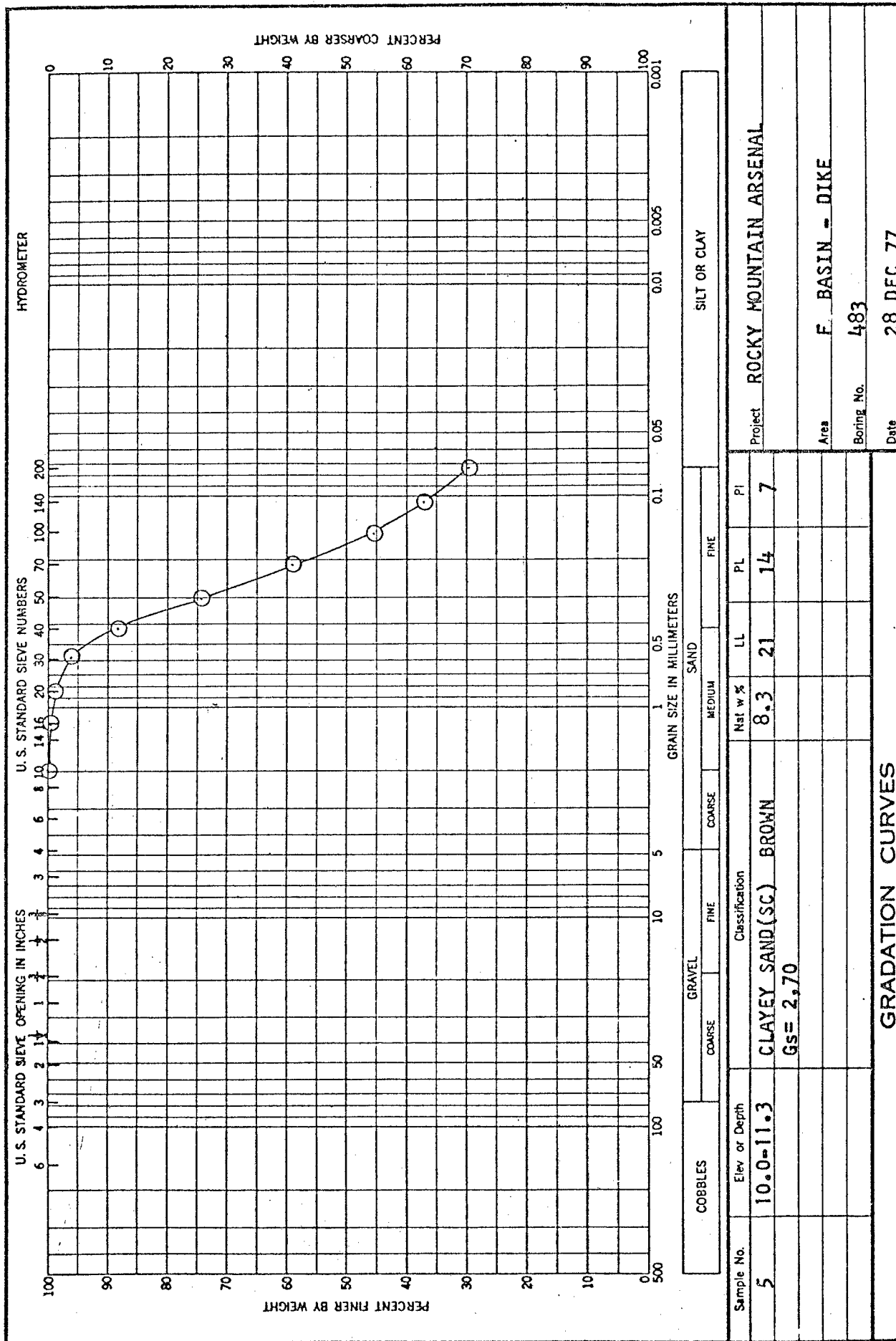


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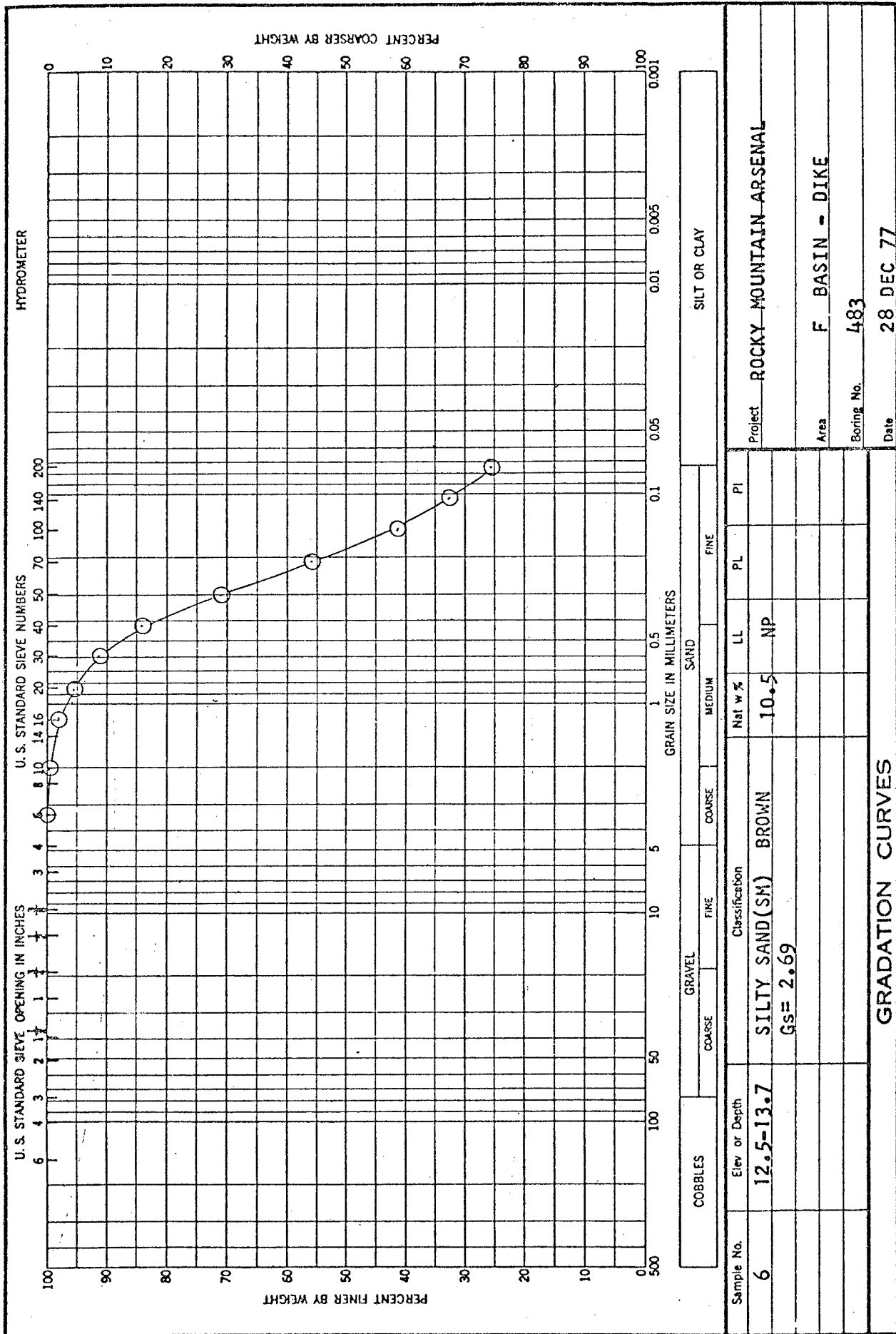
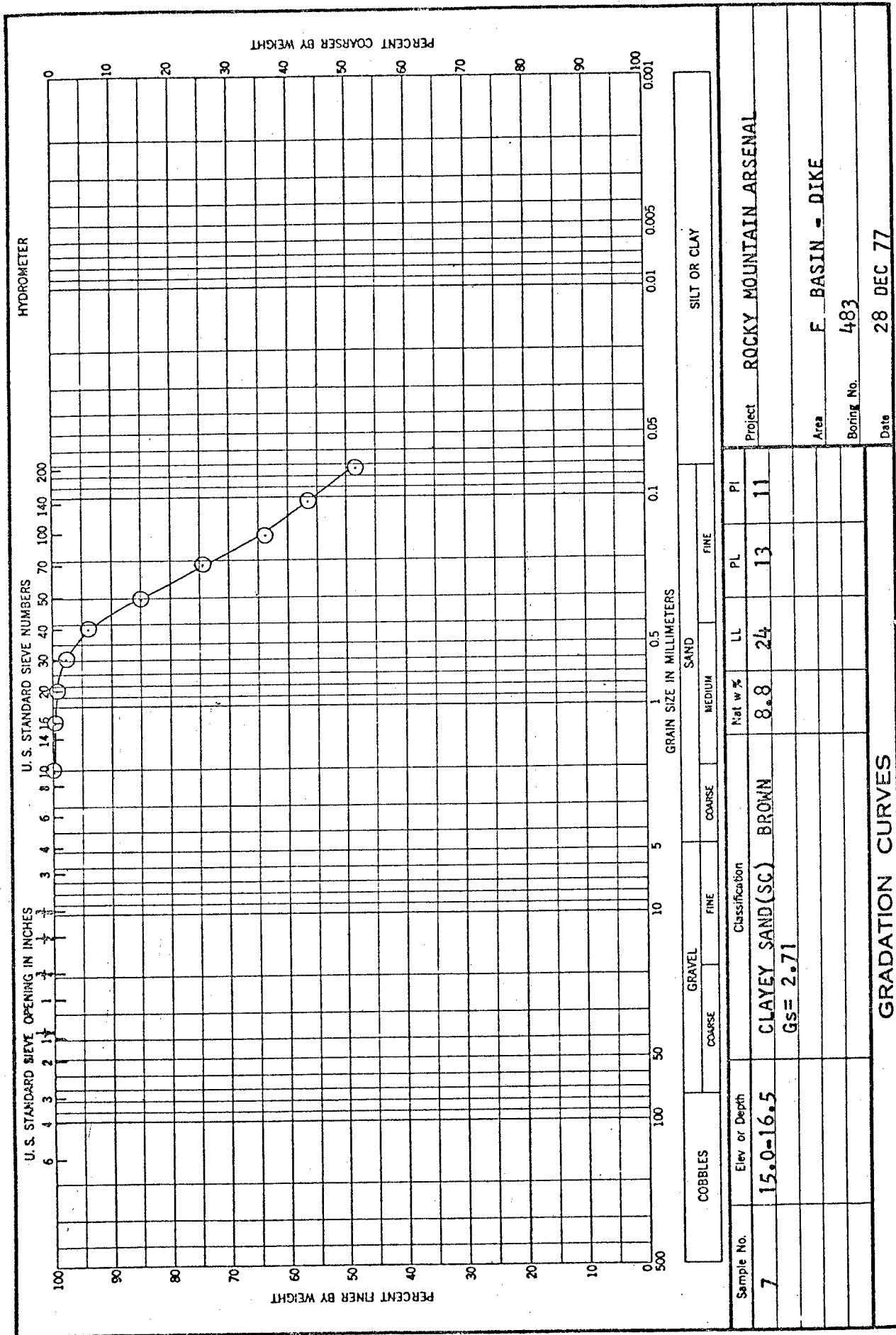


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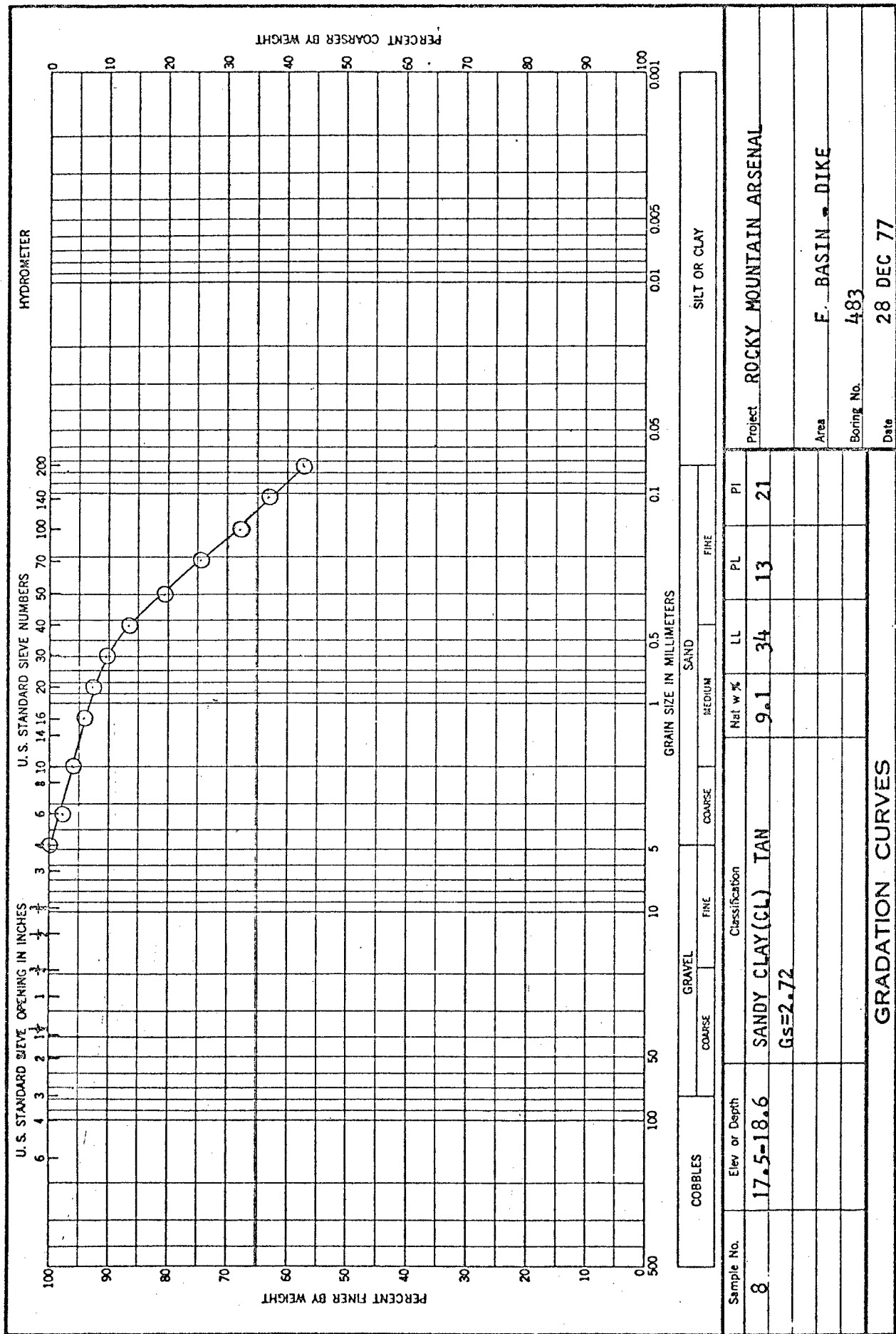
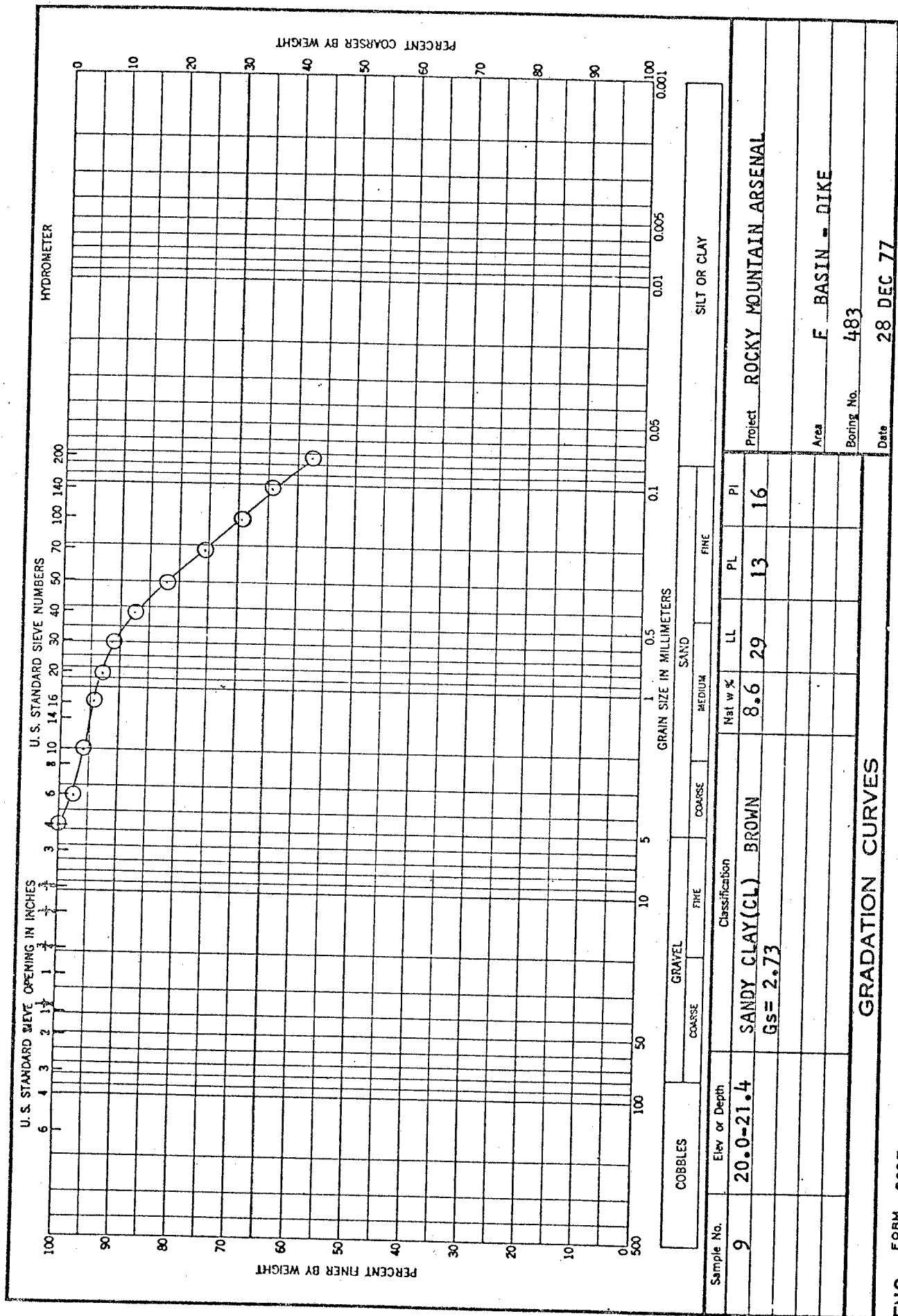
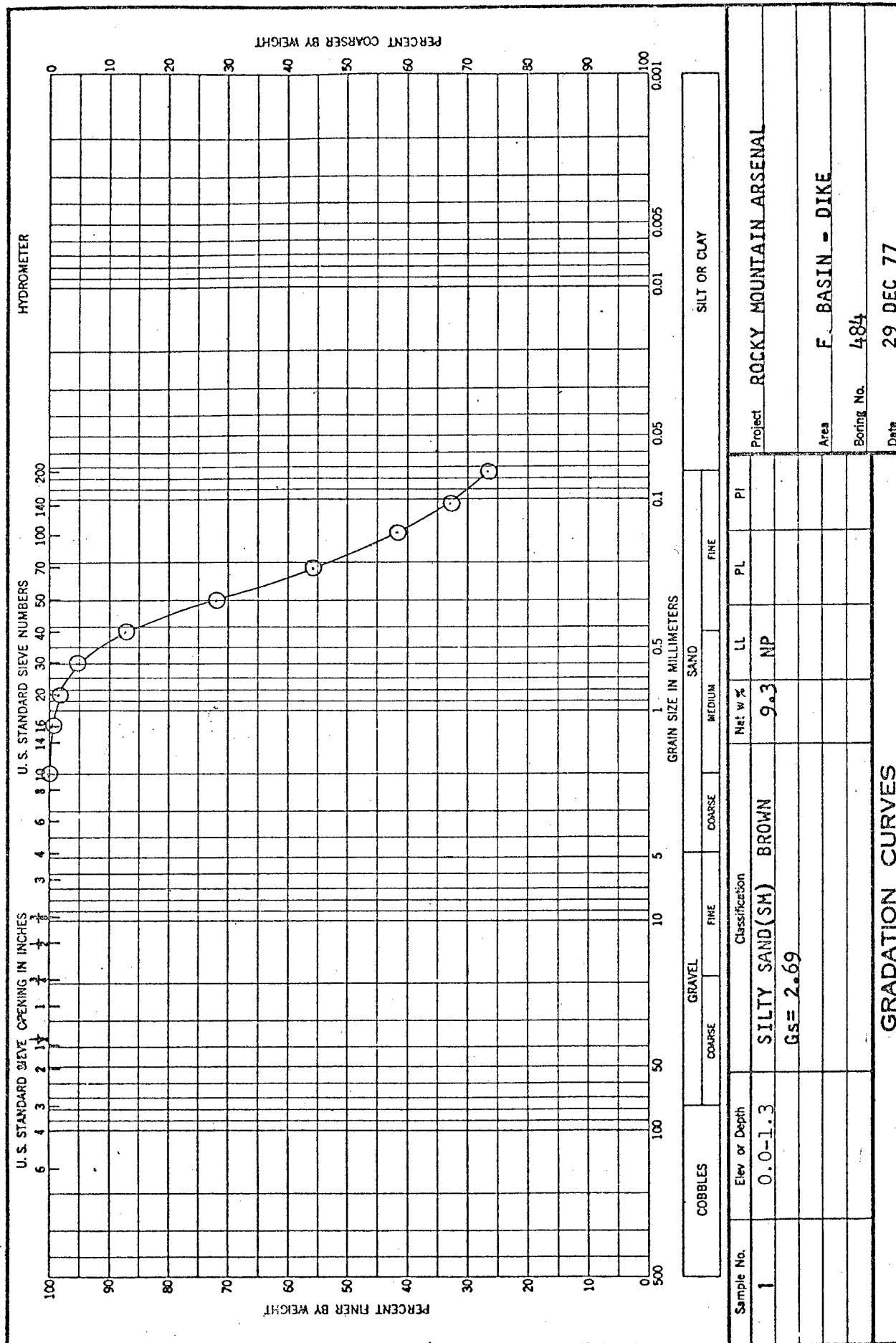


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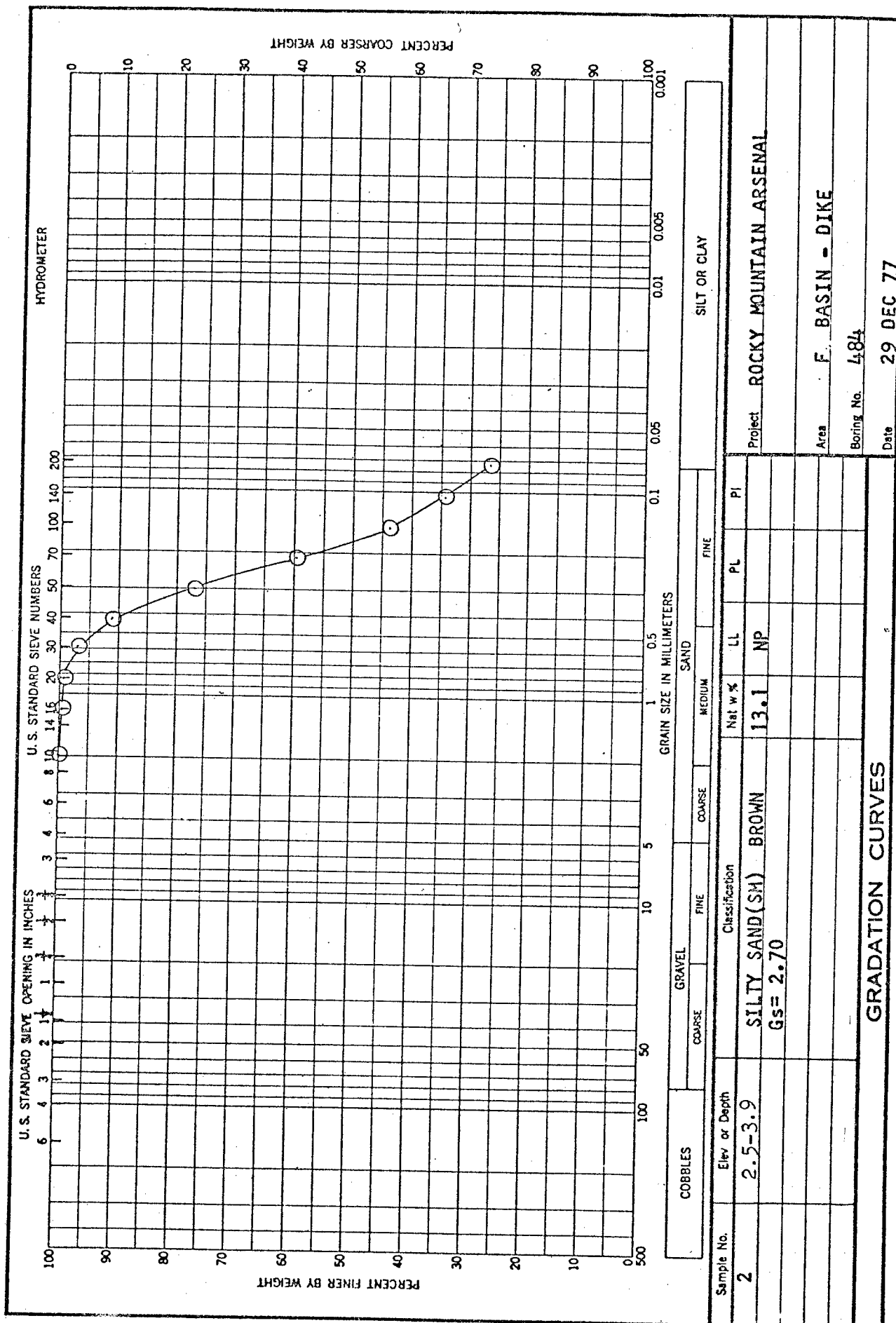
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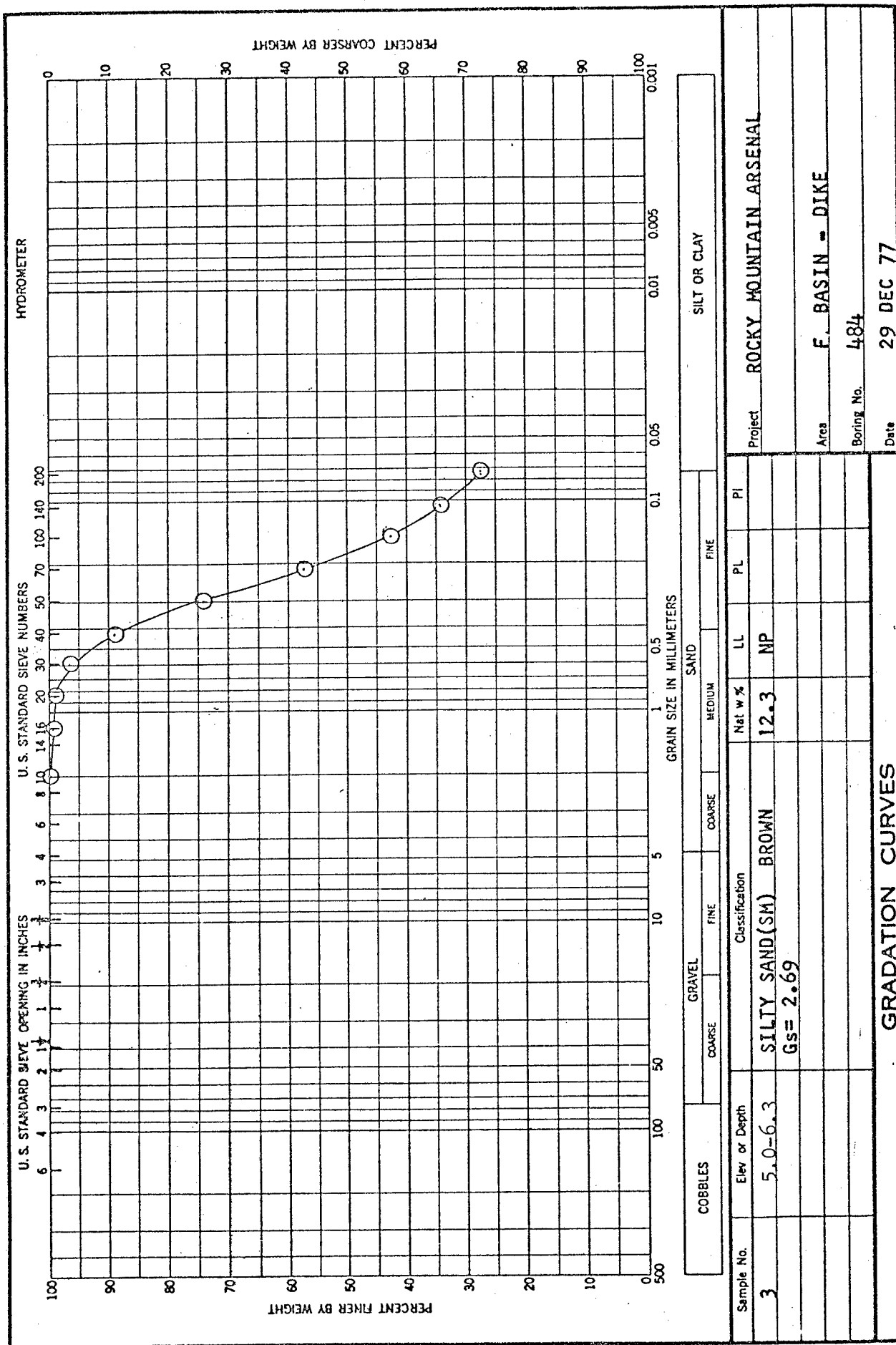
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Figure 22.





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Figure 24

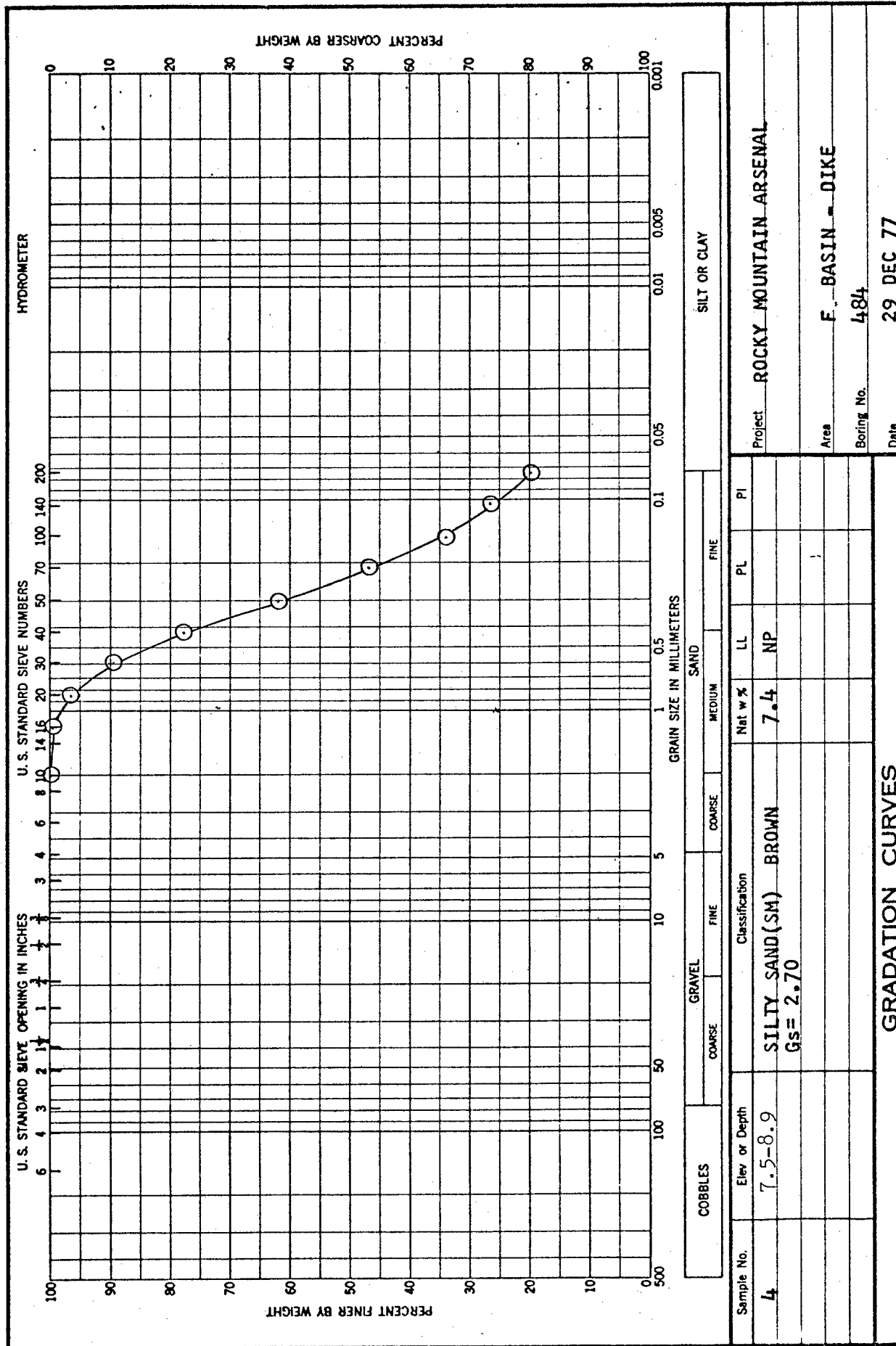


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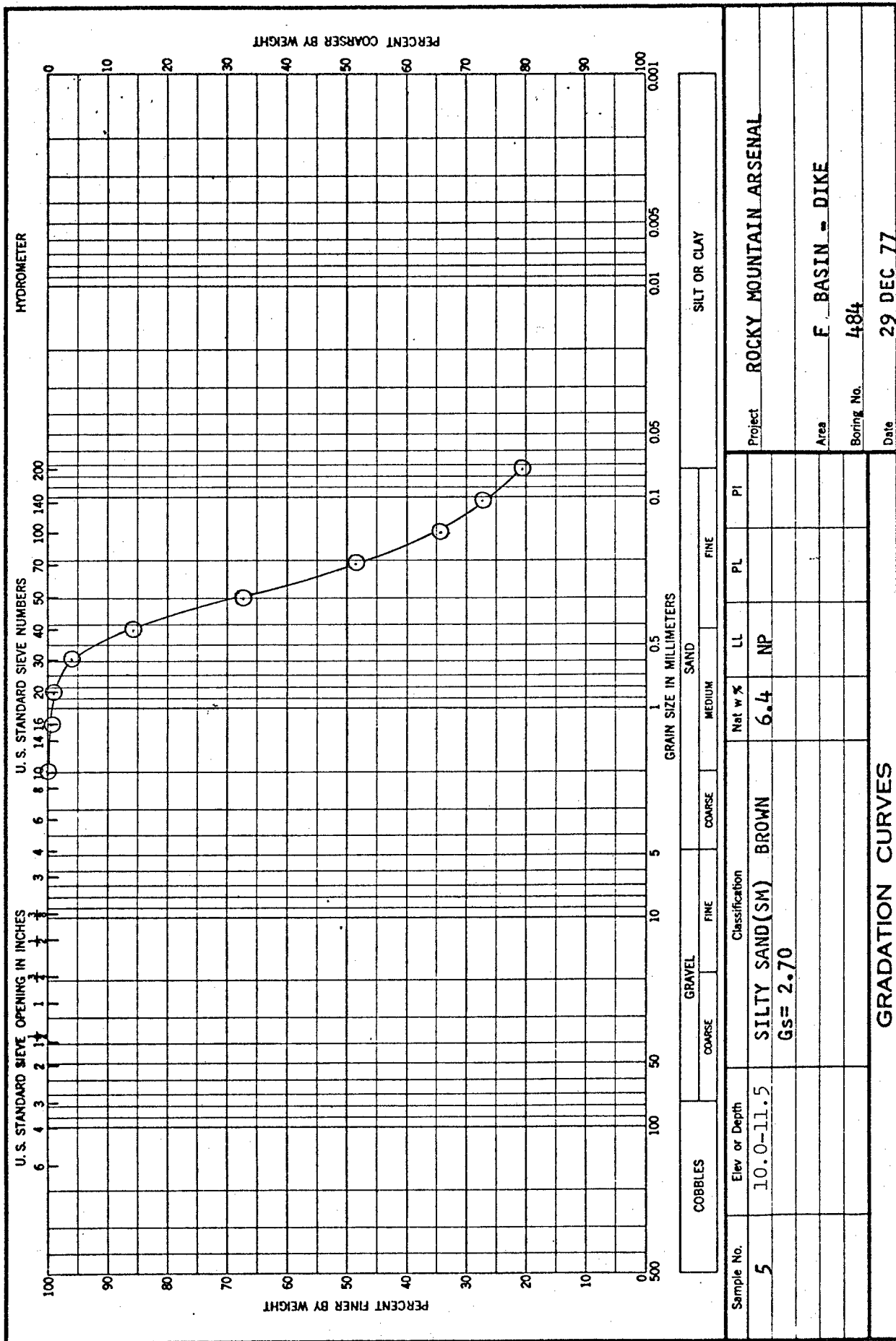
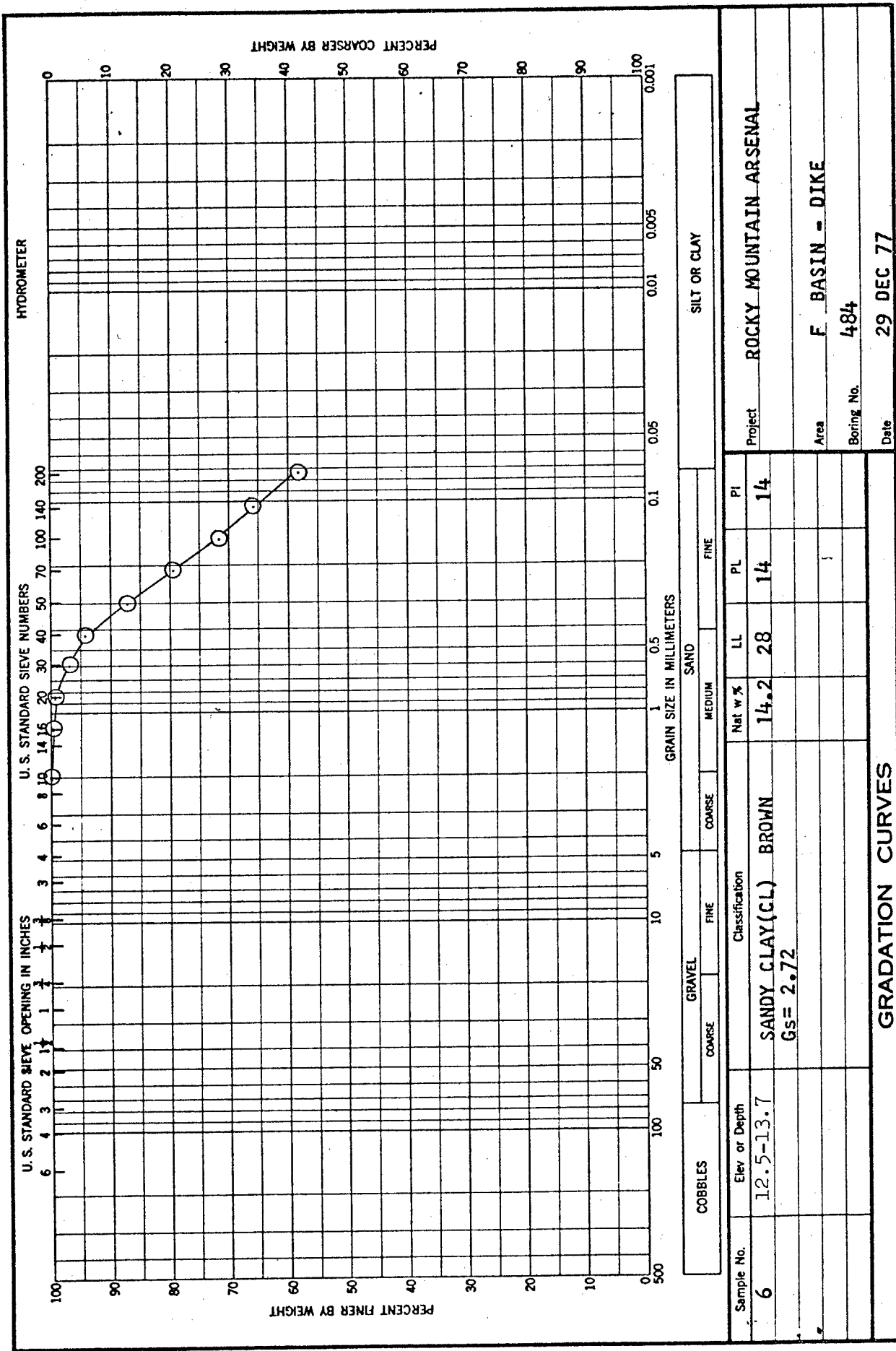


Figure 26



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Figure 27

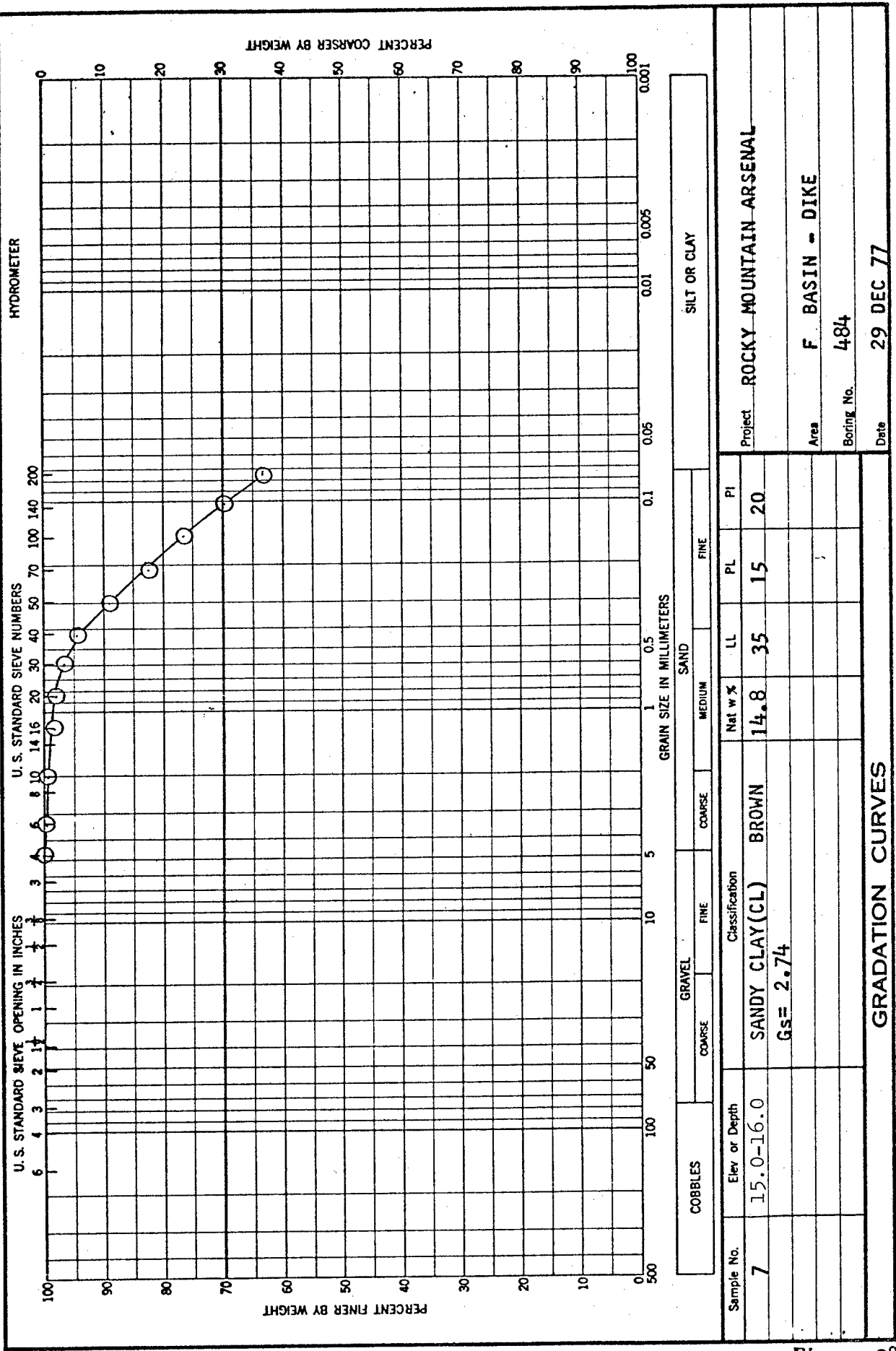


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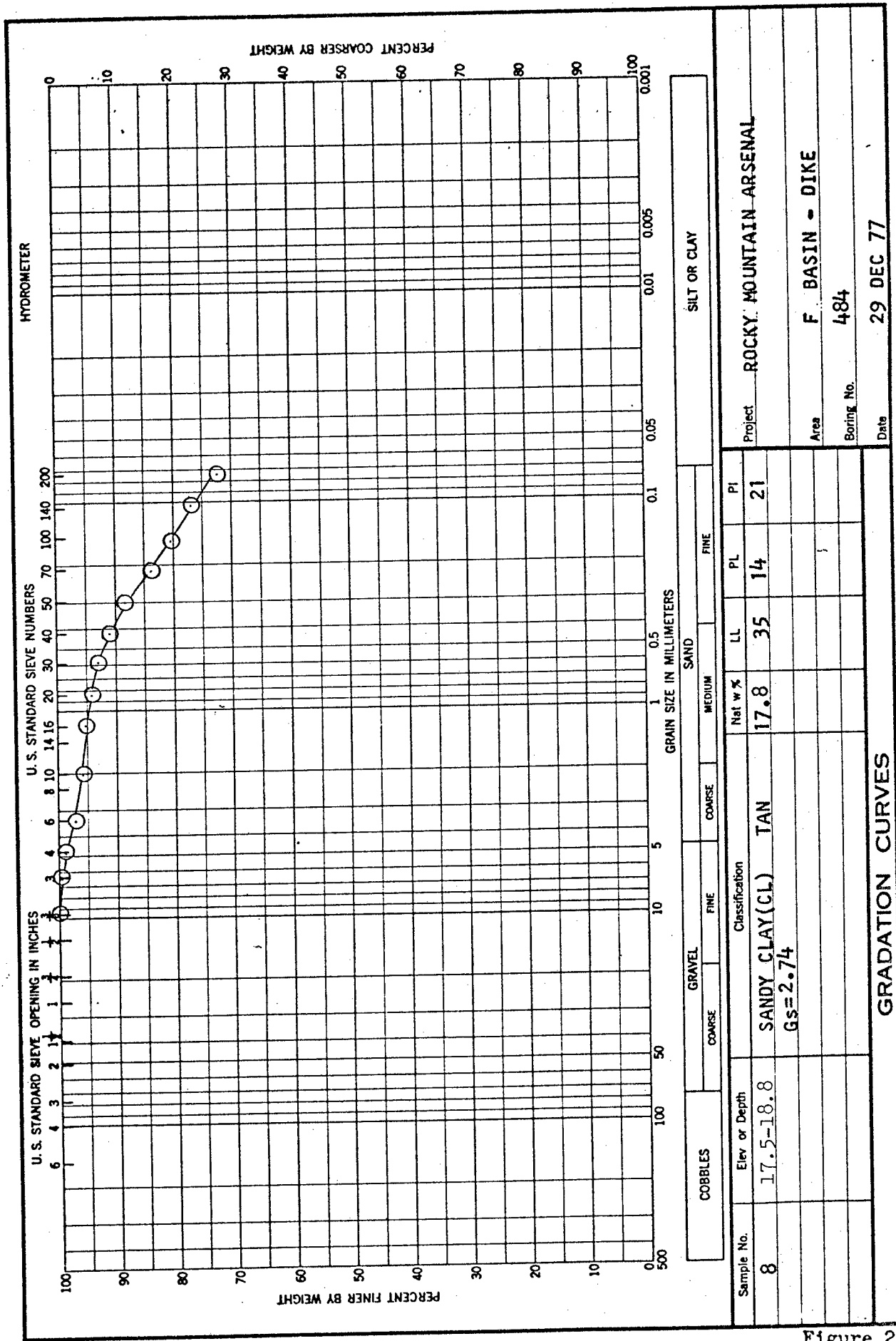


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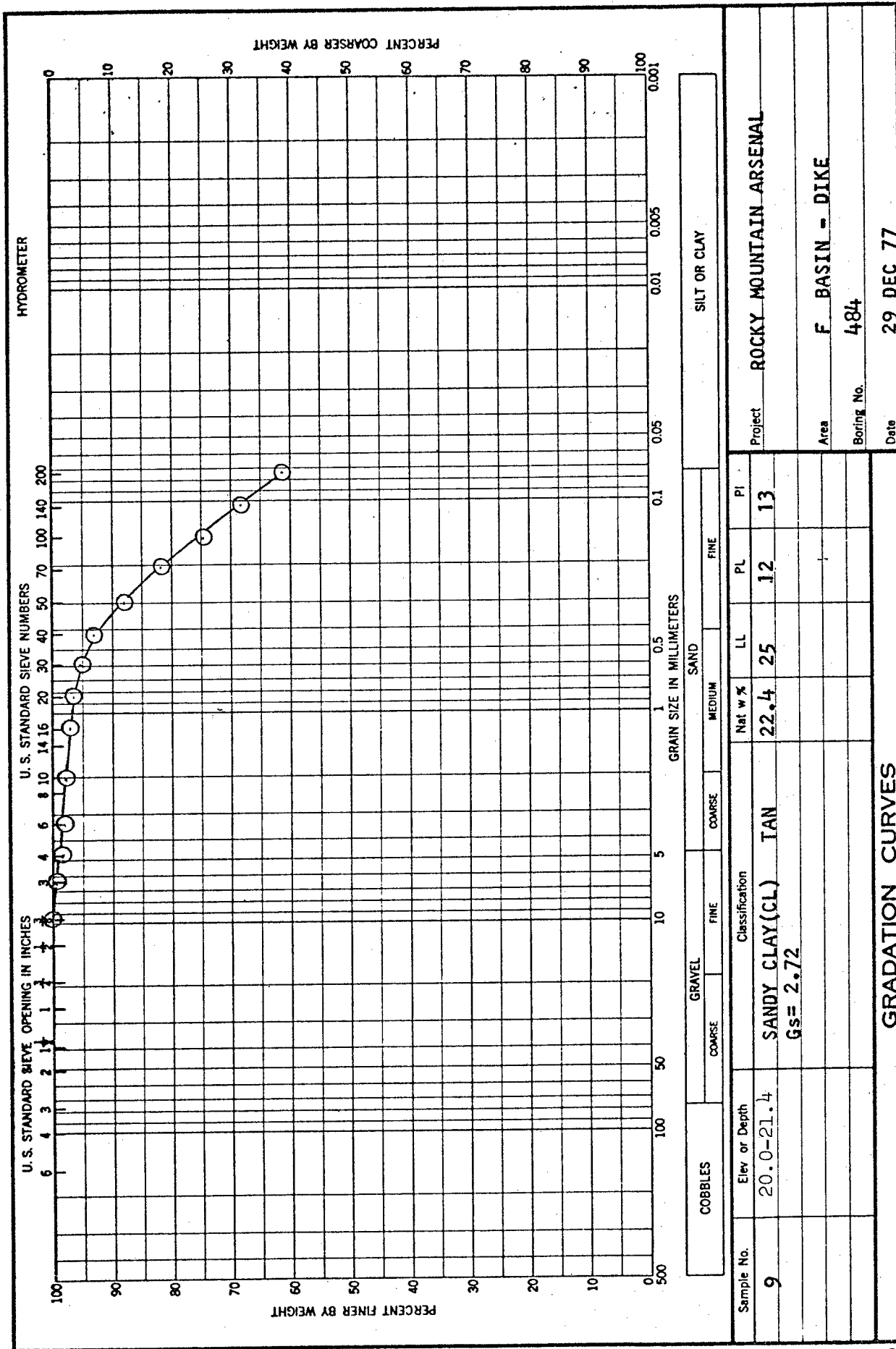
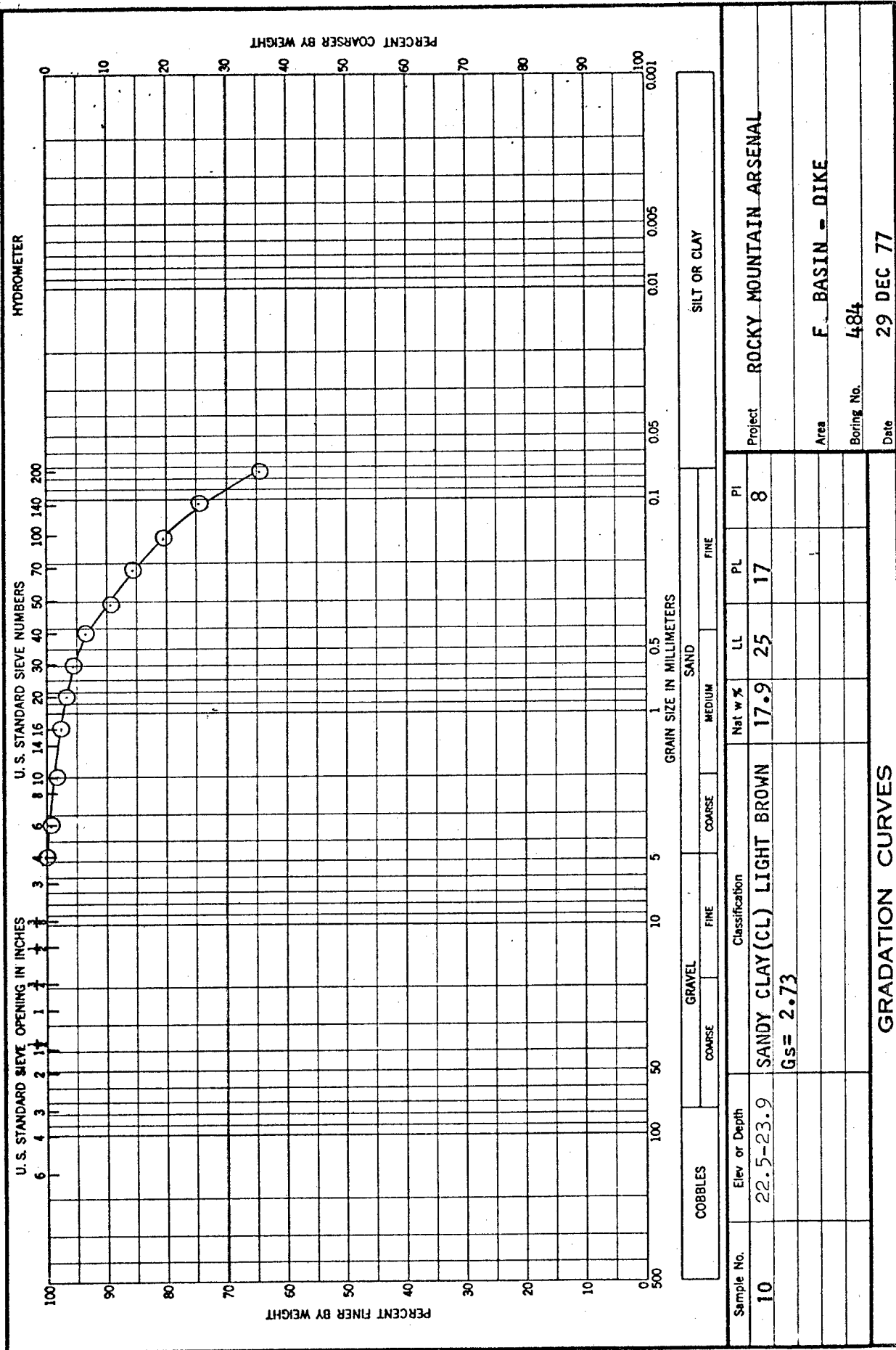


Figure 30



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Figure 31

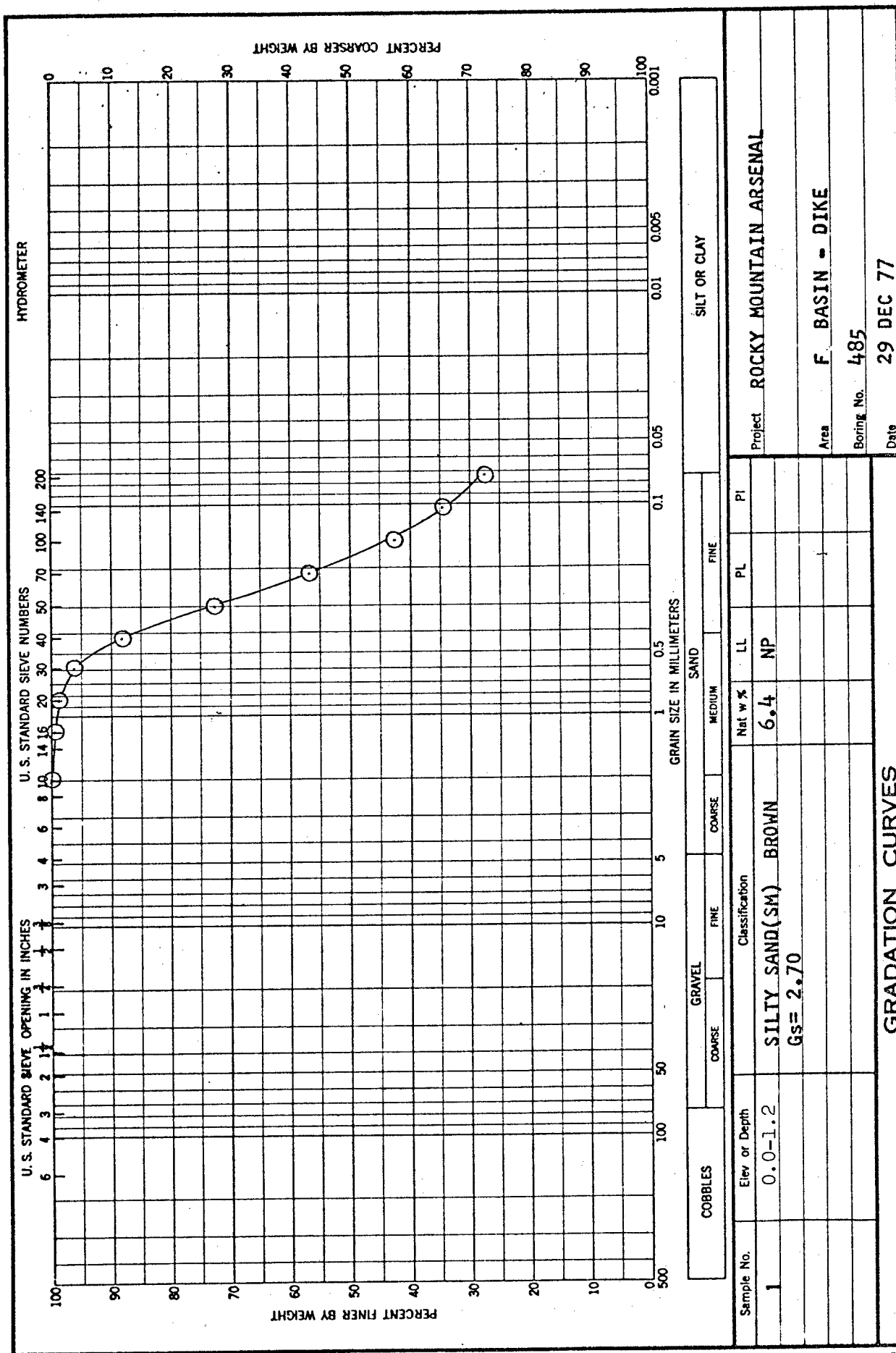


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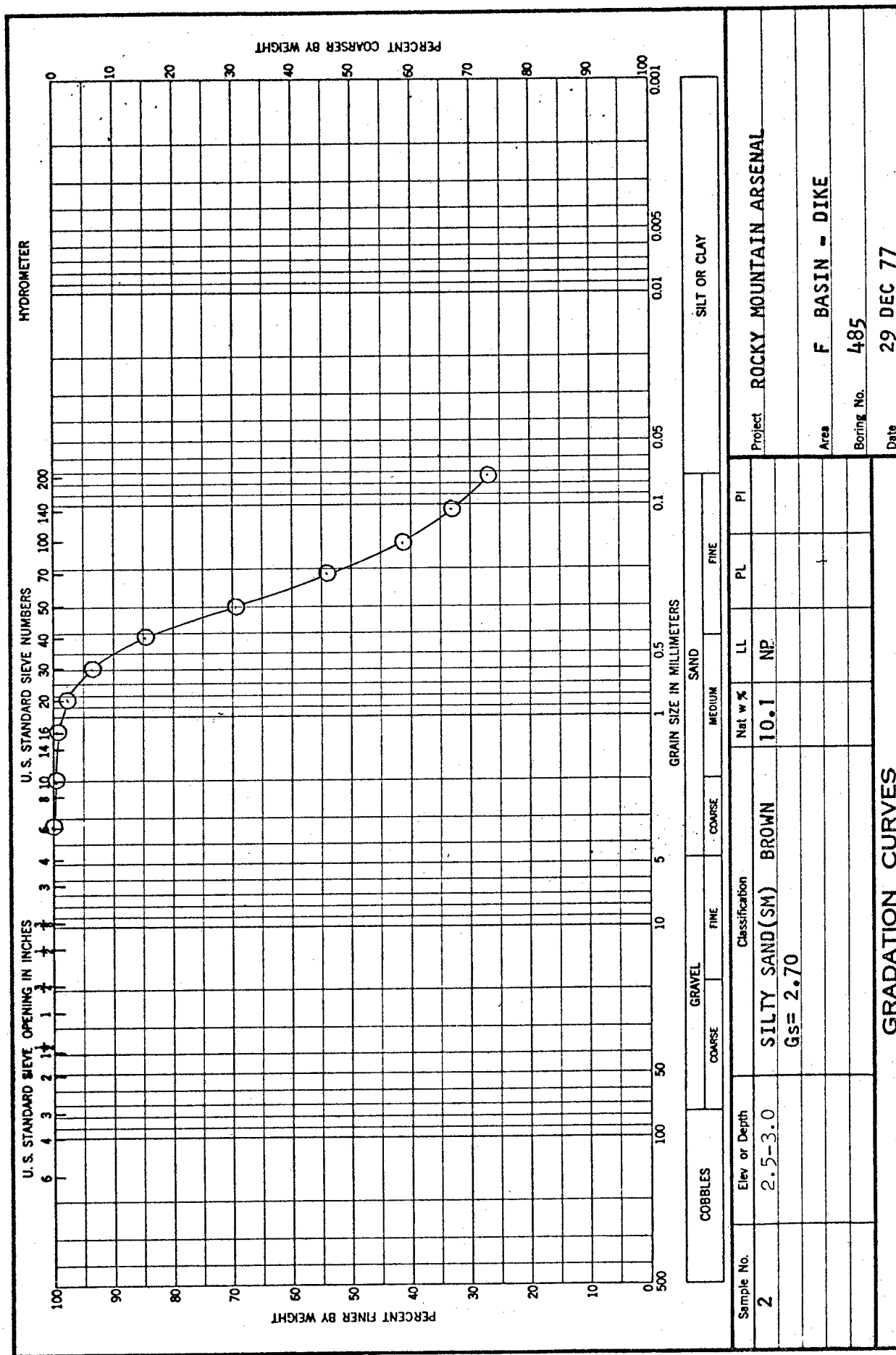


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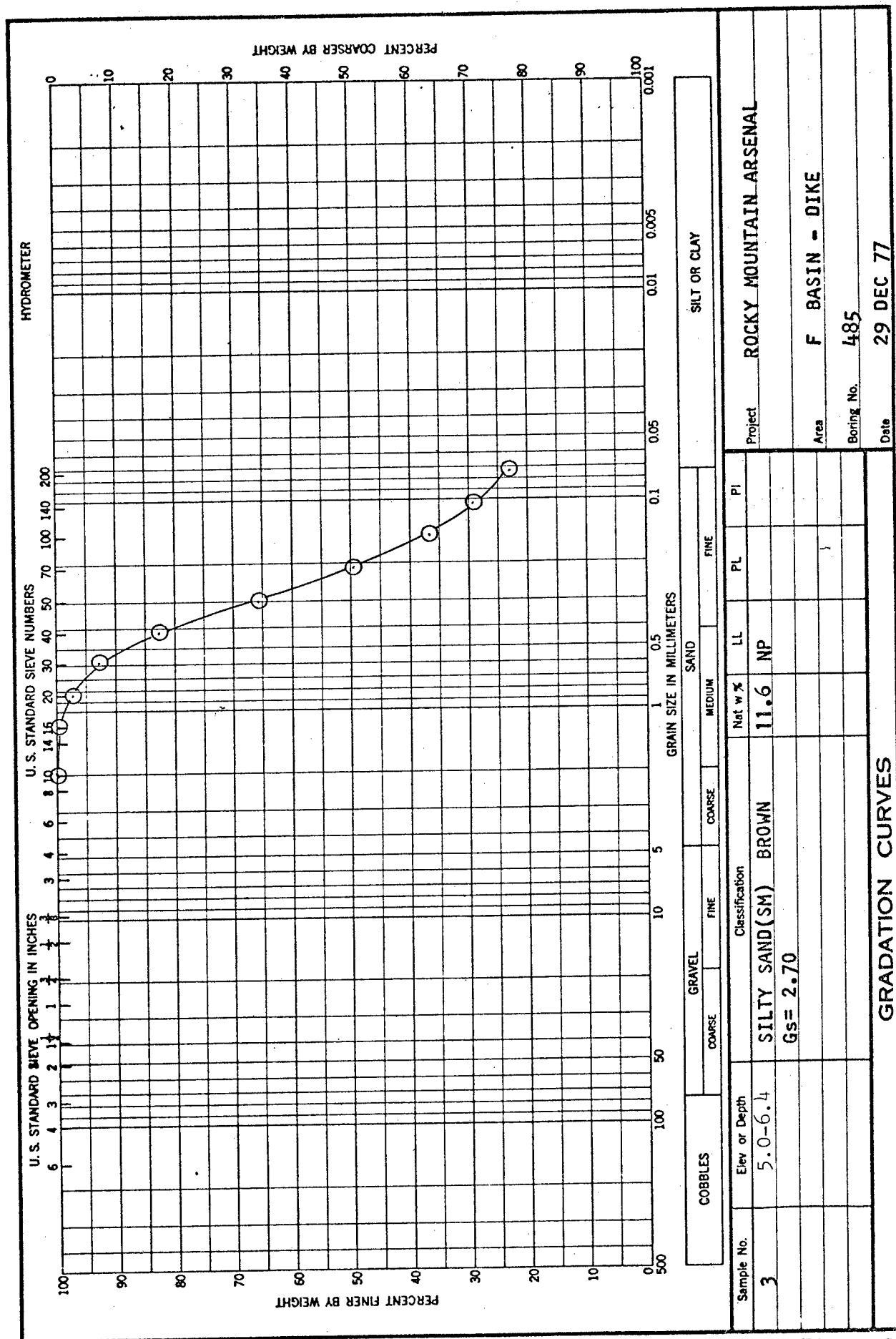


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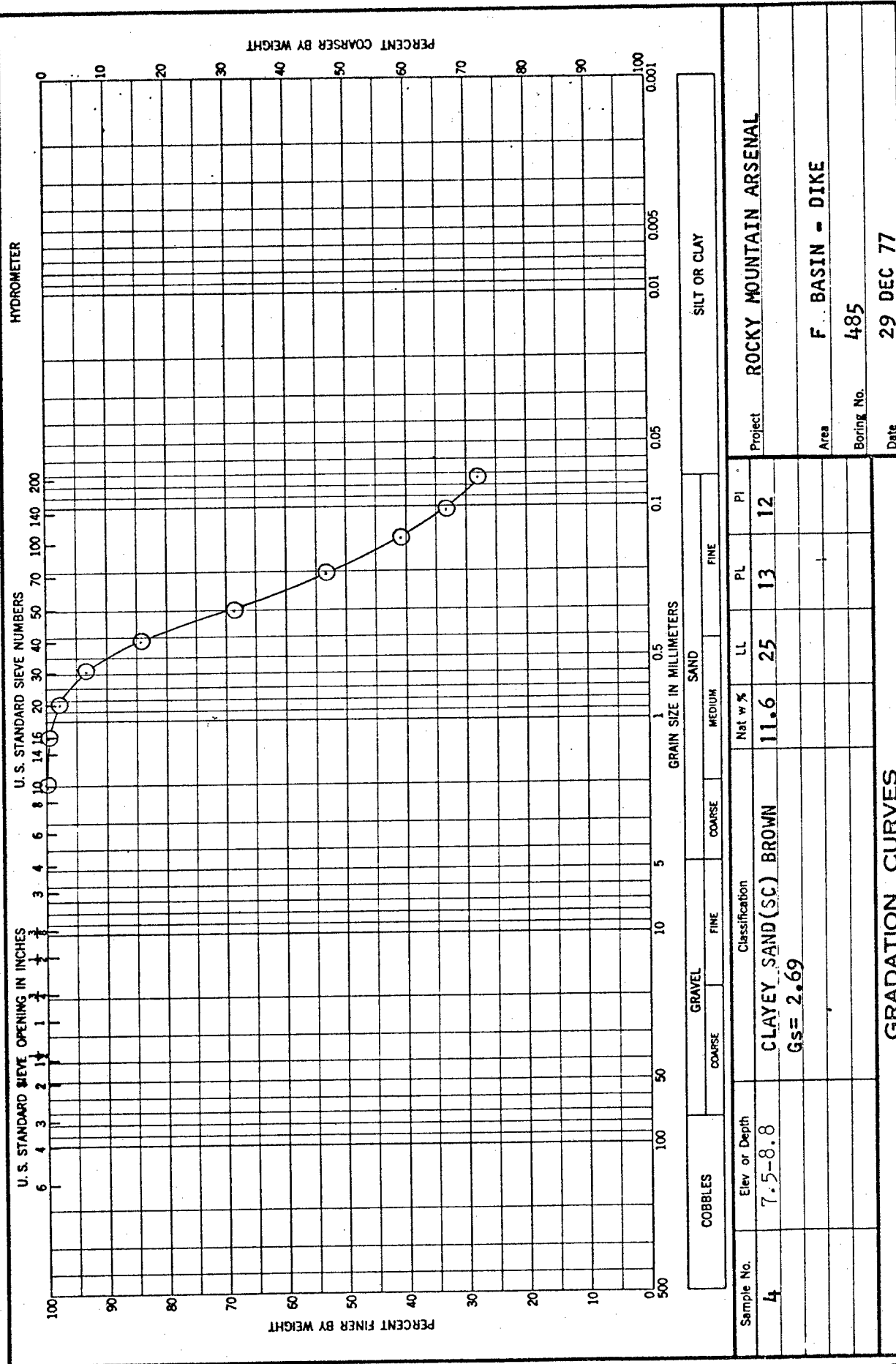


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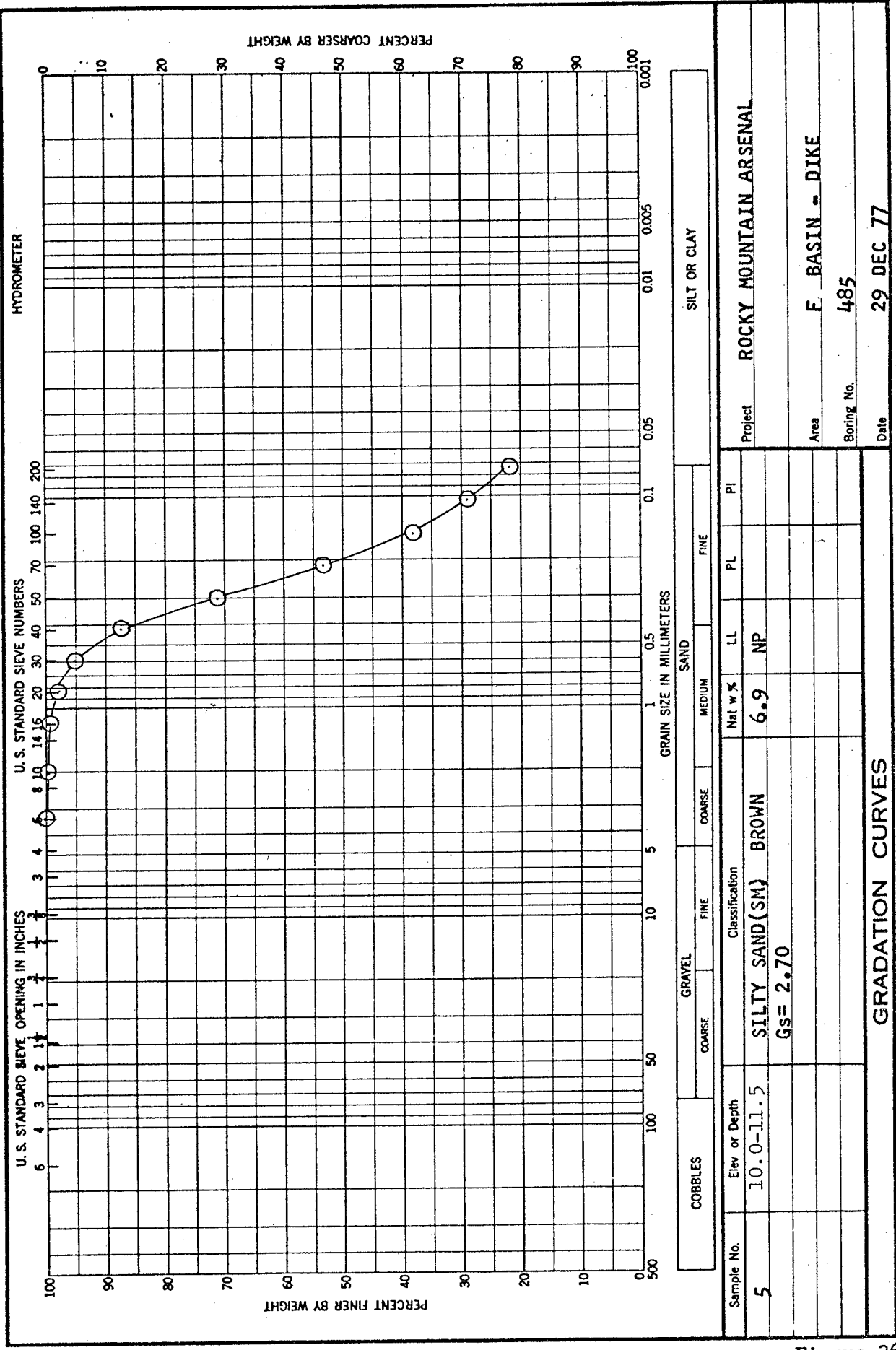


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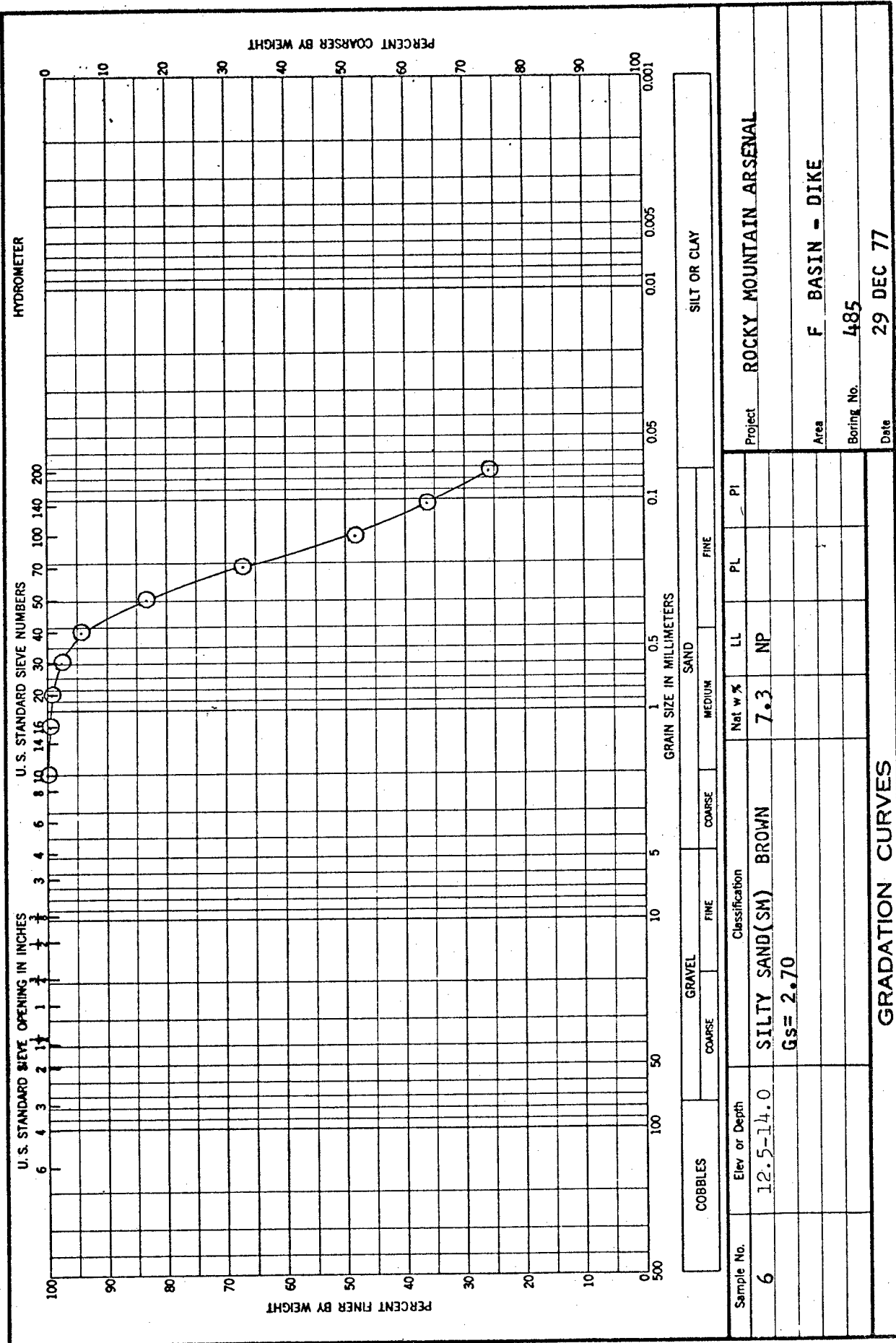


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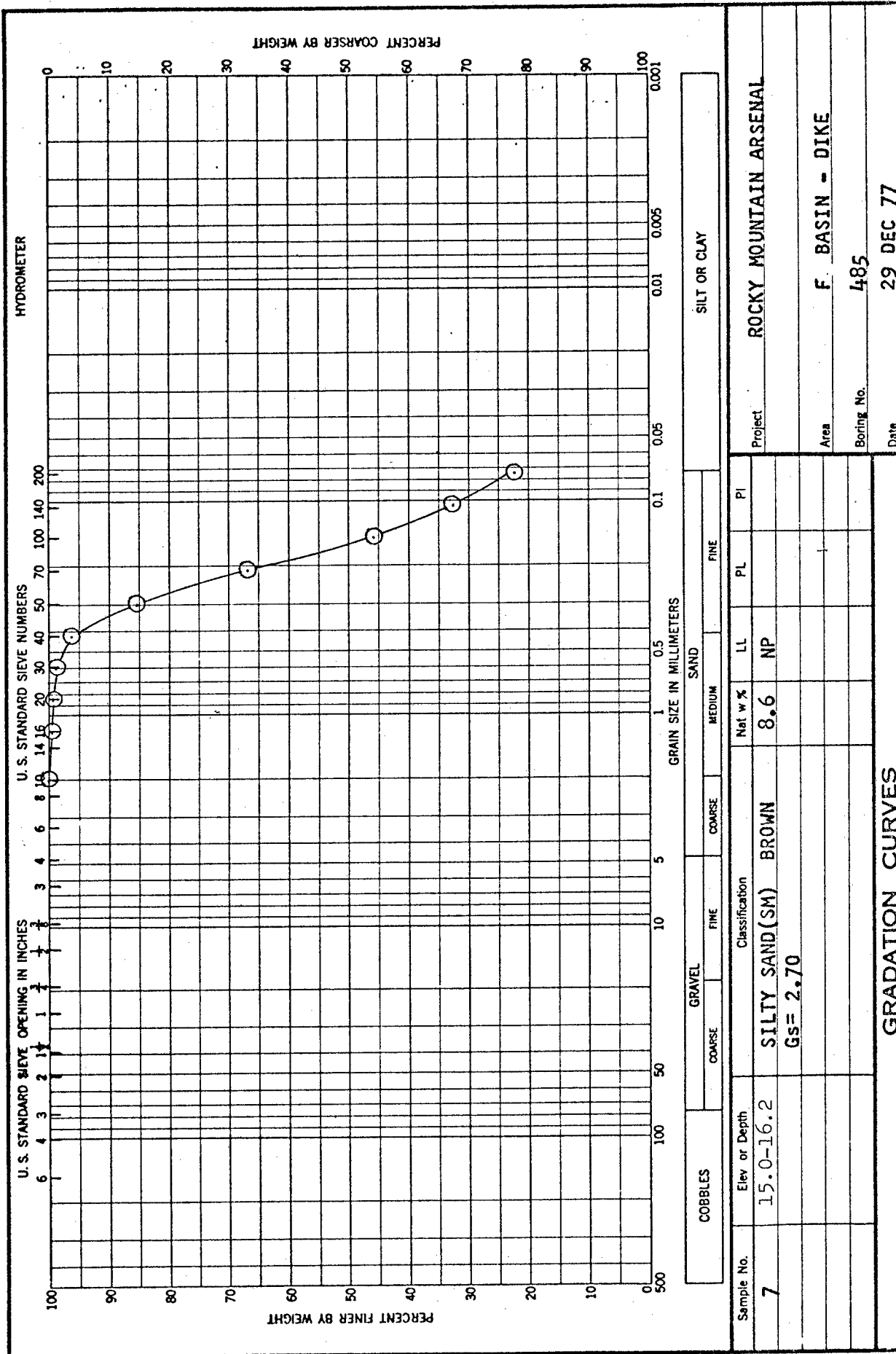


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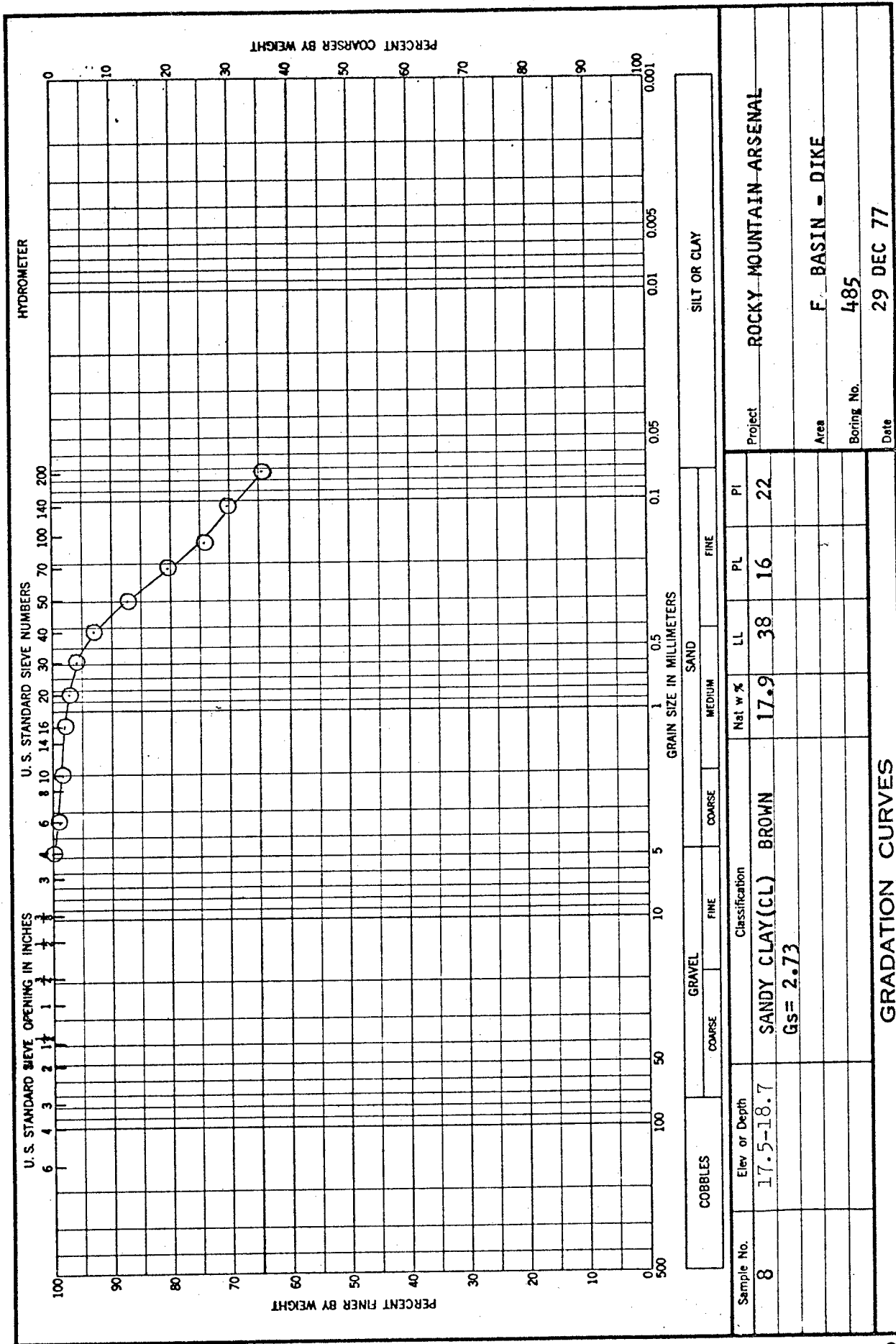


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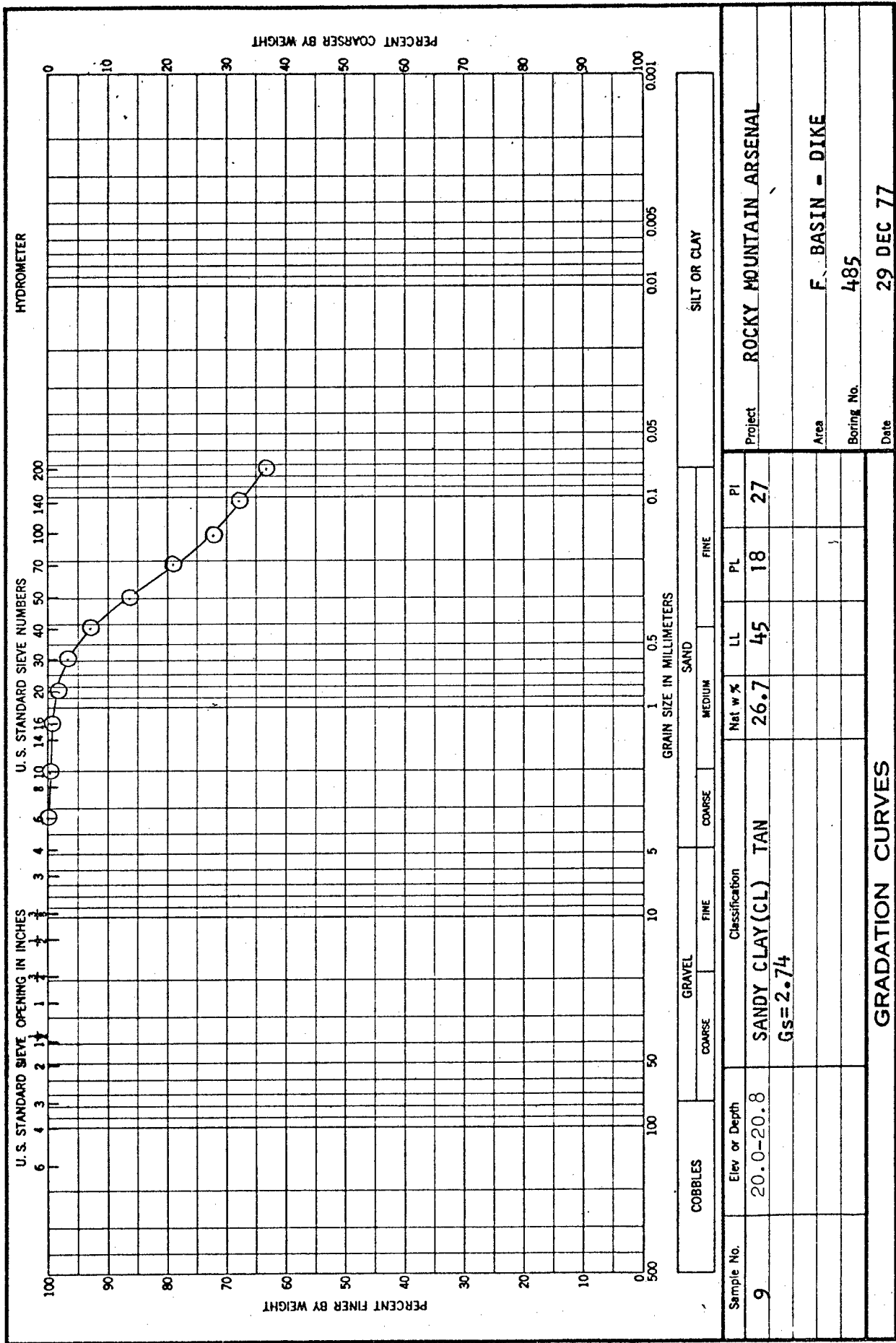


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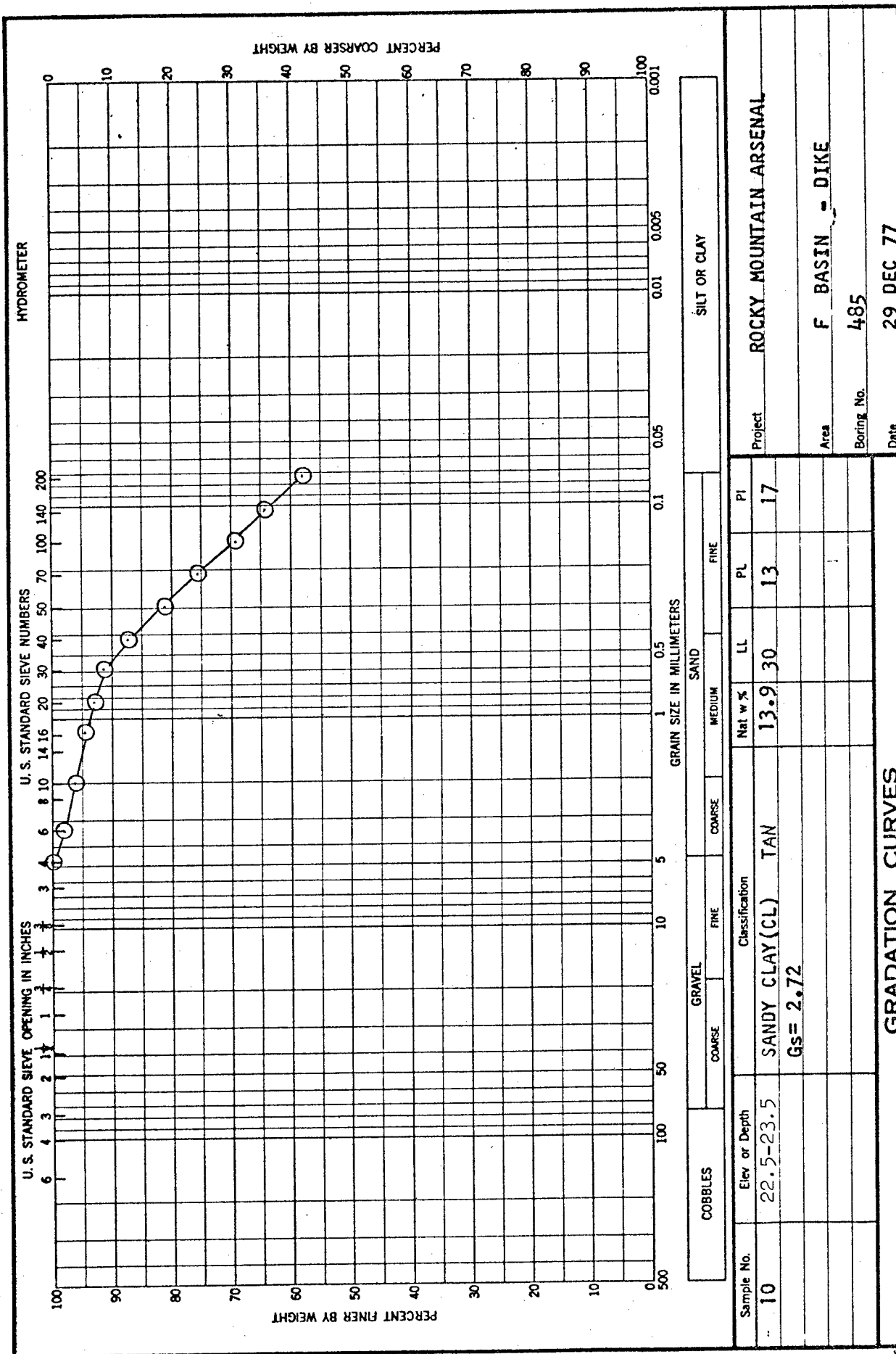
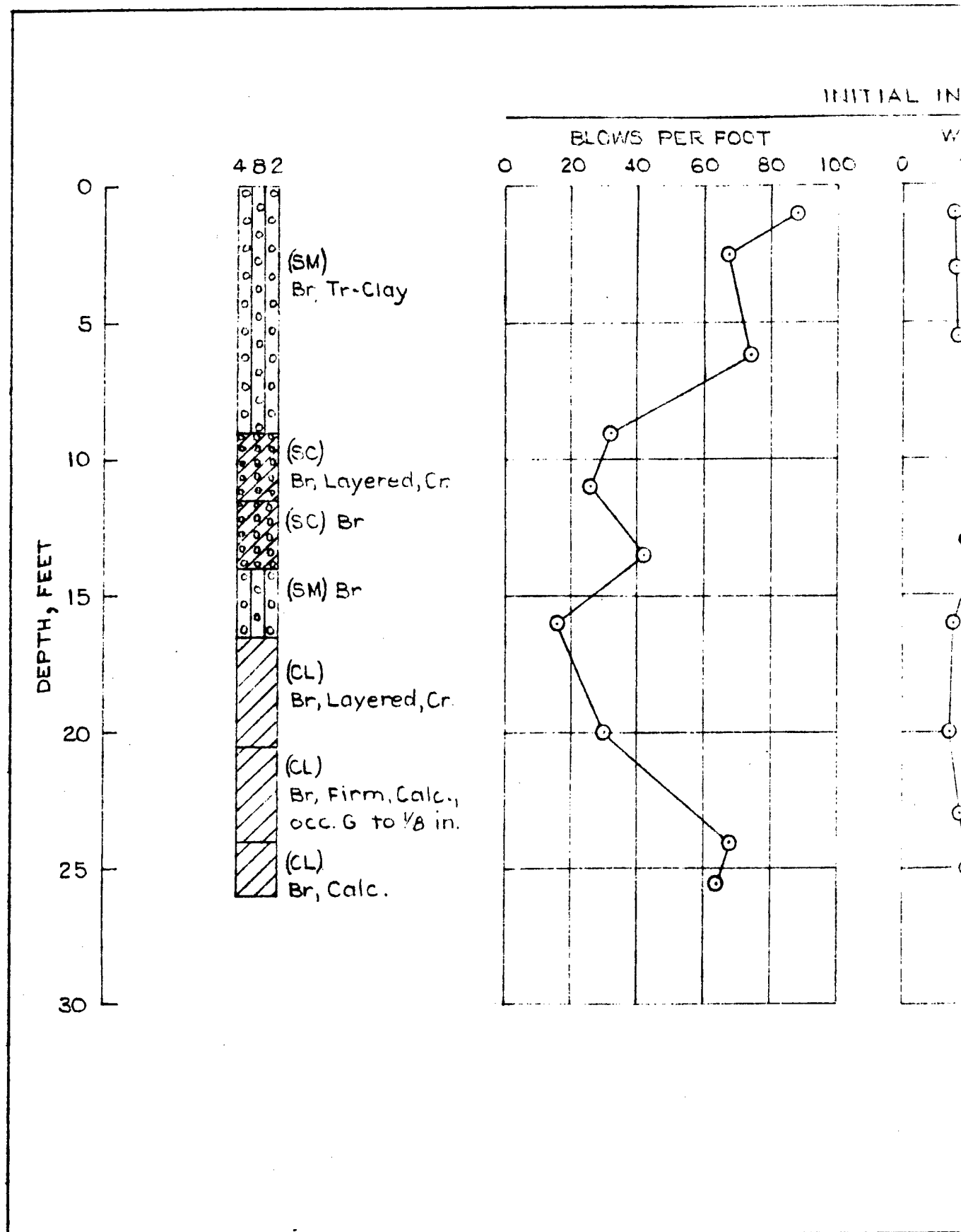


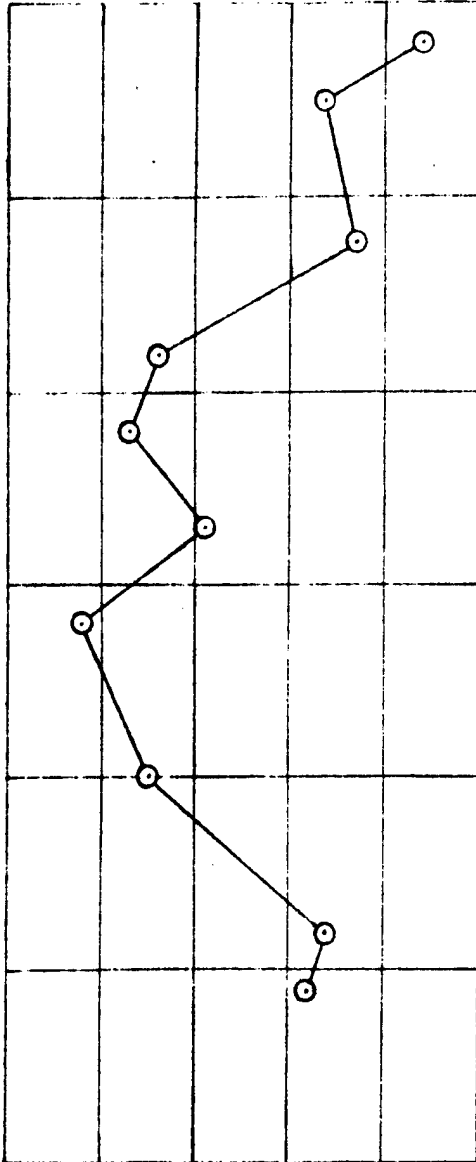
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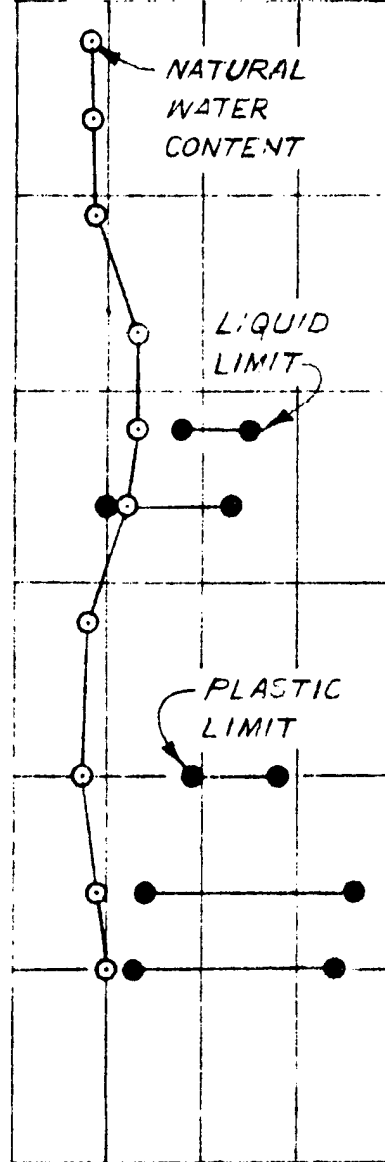
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INITIAL INVESTIGATION

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WATER CONTENT, %
0 10 20 30 40



ESTIMATED VALUES

γ_{sat} , PCF	ϕ , DEG	C, PSF
131	47	0
127	36	0
134	32	0
137	0	4350
138	0	9930

ESTIMATED VALUES

γ_w , PCF	ϕ , DEG	C, PSF
131	47	0
127	36	0
134	32	0
137	0	4350
138	0	9930

FINAL INVESTIGATION

SELECTED LABORATORY VALUES

	Q TEST		S TEST	
γ_w , PCF	ϕ	C	ϕ	C
132	32	900	34	0
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115	15	840	32	0
<u>SOIL #2</u>				

DEPTH, FEET

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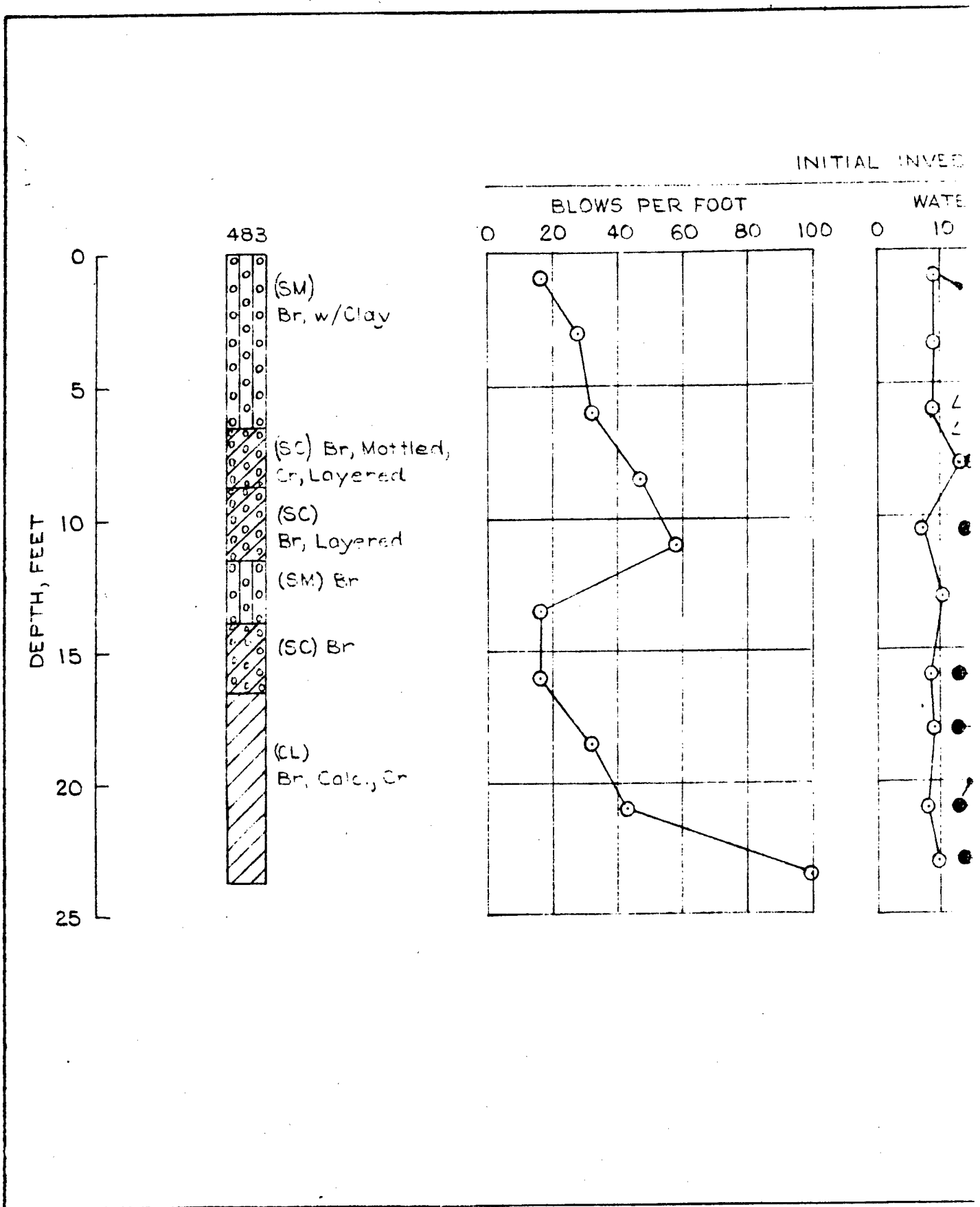
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20

25

DEPTH, FEET

GRAPHIC BORING LOGS & STRENGTH VALUES
 DIKE STABILITY ANALYSIS
 BASIN F
 ROCKY MOUNTAIN ARSENAL
 DENVER, COLORADO



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INITIAL INVESTIGATION

BLOWS PER FOOT

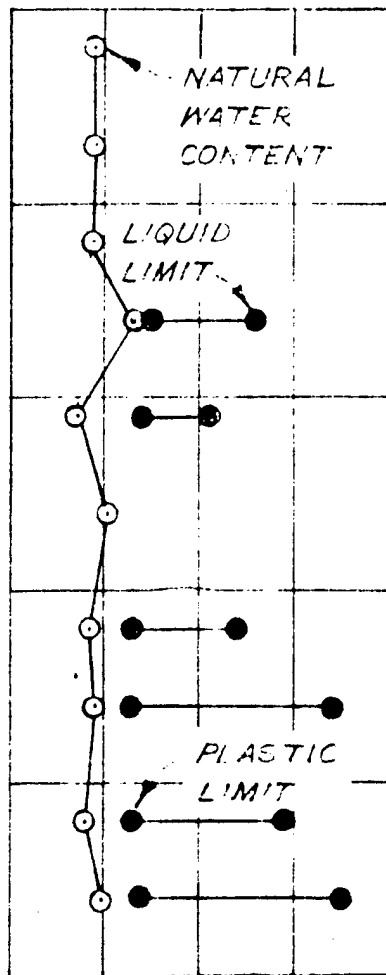
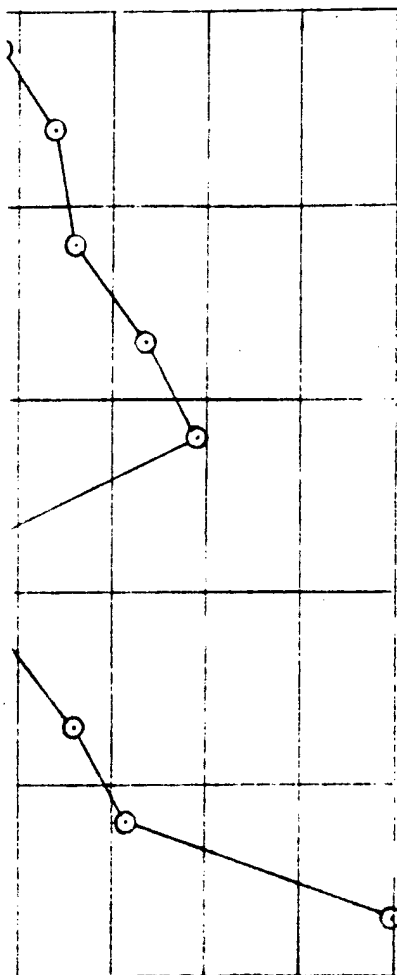
20 40 60 80 100

WATER CONTENT

0 10 20 30 40

ESTIMATED VALUES

γ_w , PCF ϕ , DEG. C, PSF



γ_w , PCF	ϕ , DEG.	C, PSF
135	34	0
132	41	0
134	32	0
137	0	5550
0	0	15000

ESTIMATED VALUES		
γ_w , PCF	ϕ , DEG.	C, PSF
135	34	0
132	41	0
134	32	0
137	0	5550
0	0	15000

FINAL INVESTIGATION
SELECTED LABORATORY VALUES

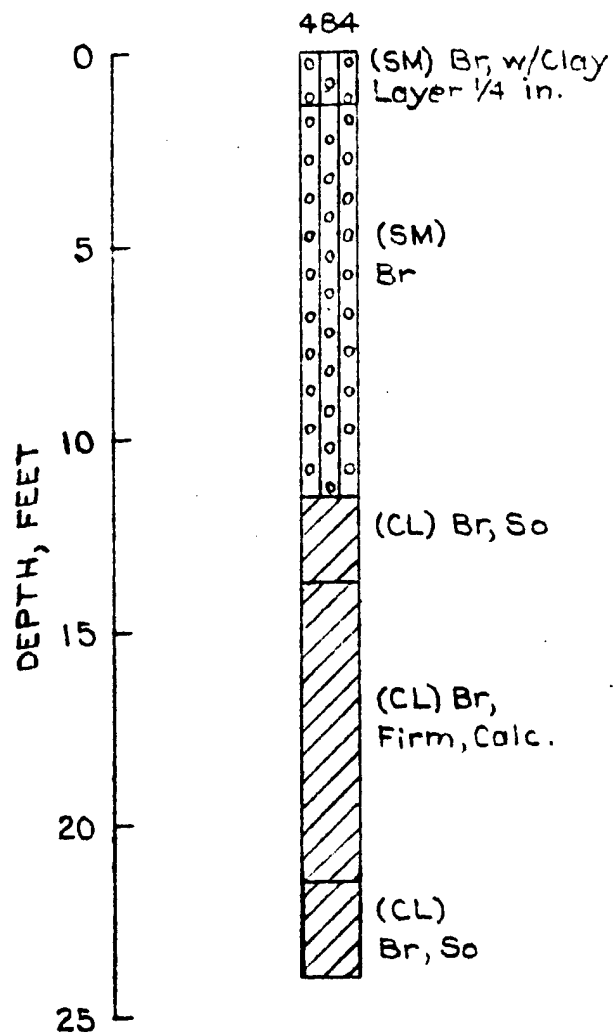
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γ_{ut} , PCF	ϕ	C	ϕ	C
132	30	900	34	0
<u>SOIL #1</u>				
115	15	840	32	0
<u>SOIL #2</u>				

DEPTH, FEET

GRAPHIC BORING LOGS & STRENGTH VALUES
DIKE STABILITY ANALYSIS
BASIN F
ROCKY MOUNTAIN ARSENAL
DENVER, COLORADO

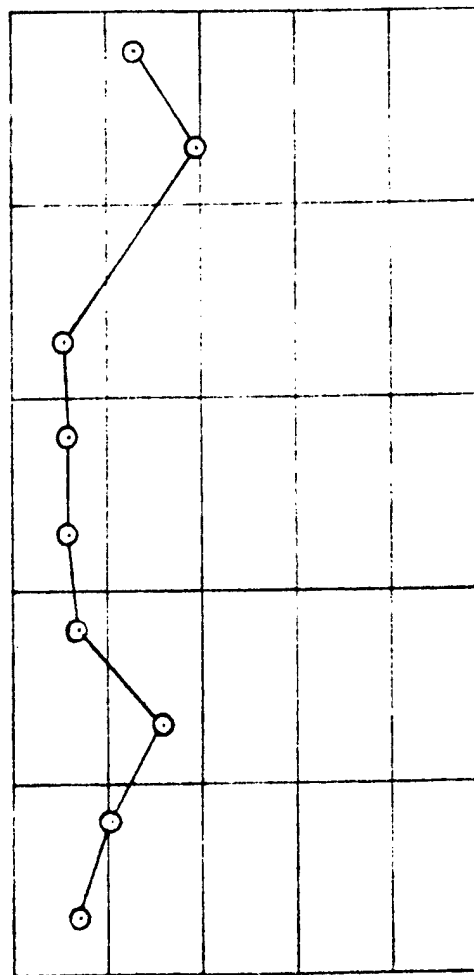
Figure 43

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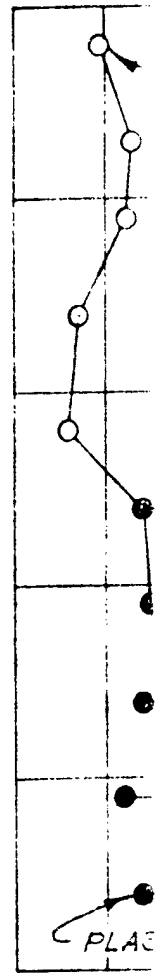
0 20 40 60 80 100

FLWS PER FOOT



0 10

WATER



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INITIAL INVESTIGATION

PER FOOT

60 80 100

WATER CONTENT

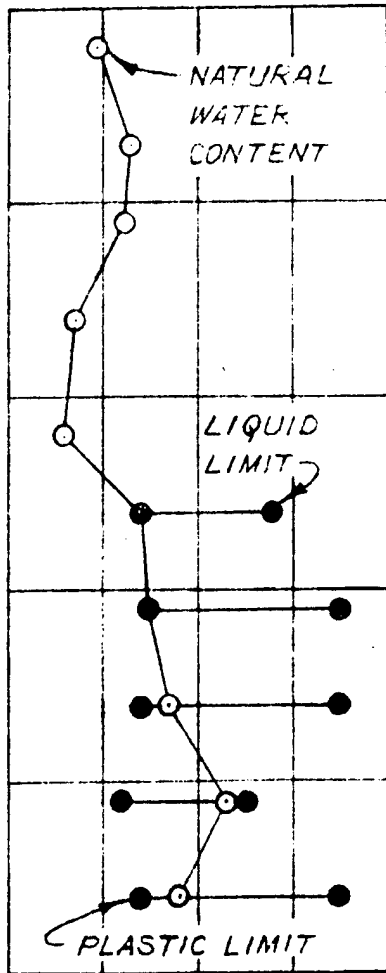
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ESTIMATED VALUES

γ_{sat} , PCF ϕ , DEG. C, PSF

SELECTED

γ_w , PCF



γ_{sat} , PCF	ϕ , DEG. C, PSF	
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133	31	0
119	0	2760

132	
115	

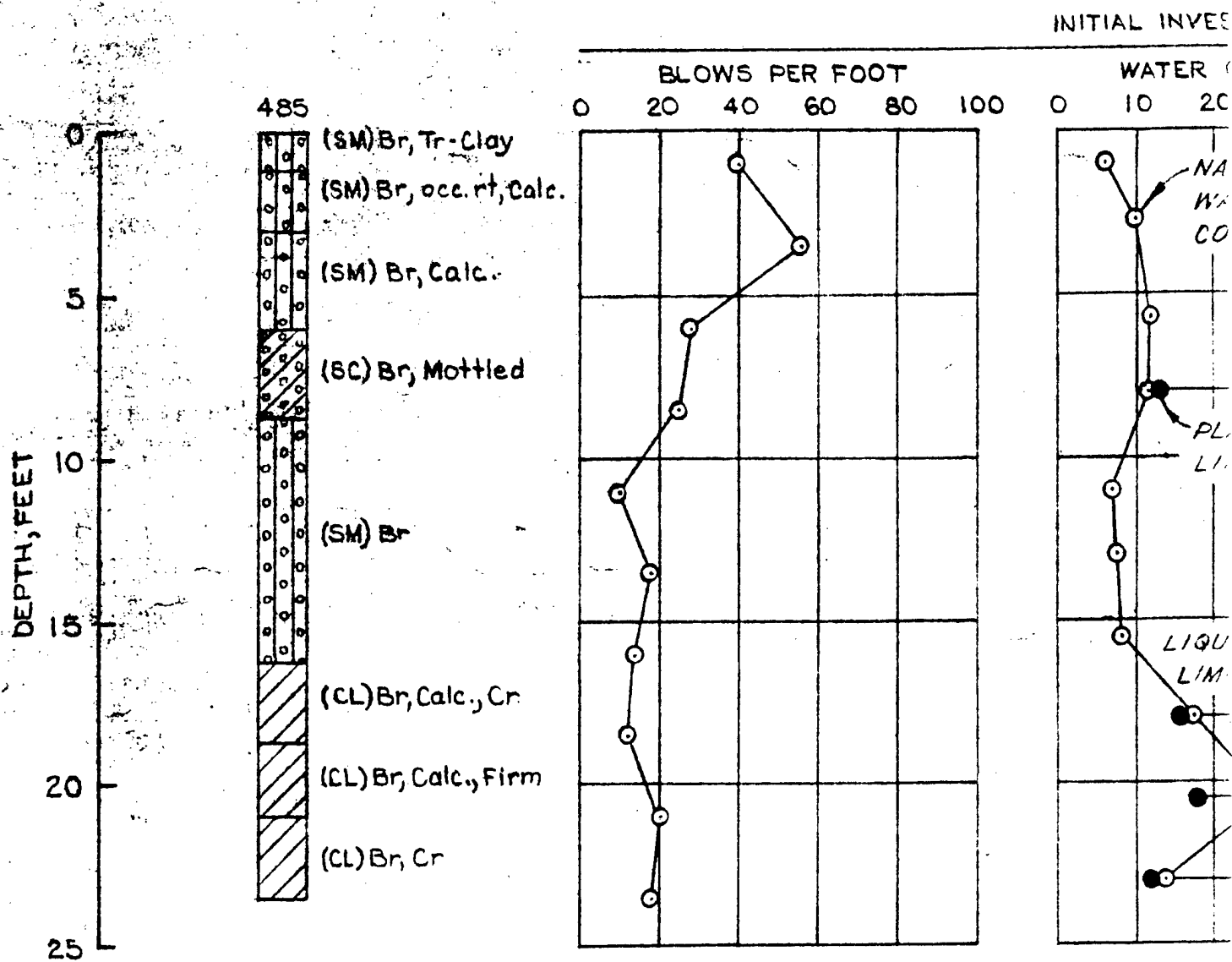
ESTIMATED VALUES		
γ_{ut} , PCF	ϕ , DEG.	C, PSF
129	36	0
133	31	0
119	0	2760

FINAL INVESTIGATION

SELECTED LABORATORY VALUES				
γ_w , PCF	Q TEST		S TEST	
	ϕ	C	ϕ	C
132	31.3	SOIL # 1		
		860	34	0
115	15	SOIL # 2		
		840	32	0

0
5
10
15
20
25
DEPTH, FEET

GEOTECHNICAL BORING LOGS & STRENGTH VALUES
 DIKE STABILITY ANALYSIS
 BASIN F
 ROCKY MOUNTAIN ARSENAL
 DENVER, COLORADO



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FINAL

INITIAL INVESTIGATION

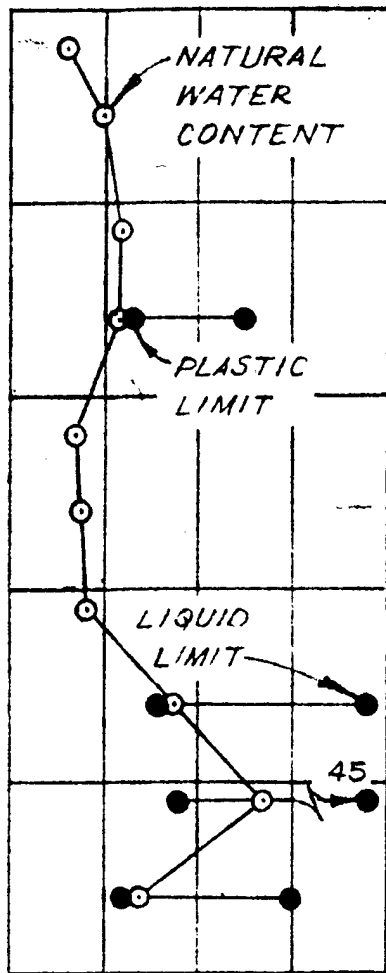
SELECTED LA

FOOT
30 80 100 0 10 20 30 40

ESTIMATED VALUES

γ_w , PCF ϕ , DEG. C, PSF

γ_w , PCF ϕ



γ_w , PCF	ϕ , DEG.	C, PSF
136	39	0
129	35	0
140	31	0
116	0	2650

γ_w , PCF	ϕ
132	31.3
115	15

GRAPH

2

40

ESTIMATED VALUES

γ_w , PCF	ϕ , DEG.	C, PSF
136	39	0
129	35	0
140	31	0
116	0	2650

FINAL INVESTIGATION

SELECTED LABORATORY VALUES

γ_w , PCF	Q TEST		S TEST	
	ϕ	C	ϕ	C
132	SOIL #1		34	0
	31.3	860		
115	SOIL #2		32	0
	15	840		

0

5

10

15

20

25

DEPTH, FEET

GRAPHIC BORING LOGS & STRENGTH VALUES
 DIKE STABILITY ANALYSIS
 BASIN F
 ROCKY MOUNTAIN ARSENAL
 DENVER, COLORADO

Figure 10

3

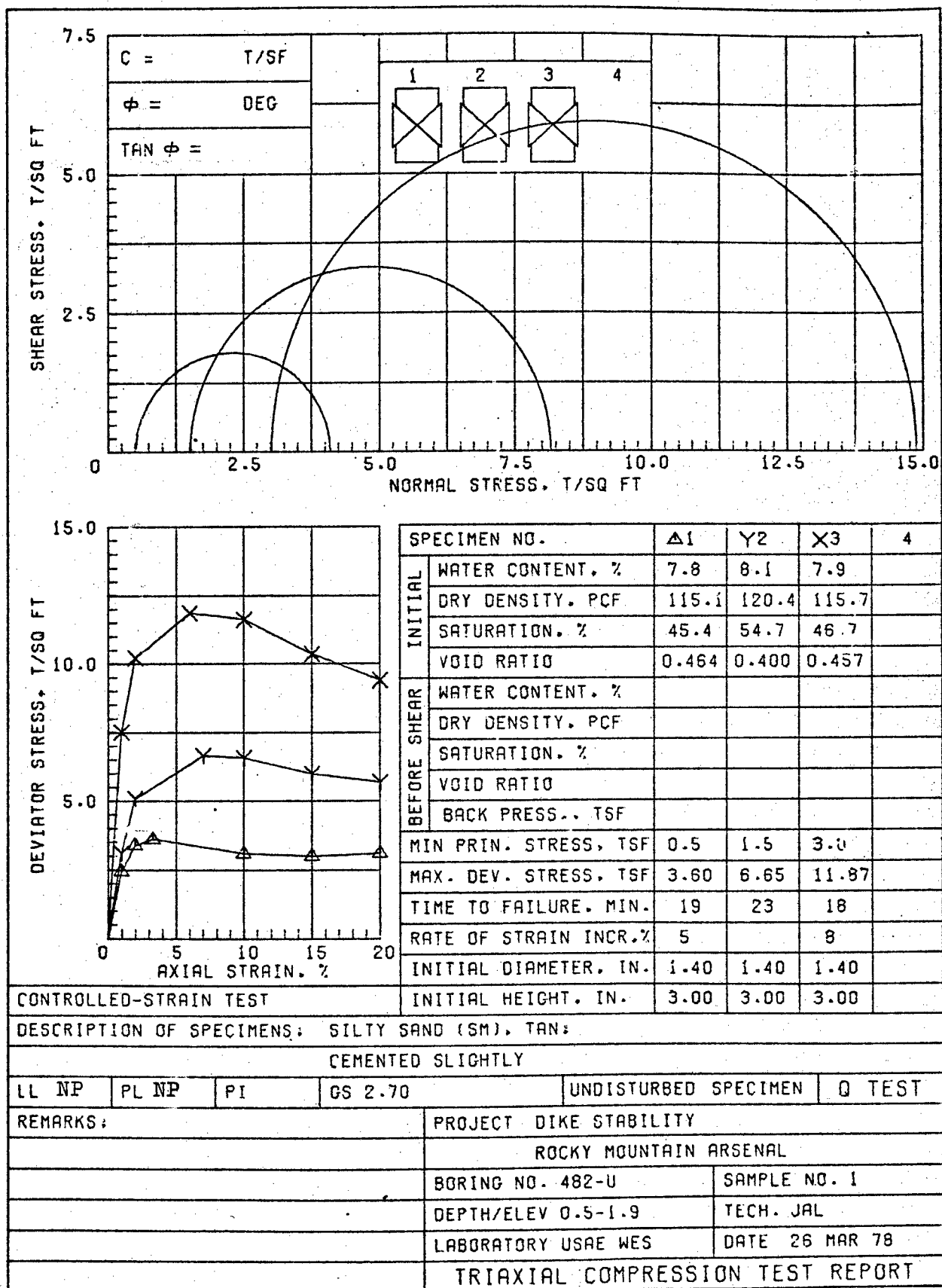


Figure 46

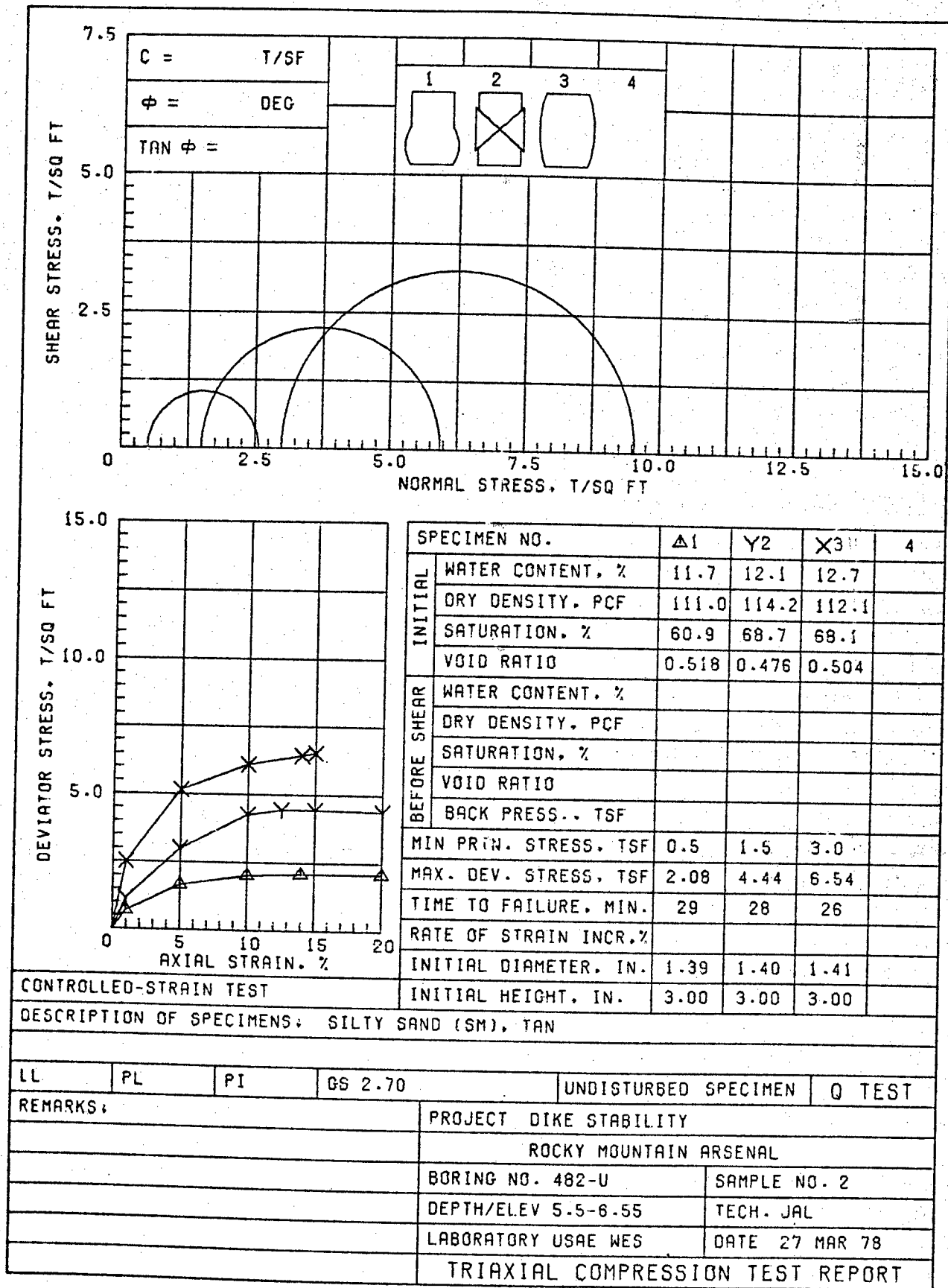


Figure 47

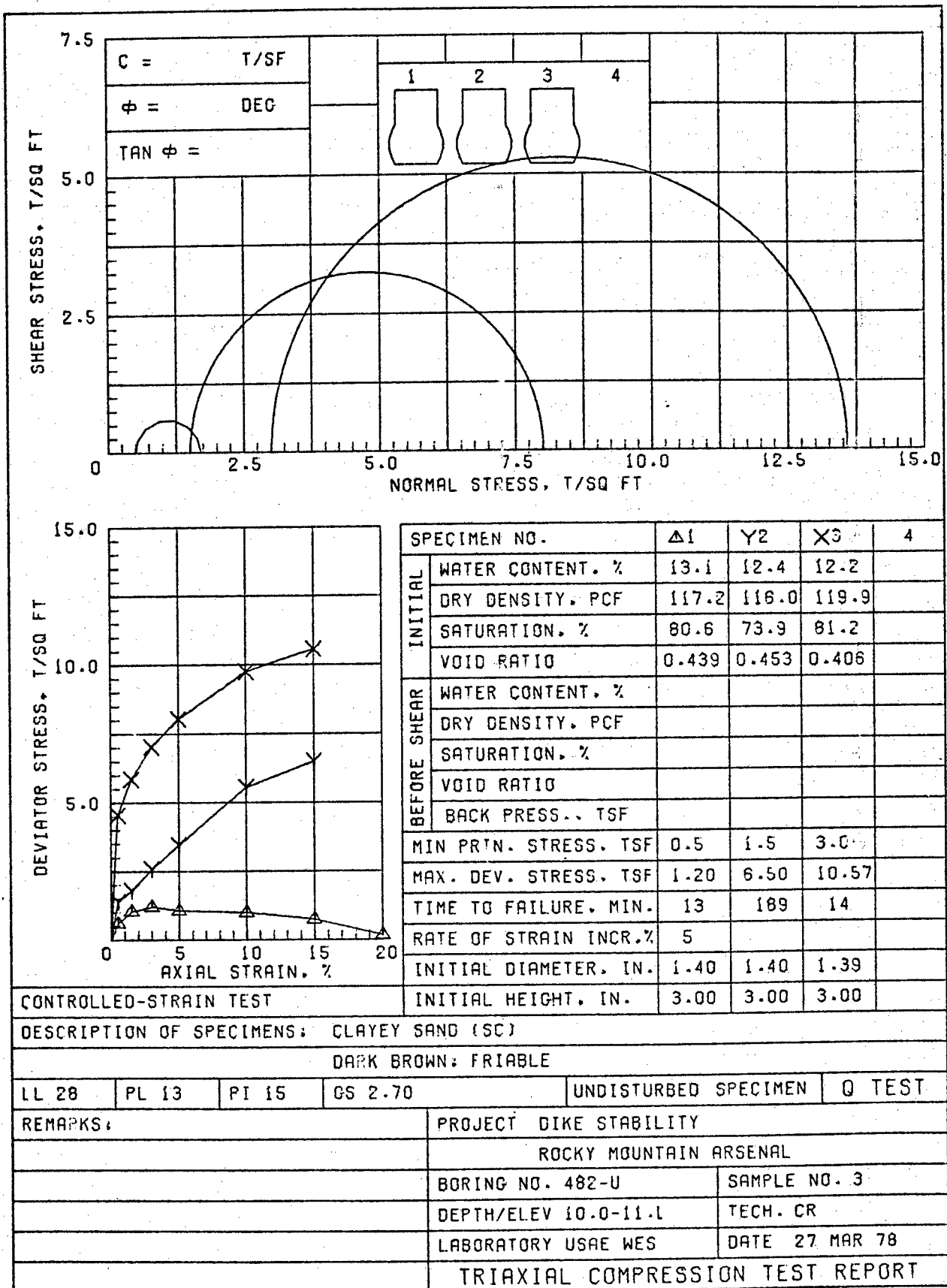
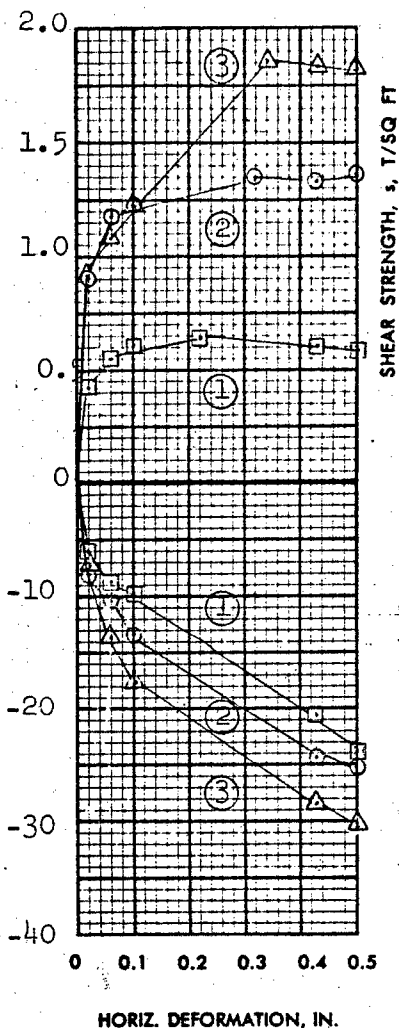


Figure 48

SHEAR STRESS, τ , T/SQ FT



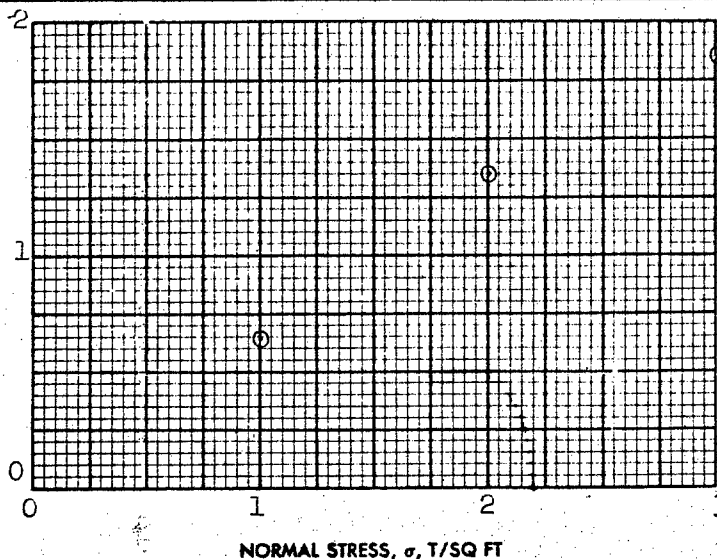
SHEAR STRENGTH PARAMETERS

$\phi' =$ _____

$\tan \phi' =$ _____

$c' =$ _____ T/SQ FT

- ☐ CONTROLLED STRESS
☒ CONTROLLED STRAIN



TEST NO.		1	2	3	
INITIAL	WATER CONTENT	w_o 4.4%	4.4 %	4.6 %	%
	VOID RATIO	e_o 0.761	0.750	0.769	
	SATURATION	S_o 15.6 %	15.8 %	16.1 %	%
	DRY DENSITY, LB/CU FT	γ_d 95.7	96.3	95.3	
VOID RATIO AFTER CONSOLIDATION		e_c			
TIME FOR 50 PERCENT CONSOLIDATION, MIN		t_{50}			
FINAL	WATER CONTENT	w_f 12.5%	12.8%	13.4%	%
	VOID RATIO	e_f			
	SATURATION	S_f	%	%	%
NORMAL STRESS, T/SQ FT		σ	1.0	2.0	3.0
MAXIMUM SHEAR STRESS, T/SQ FT		τ_{max}	0.64	1.35	1.85
ACTUAL TIME TO FAILURE, MIN		t_f	660	930	990
RATE OF STRAIN, IN./MIN			.00037	.00037	.00037
ULTIMATE SHEAR STRESS, T/SQ FT		τ_{ult}			

TYPE OF SPECIMEN **UNDISTURBED** **3.00 IN. SQUARE** **0.547 IN. THICK**

CLASSIFICATION **SILTY SAND (SM), TAN**

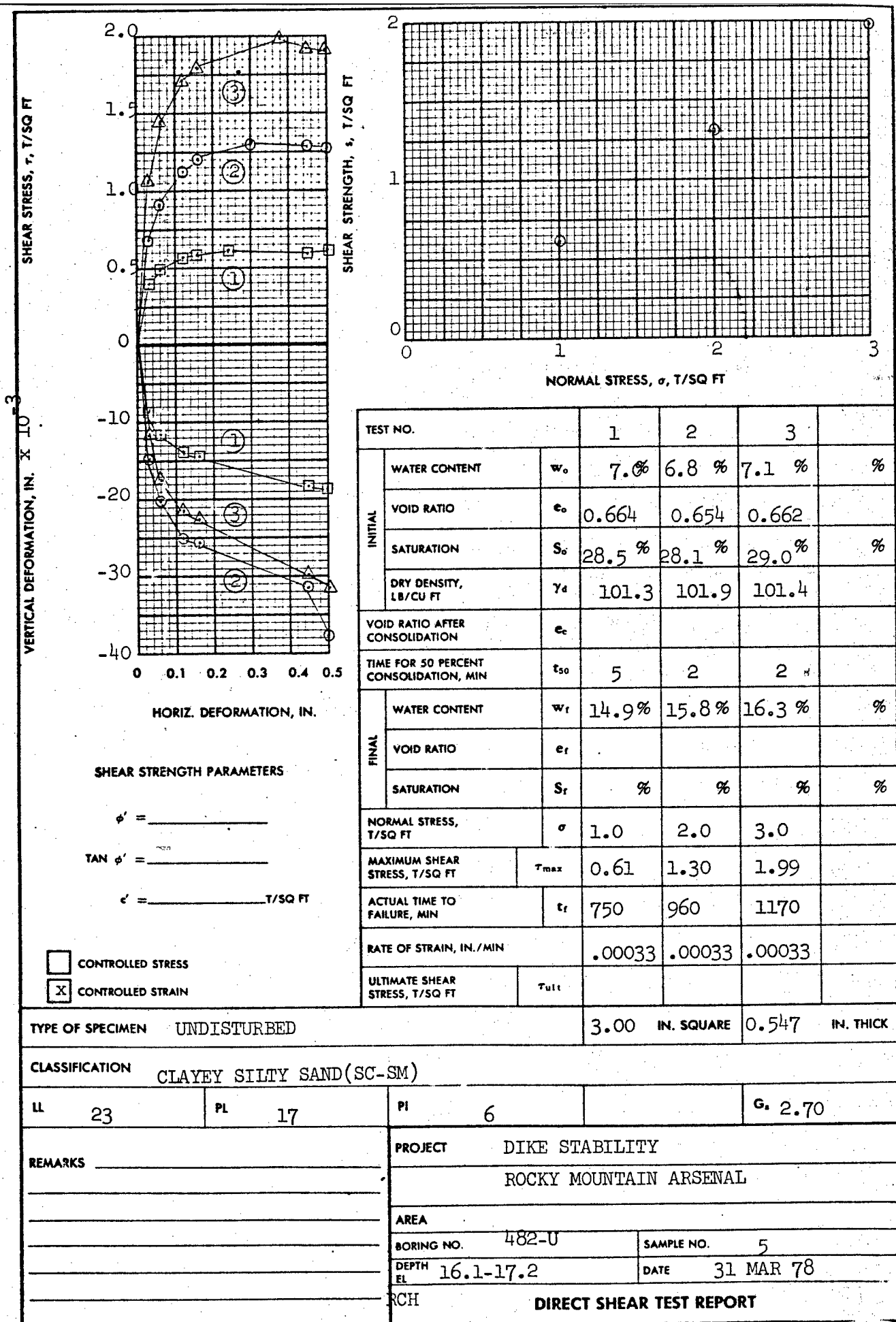
LL **NP** PL **NP** PI **NP** **G_s 2.70**

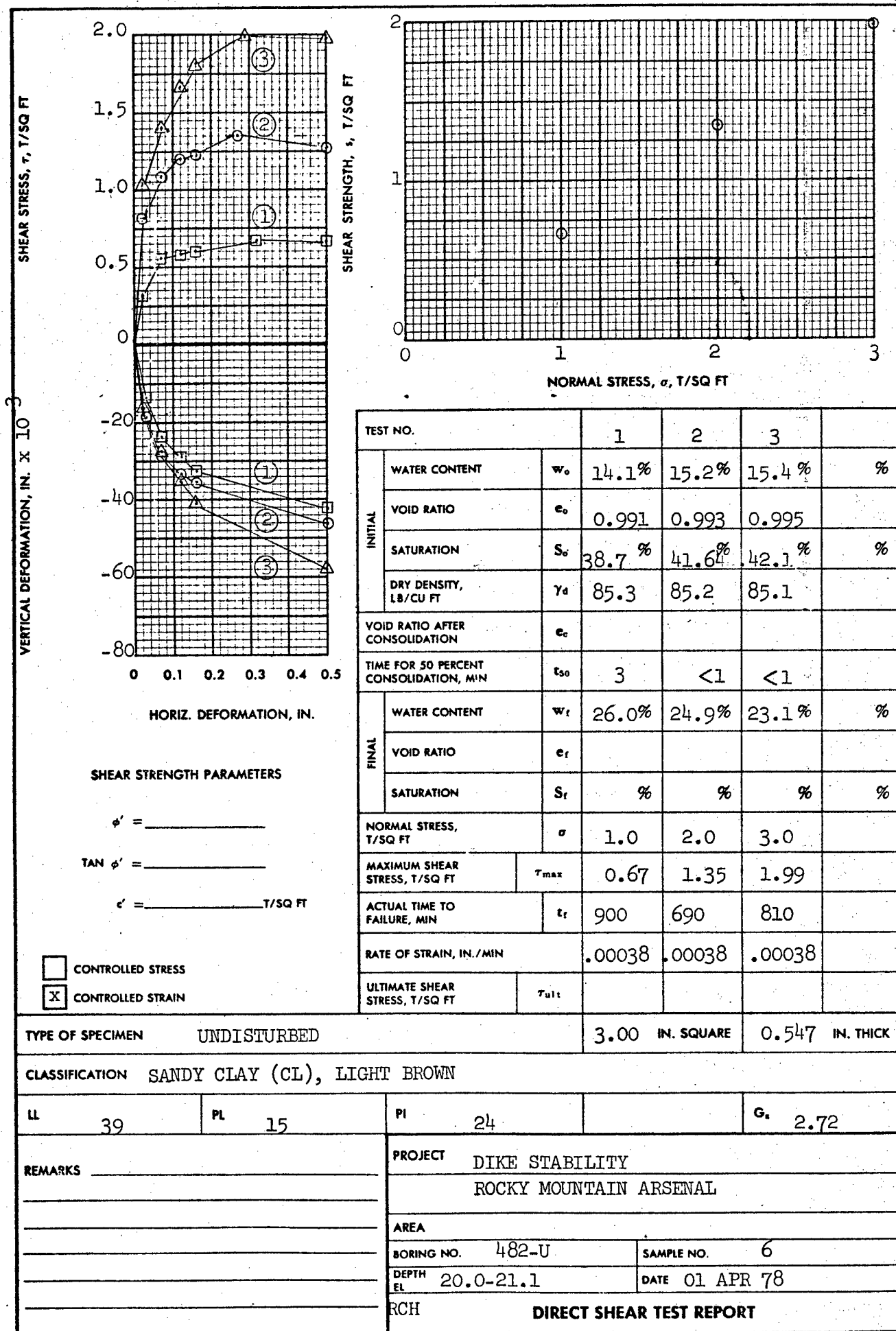
REMARKS _____

PROJECT **DIKE STABILITY**
ROCKY MOUNTAIN ARSENAL

AREA _____
 BORING NO. **482-U** SAMPLE NO. **4**
 DEPTH **15.0-16.0** DATE **30 MAR 78**

RCH **DIRECT SHEAR TEST REPORT**





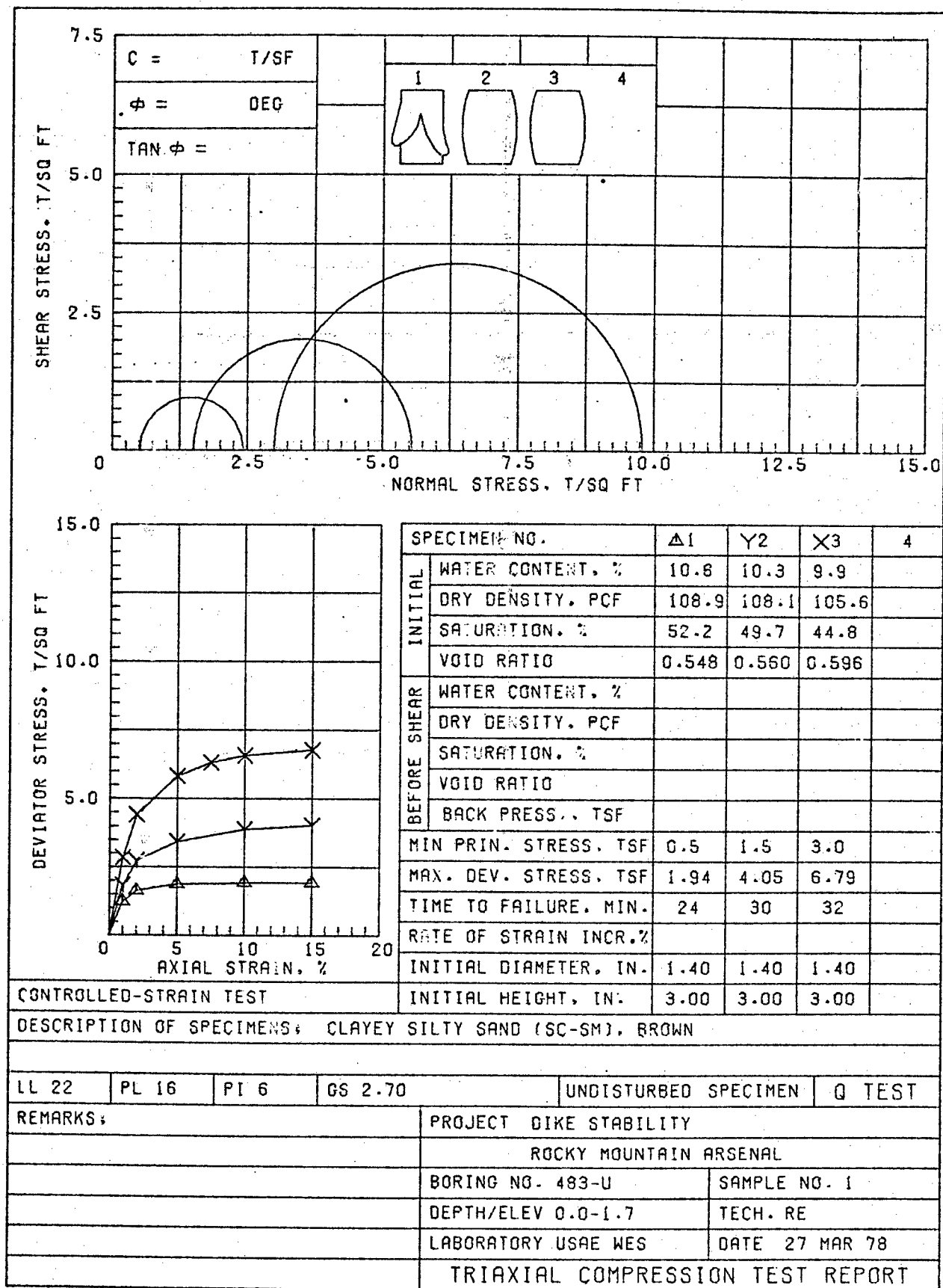


Figure 52

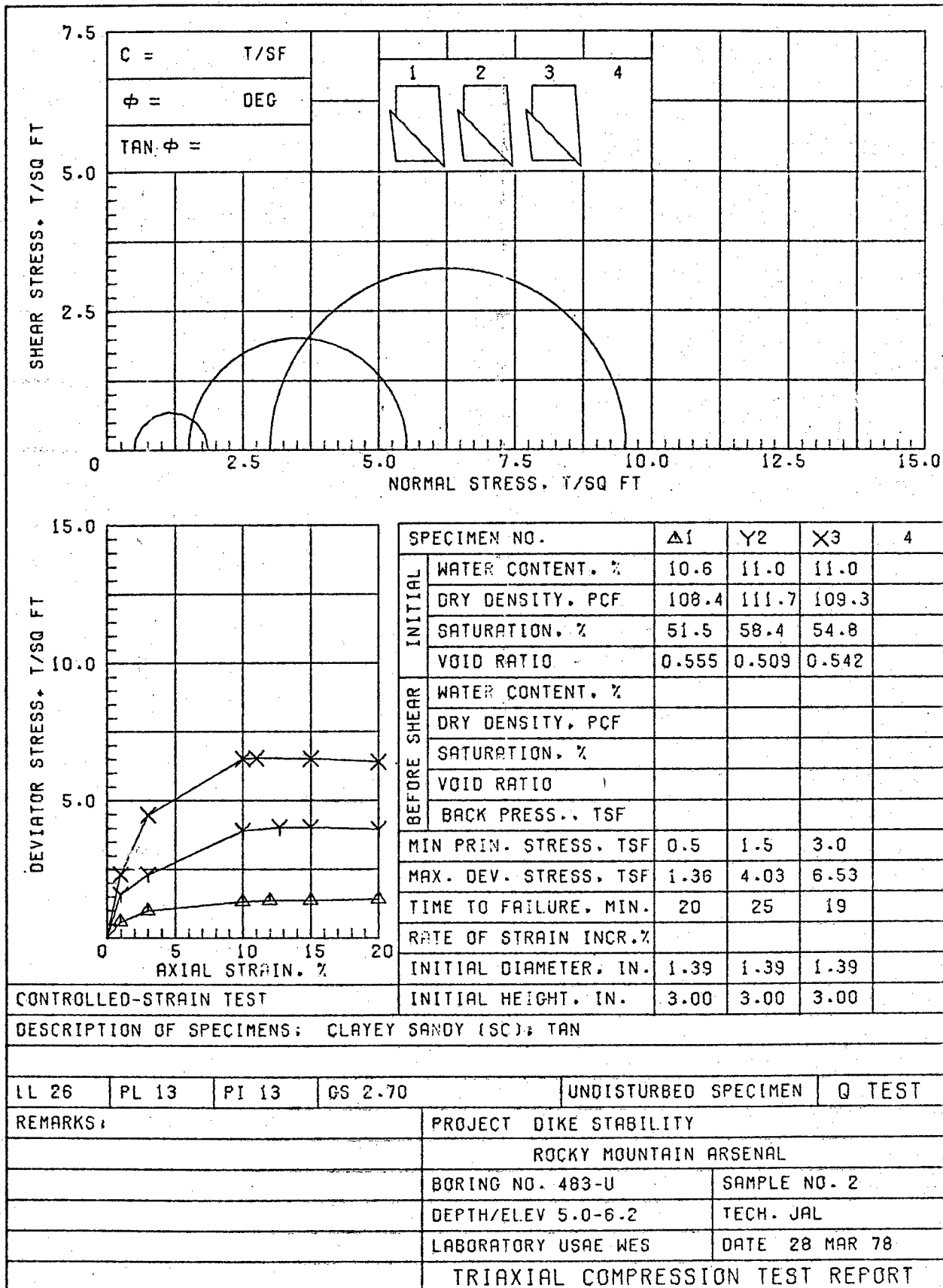


Figure 53

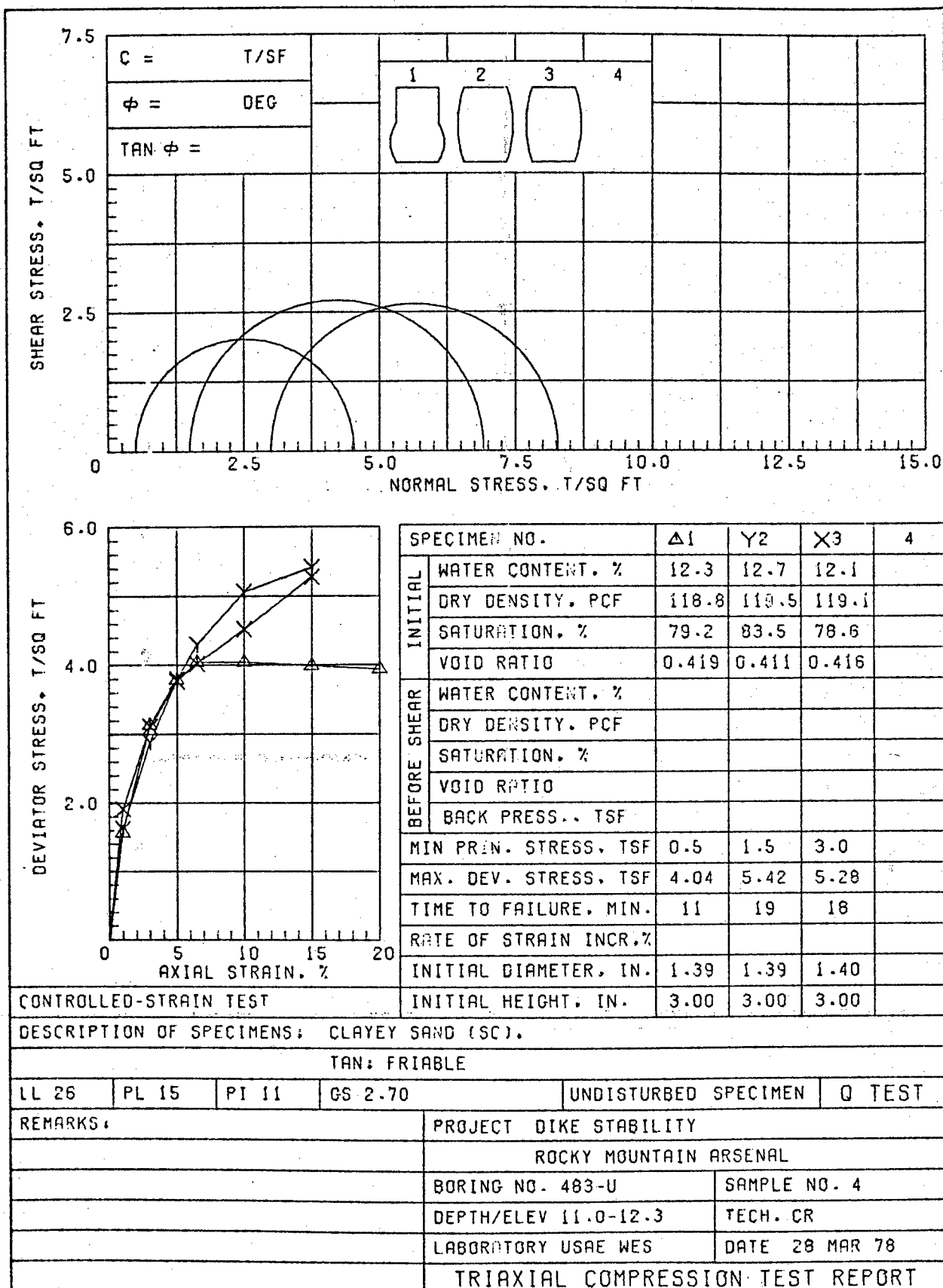


Figure 54

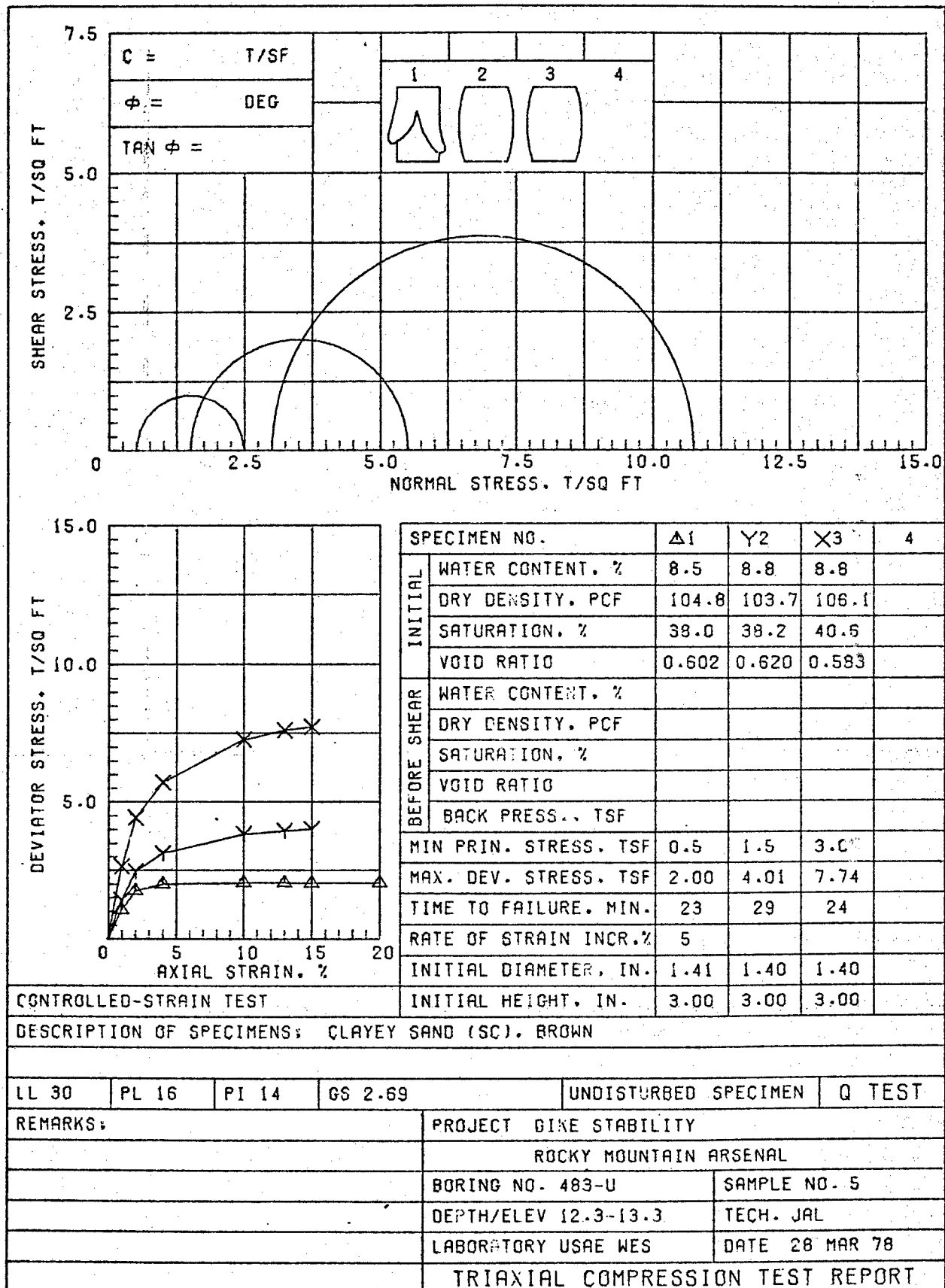


Figure 55

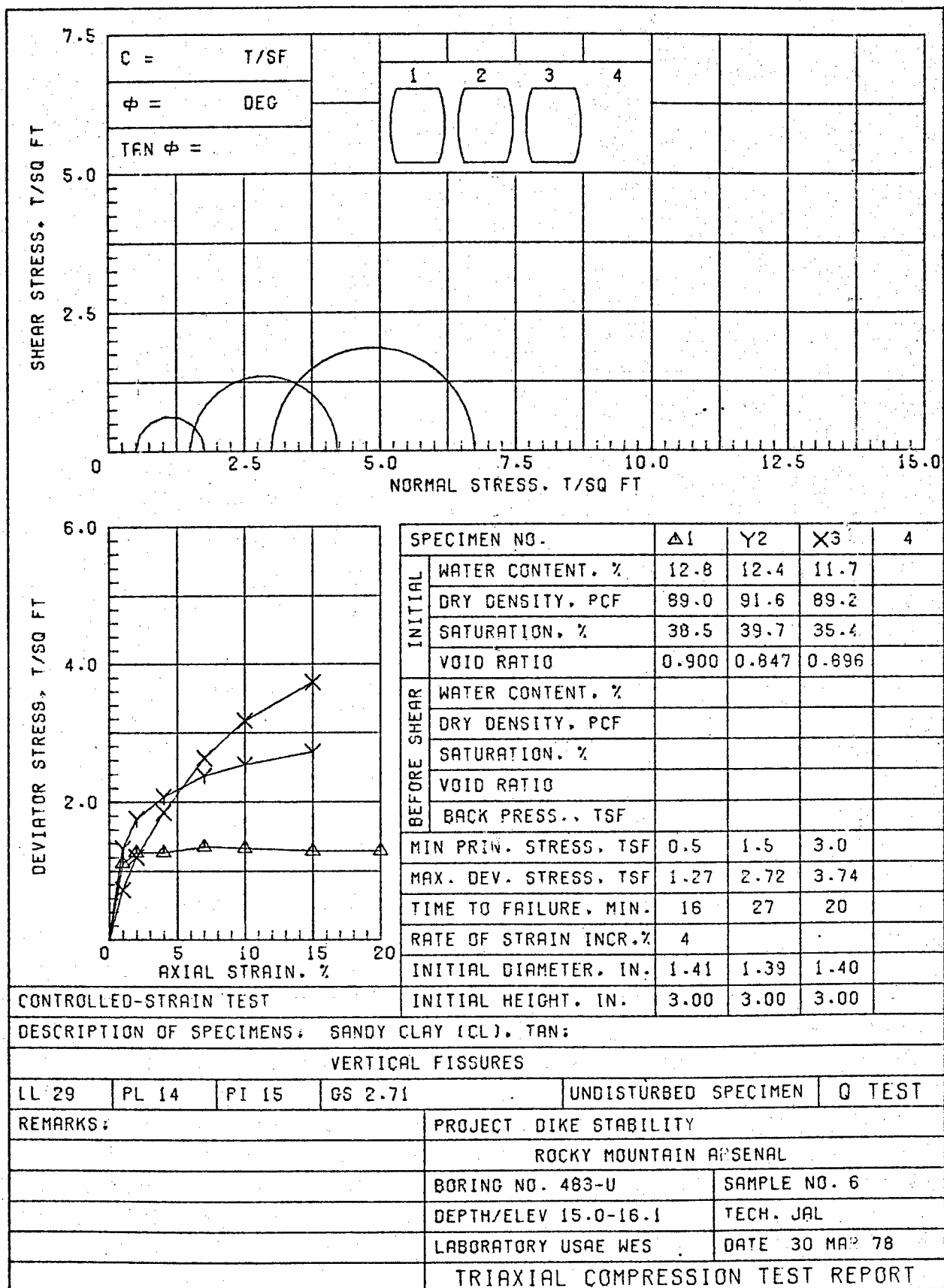
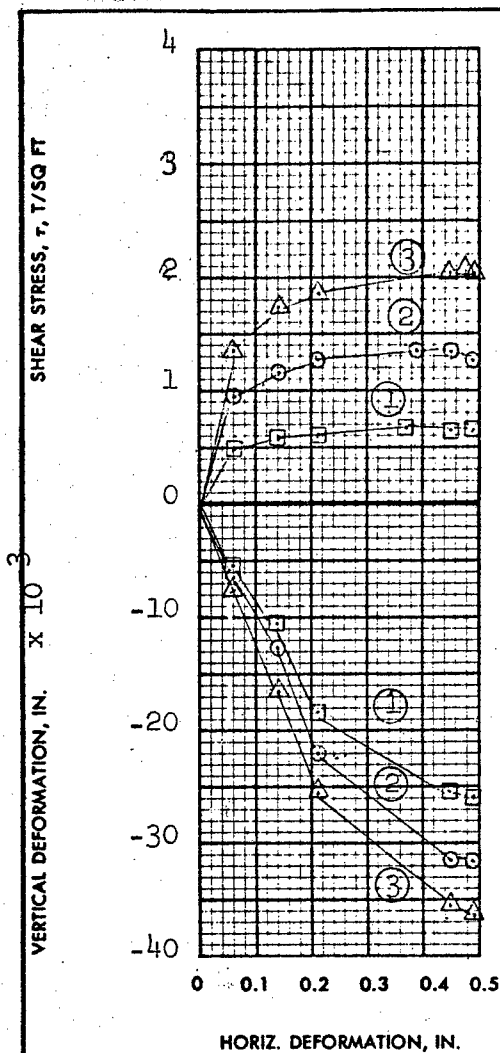


Figure 56



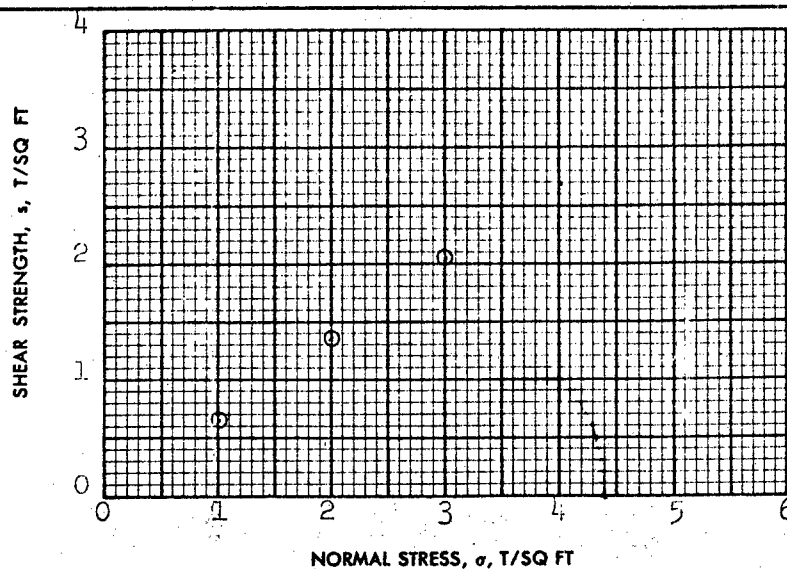
SHEAR STRENGTH PARAMETERS

$\phi' =$ _____

$\tan \phi' =$ _____

$c' =$ _____ T/SQ FT

- ☐ CONTROLLED STRESS
- ☒ CONTROLLED STRAIN



TEST NO.			1	2	3	
INITIAL	WATER CONTENT	w _o	15.5%	15.1%	15.0%	%
	VOID RATIO	e _o	0.695	0.752	0.730	
	SATURATION	S _o	28.9 %	29.5%	31.3%	%
	DRY DENSITY, LB/CU FT	γ _d	99.8	98.1	97.8	
VOID RATIO AFTER CONSOLIDATION		e _c				
TIME FOR 50 PERCENT CONSOLIDATION, MIN		t ₅₀				
FINAL	WATER CONTENT	w _f	15.5%	15.1%	15.0%	%
	VOID RATIO	e _f				
	SATURATION	S _f	%	%	%	%
NORMAL STRESS, T/SQ FT		σ	1.0	2.0	3.0	
MAXIMUM SHEAR STRESS, T/SQ FT		τ _{max}	0.67	1.35	2.05	
ACTUAL TIME TO FAILURE, MIN		t _f	1200	1260	1530	
RATE OF STRAIN, IN./MIN			.00032	.00032	.00032	
ULTIMATE SHEAR STRESS, T/SQ FT		τ _{ult}				

TYPE OF SPECIMEN **UNDISTURBED** **3.00 IN. SQUARE** **0.457 IN. THICK**

CLASSIFICATION **SANDY CLAY (CL), LIGHT BROWN**

LL **29** PL **14** PI **15** G. **2.71**

REMARKS _____

PROJECT **DIKE STABILITY**

ROCKY MOUNTAIN ARSENAL

AREA _____

BORING NO. **483-U**

SAMPLE NO. **7**

DEPTH EL **16.1-17.1**

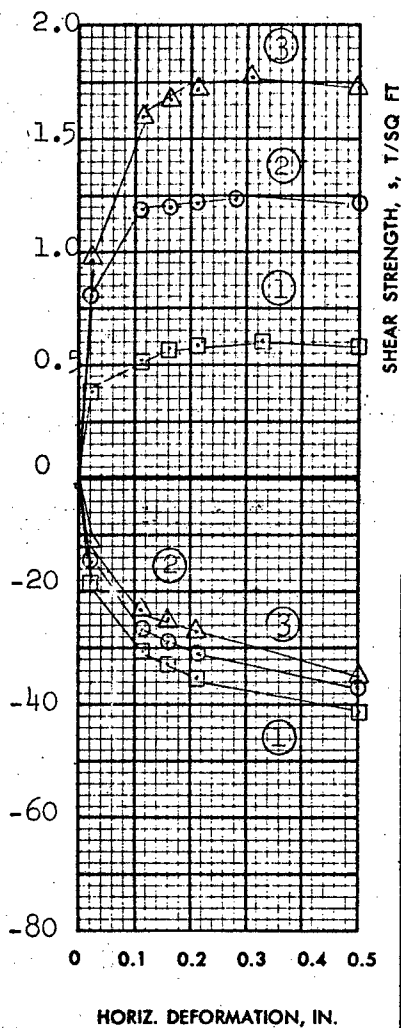
DATE **02 APR 78**

RCH

DIRECT SHEAR TEST REPORT

SHEAR STRESS, τ , T/SQ FT

VERTICAL DEFORMATION, IN. $\times 10^{-3}$



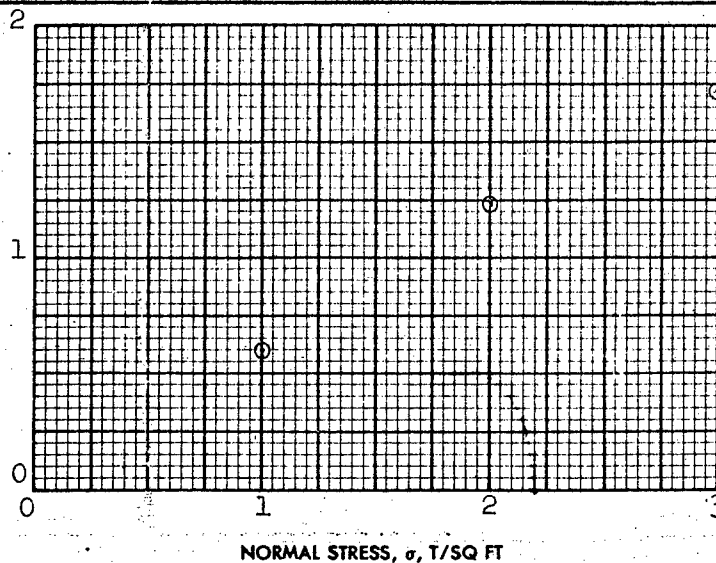
SHEAR STRENGTH PARAMETERS

$\phi' =$ _____

$\tan \phi' =$ _____

$c' =$ _____ T/SQ FT

- ☐ CONTROLLED STRESS
- ☒ CONTROLLED STRAIN



TEST NO.		1	2	3	
INITIAL	WATER CONTENT	w_o 8.1 %	7.8 %	7.7 %	%
	VOID RATIO	e_o 0.898	0.902	0.928	
	SATURATION	S_o 24.6 %	23.6 %	22.6 %	%
	DRY DENSITY, LB/CU FT	γ_d 89.8	89.6	88.4	
VOID RATIO AFTER CONSOLIDATION		e_c			
TIME FOR 50 PERCENT CONSOLIDATION, MIN		t_{50}			
FINAL	WATER CONTENT	w_f 21.3 %	20.0 %	18.1 %	%
	VOID RATIO	e_f			
	SATURATION	S_f %	%	%	%
NORMAL STRESS, T/SQ FT		σ 1.0	2.0	3.0	
MAXIMUM SHEAR STRESS, T/SQ FT		τ_{max} 0.60	1.24	1.77	
ACTUAL TIME TO FAILURE, MIN		t_f 870	720	780	
RATE OF STRAIN, IN./MIN		.00036	.00036	.00036	
ULTIMATE SHEAR STRESS, T/SQ FT		τ_{ult}			

TYPE OF SPECIMEN UNDISTURBED

3.00 IN. SQUARE 0.547 IN. THICK

CLASSIFICATION SANDY CLAY (CL), BROWN

LL 40 PL 15 PI 25 G. 2.73

REMARKS

PROJECT DIKE STABILITY

ROCKY MOUNTAIN ARSENAL

AREA

BORING NO. 483-U

SAMPLE NO. 8

DEPTH EL 20.0-21.2

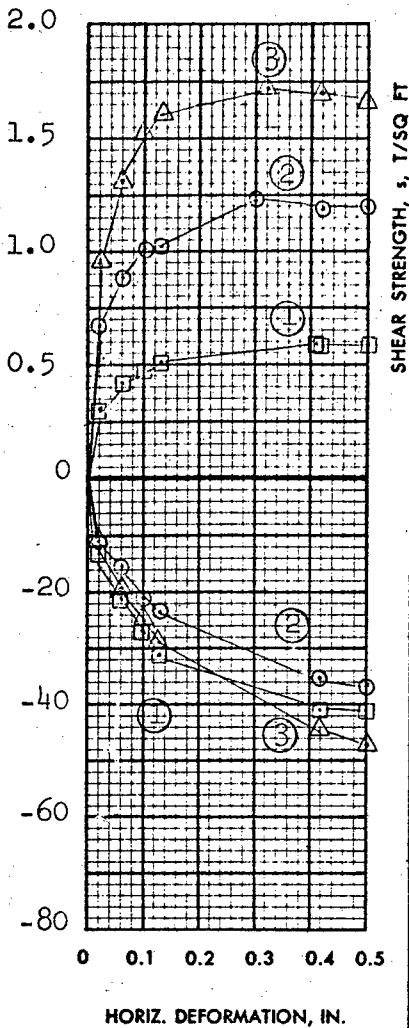
DATE 04 APR 78

RCH

DIRECT SHEAR TEST REPORT

SHEAR STRESS, τ , T/SQ FT

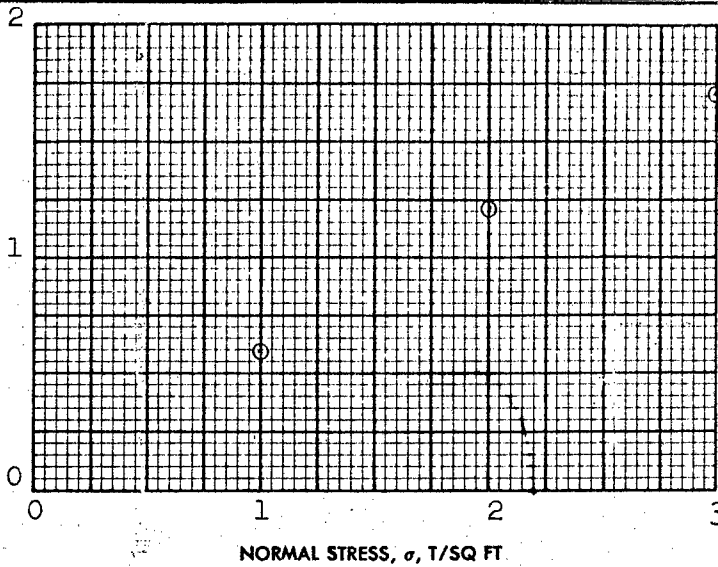
VERTICAL DEFORMATION, IN. $\times 10^{-3}$



SHEAR STRENGTH PARAMETERS

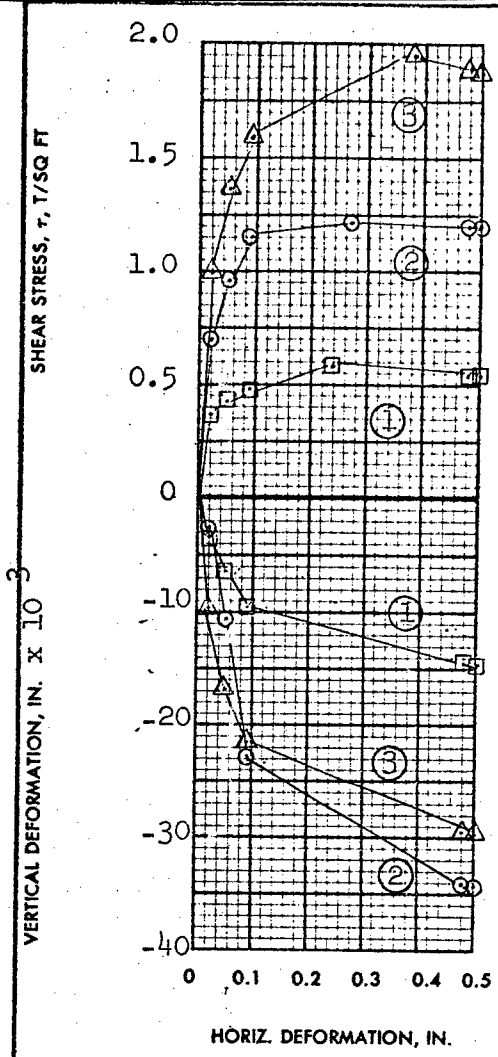
$\phi' =$ _____
 $\tan \phi' =$ _____
 $c' =$ _____ T/SQ FT

☐ CONTROLLED STRESS
☒ CONTROLLED STRAIN



TEST NO.		1	2	3	
INITIAL	WATER CONTENT	w_o	8.3 %	8.2 %	8.3 %
	VOID RATIO	e_o	0.867	0.856	0.887
	SATURATION	S_o	26.1 %	26.3 %	25.5 %
	DRY DENSITY, LB/CU FT	γ_d	91.3	91.8	90.3
VOID RATIO AFTER CONSOLIDATION		e_c			
TIME FOR 50 PERCENT CONSOLIDATION, MIN		t_{50}	3	< 1	< 1
FINAL	WATER CONTENT	w_f	21.0 %	18.0 %	17.2 %
	VOID RATIO	e_f			
	SATURATION	S_f	%	%	%
NORMAL STRESS, T/SQ FT		σ	1.0	2.0	3.0
MAXIMUM SHEAR STRESS, T/SQ FT		τ_{max}	0.59	1.22	1.73
ACTUAL TIME TO FAILURE, MIN		t_f	645	960	1020
RATE OF STRAIN, IN./MIN			.00033	.00033	.00033
ULTIMATE SHEAR STRESS, T/SQ FT		τ_{ult}			

TYPE OF SPECIMEN		UNDISTURBED		3.00 IN. SQUARE		0.547 IN. THICK	
CLASSIFICATION SANDY CLAY (CL), LIGHT BROWN							
LL	39	PL	17	PI	22	G_s	2.73
REMARKS				PROJECT DIKE STABILITY			
				ROCKY MOUNTAIN ARSENAL			
				AREA			
				BORING NO. 483-U		SAMPLE NO. 9	
				DEPTH EL 21.2-22.0		DATE 05 APR 78	
RCH				DIRECT SHEAR TEST REPORT			



SHEAR STRENGTH PARAMETERS

$\phi' =$ _____
 $\tan \phi' =$ _____
 $c' =$ _____ T/SQ FT

- ☐ CONTROLLED STRESS
- ☒ CONTROLLED STRAIN

TEST NO.		1	2	3	
INITIAL	WATER CONTENT	w_o	6.5 %	6.5%	6.6%
	VOID RATIO	e_o	0.740	0.744	0.758
	SATURATION	S_o	24.1 %	23.9 %	23.9 %
	DRY DENSITY, LB/CU FT	γ_d	98.3	98.1	97.3
VOID RATIO AFTER CONSOLIDATION		e_c			
TIME FOR 50 PERCENT CONSOLIDATION, MIN		t_{50}	5	3	3
FINAL	WATER CONTENT	w_f	19.2 %	16.5%	15.1%
	VOID RATIO	e_f			
	SATURATION	S_f	%	%	%
NORMAL STRESS, T/SQ FT		σ	1.0	2.0	3.0
MAXIMUM SHEAR STRESS, T/SQ FT		τ_{max}	0.58	1.22	1.95
ACTUAL TIME TO FAILURE, MIN		t_f	660	720	990
RATE OF STRAIN, IN./MIN			.00024	.00024	.00024
ULTIMATE SHEAR STRESS, T/SQ FT		τ_{ult}			

TYPE OF SPECIMEN		UNDISTURBED		3.00 IN. SQUARE		0.547 IN. THICK	
CLASSIFICATION SANDY CLAY (CL), BROWN							
LL	28	PL	16	PI	12	G.	2.74
REMARKS				PROJECT DIKE STABILITY			
				ROCKY MOUNTAIN ARSENAL			
				AREA			
				BORING NO. 483-U		SAMPLE NO. 10	
				DEPTH EL 25.0-26.3		DATE 05 APR 78	
RCH				DIRECT SHEAR TEST REPORT			

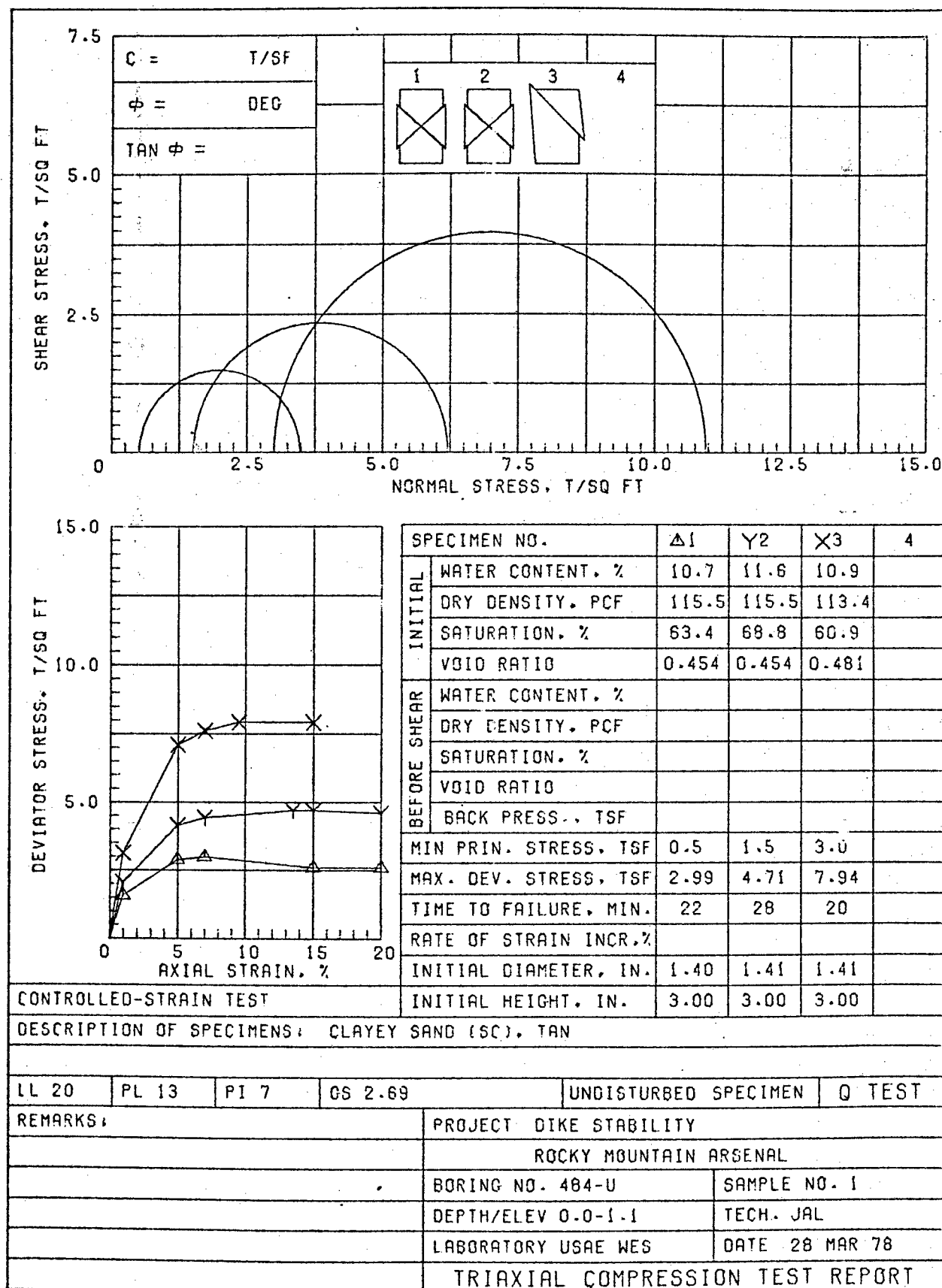


Figure 61

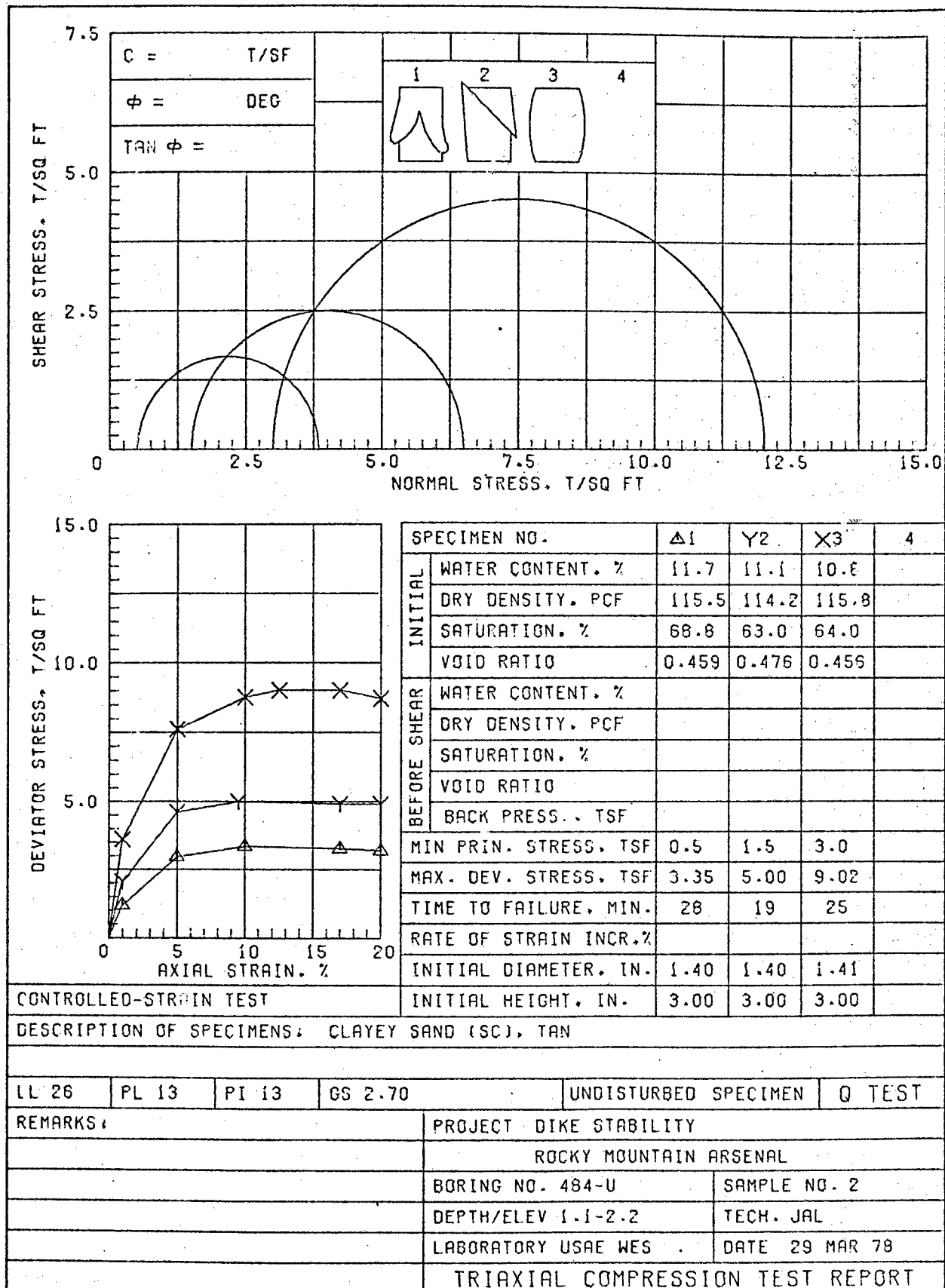


Figure 62

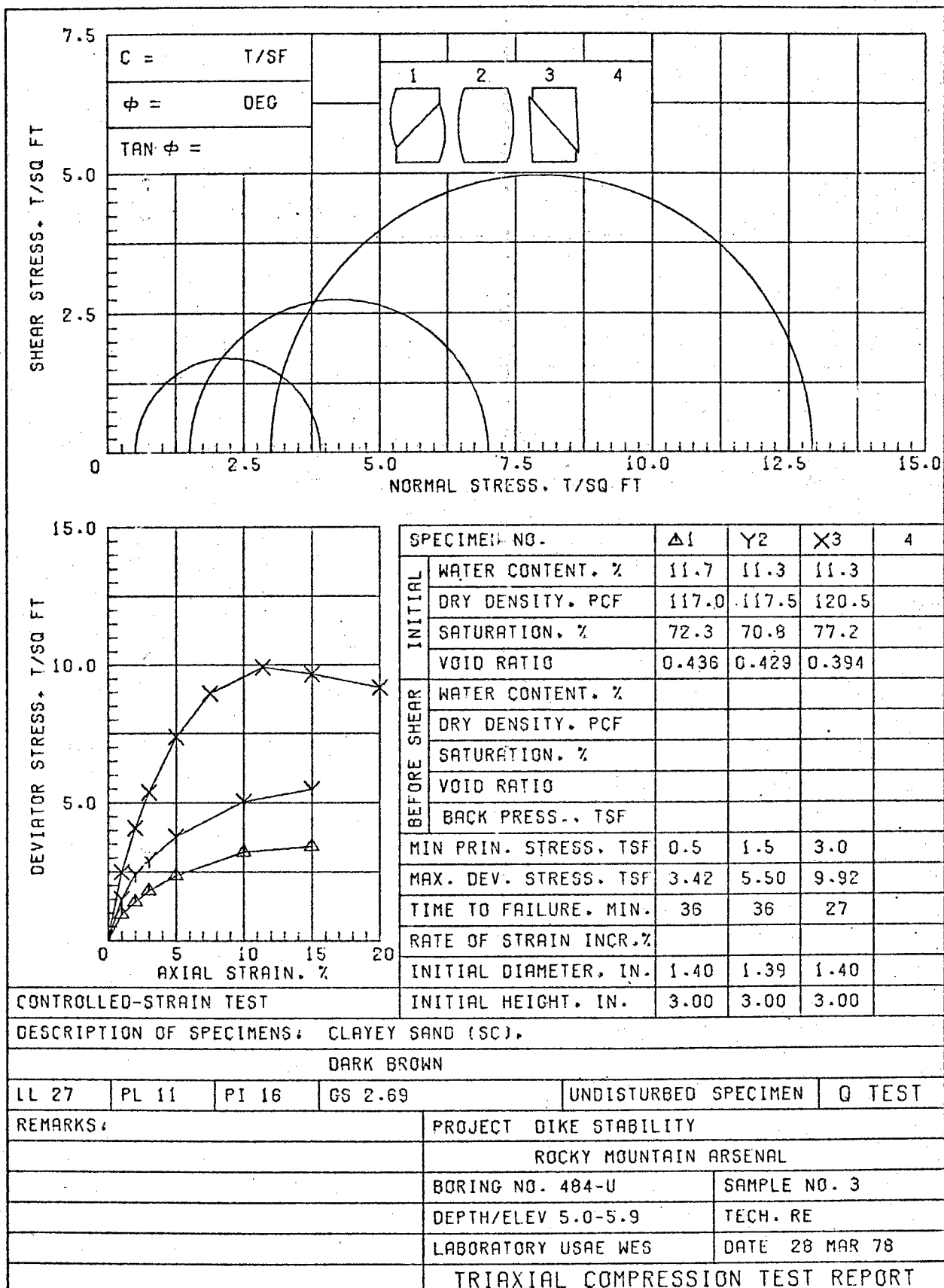


Figure 63

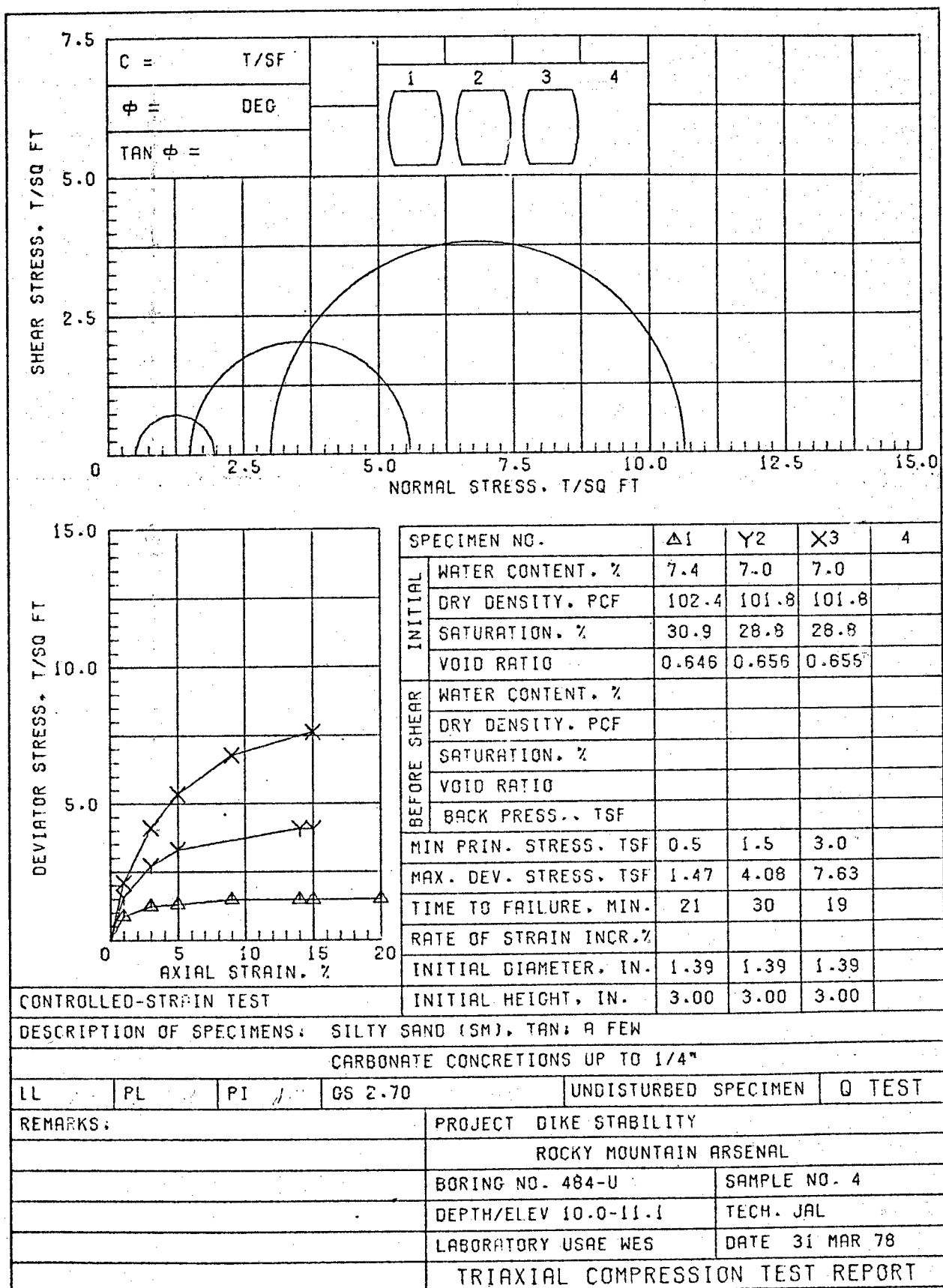
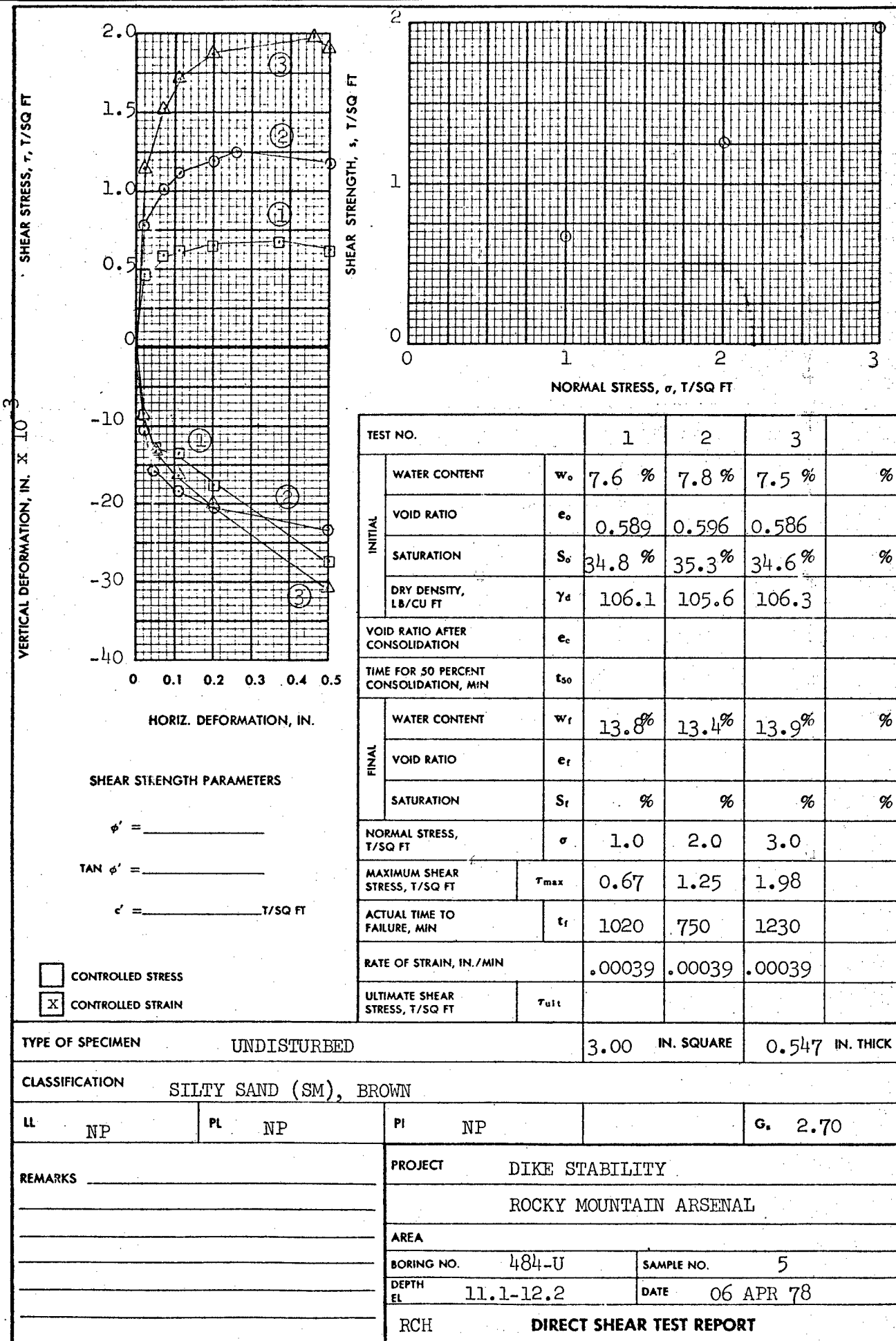
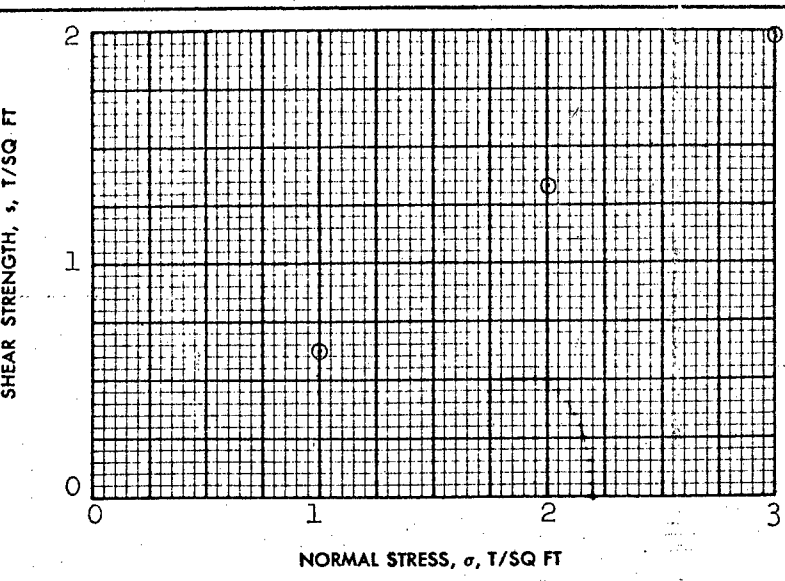
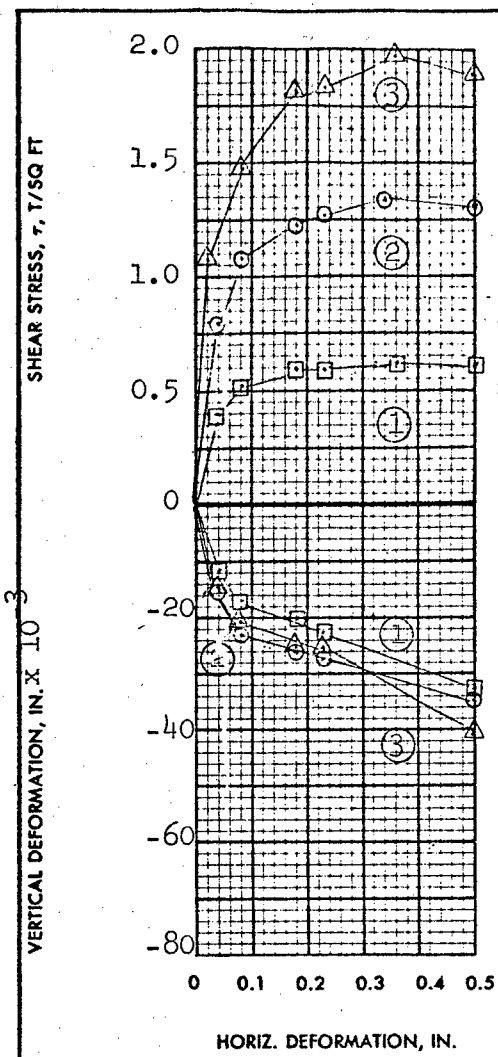


Figure 64





SHEAR STRENGTH PARAMETERS

$\phi' =$ _____
 $\tan \phi' =$ _____
 $c' =$ _____ T/SQ FT

- ☐ CONTROLLED STRESS
☒ CONTROLLED STRAIN

TEST NO.		1	2	3	
INITIAL	WATER CONTENT	w_o 10.3 %	10.7 %	11.0 %	%
	VOID RATIO	e_o 0.795	0.793	0.803	
	SATURATION	S_o 35.5 %	37.0 %	37.5 %	%
	DRY DENSITY, LB/CU FT	γ_d 95.3	95.4	94.9	
VOID RATIO AFTER CONSOLIDATION		e_c			
TIME FOR 50 PERCENT CONSOLIDATION, MIN		t_{50}			
FINAL	WATER CONTENT	w_f 16.2 %	15.4 %	15.0 %	%
	VOID RATIO	e_f			
	SATURATION	S_f	%	%	%
NORMAL STRESS, T/SQ FT		σ	1.0	2.0	3.0
MAXIMUM SHEAR STRESS, T/SQ FT		τ_{max}	0.63	1.34	1.98
ACTUAL TIME TO FAILURE, MIN		t_f	900	870	900
RATE OF STRAIN, IN./MIN			.00039	.00039	.00039
ULTIMATE SHEAR STRESS, T/SQ FT		τ_{ult}			

TYPE OF SPECIMEN **UNDISTURBED** **3.00 IN. SQUARE** **0.547 IN. THICK**

CLASSIFICATION **CLAYEY SAND (SC), BROWN**

LL **26** PL **11** PI **15** **G_s 2.74**

REMARKS	PROJECT DIKE STABILITY	
	ROCKY MOUNTAIN ARSENAL	
	AREA	
	BORING NO. 484-U	SAMPLE NO. 6
	DEPTH EL 15.0-16.1	DATE 07 APR 78
RCH		DIRECT SHEAR TEST REPORT

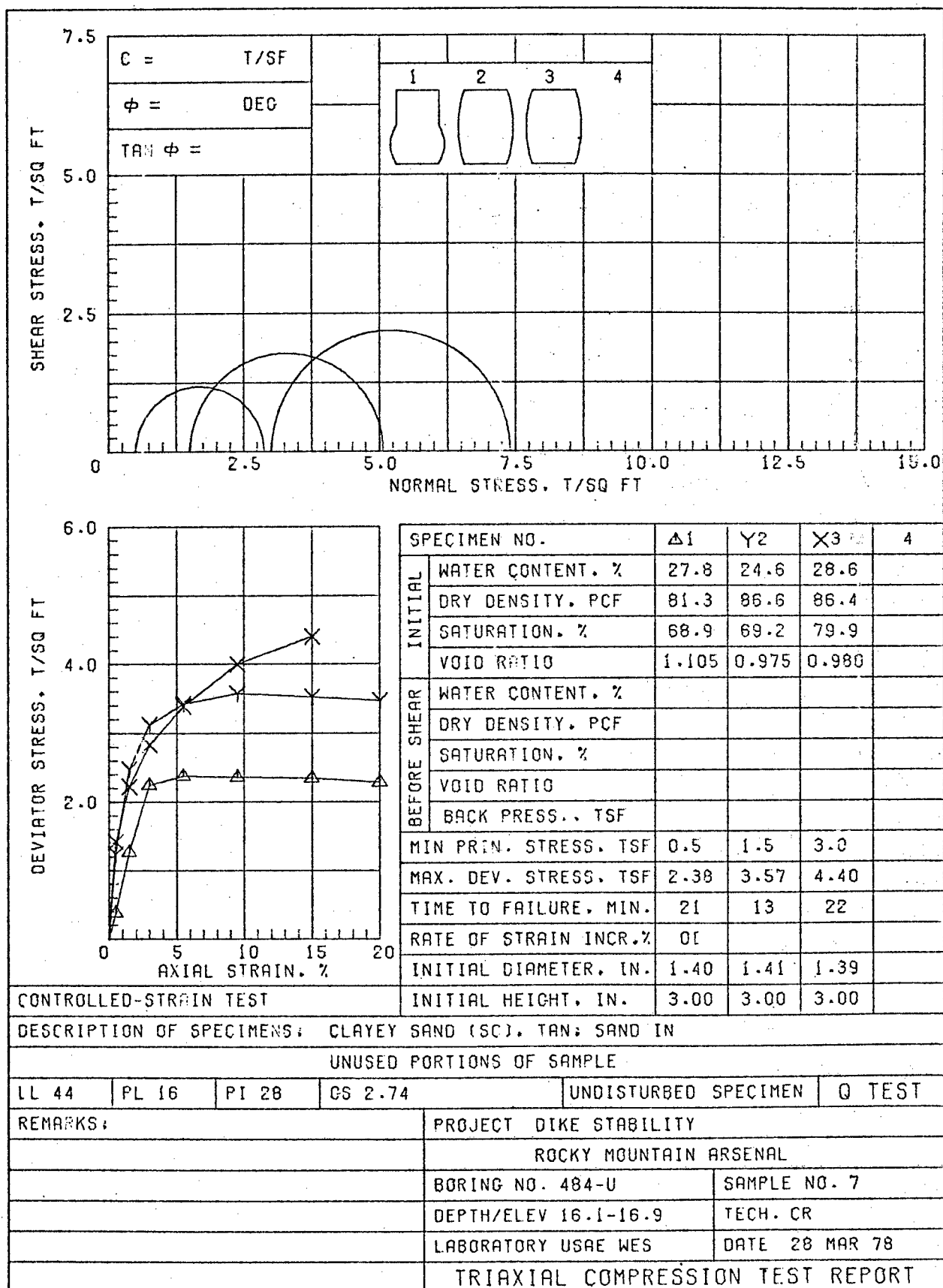


Figure 67

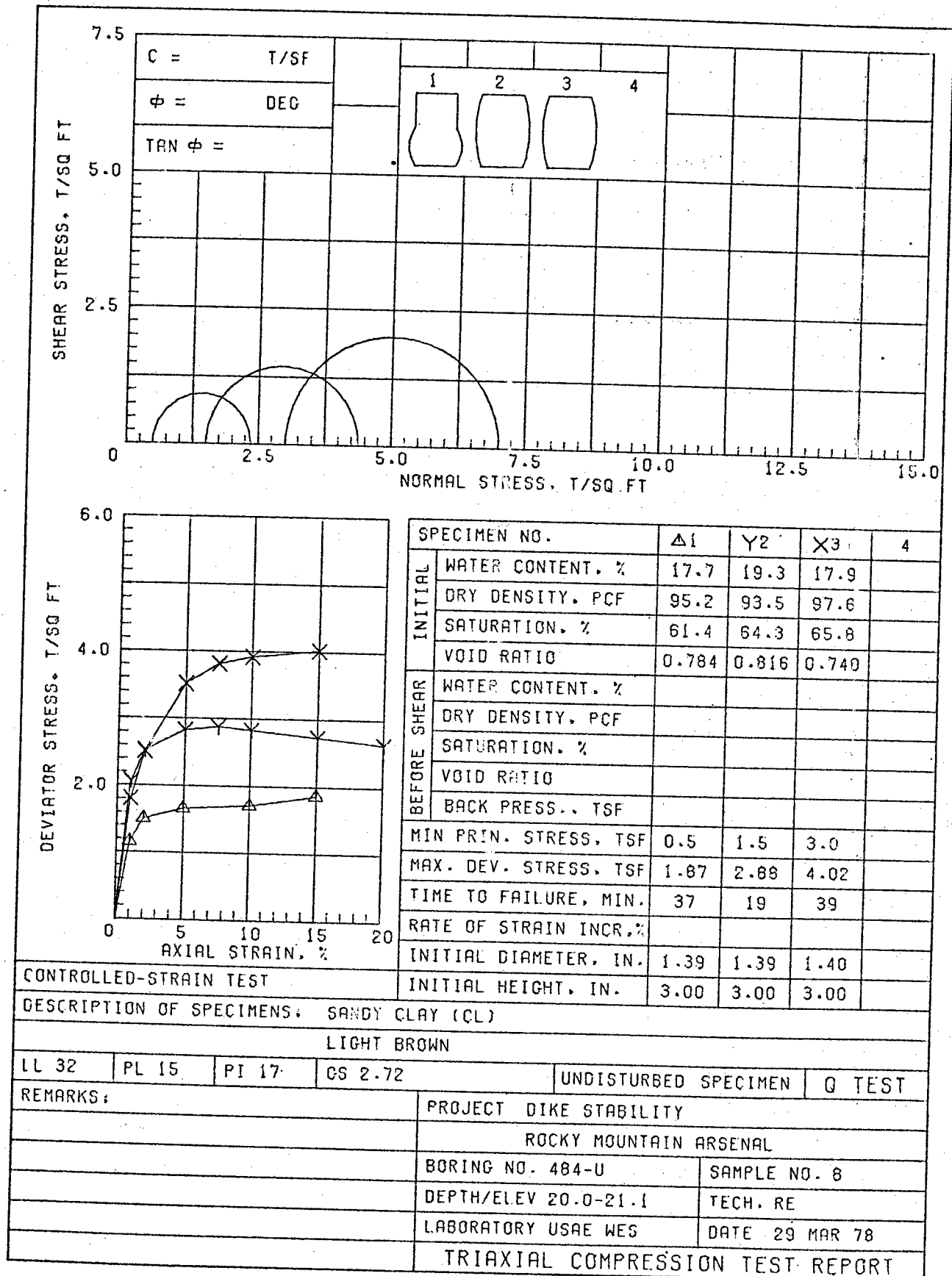


Figure 68

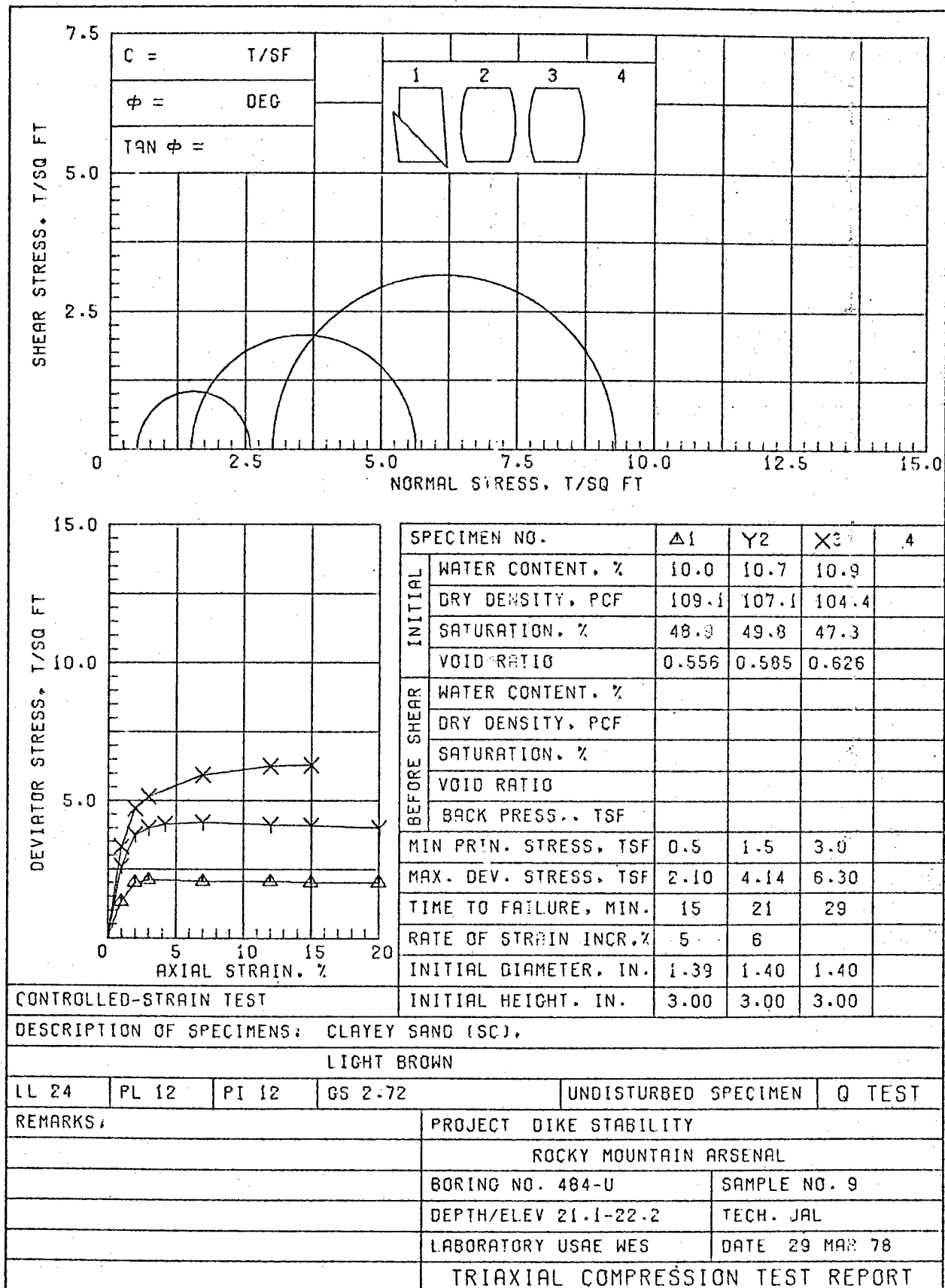


Figure 69

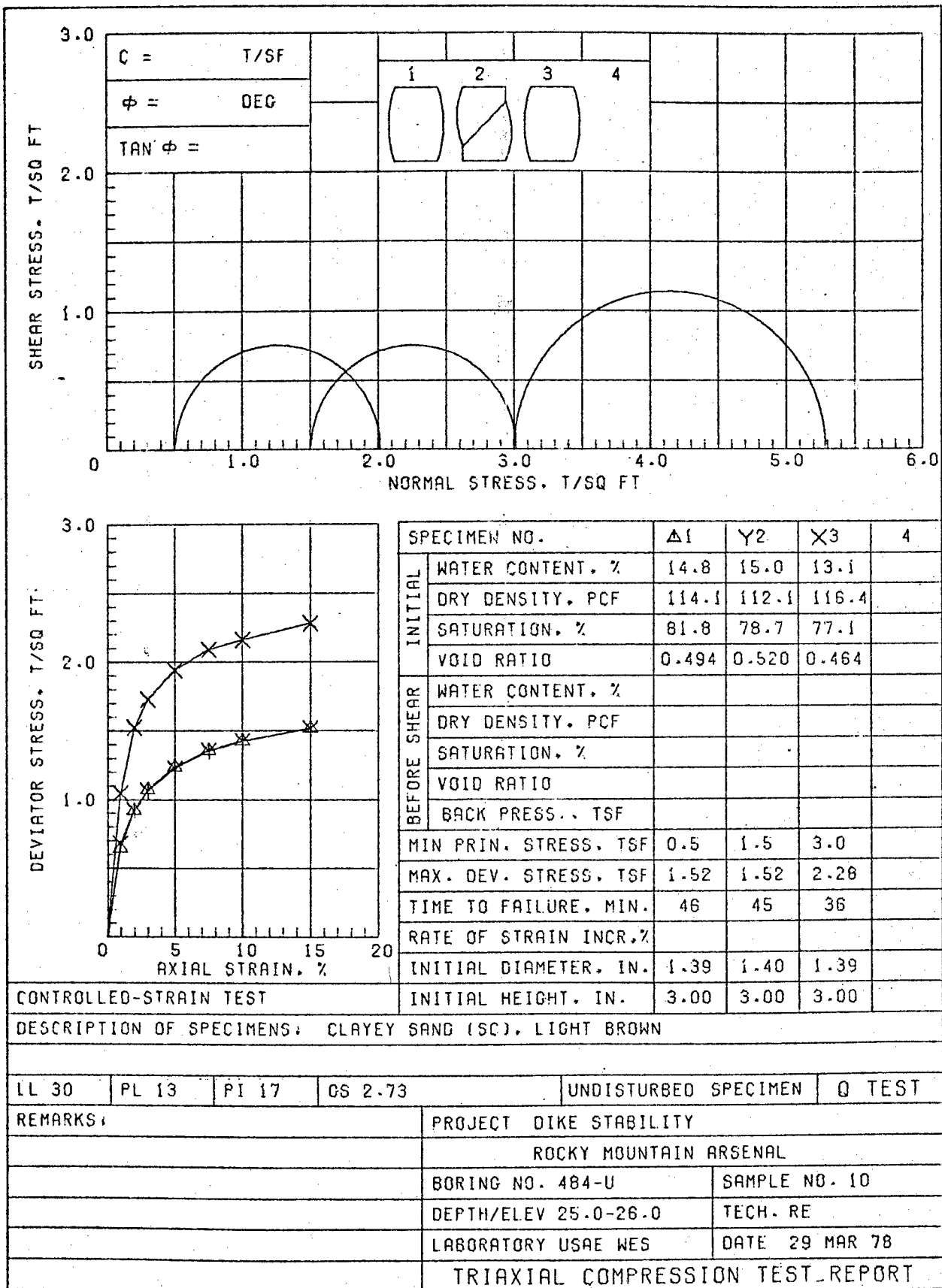


Figure 70

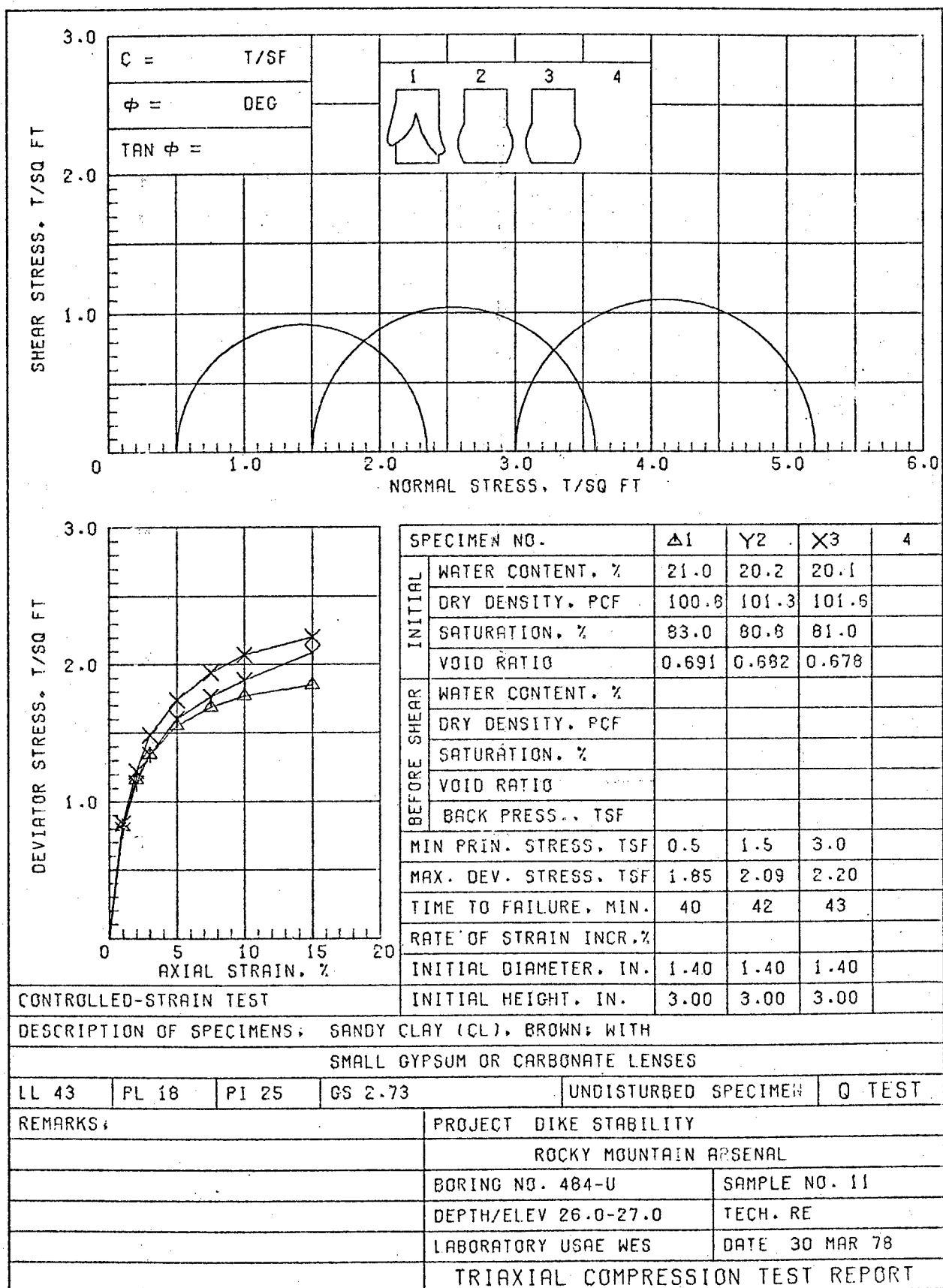
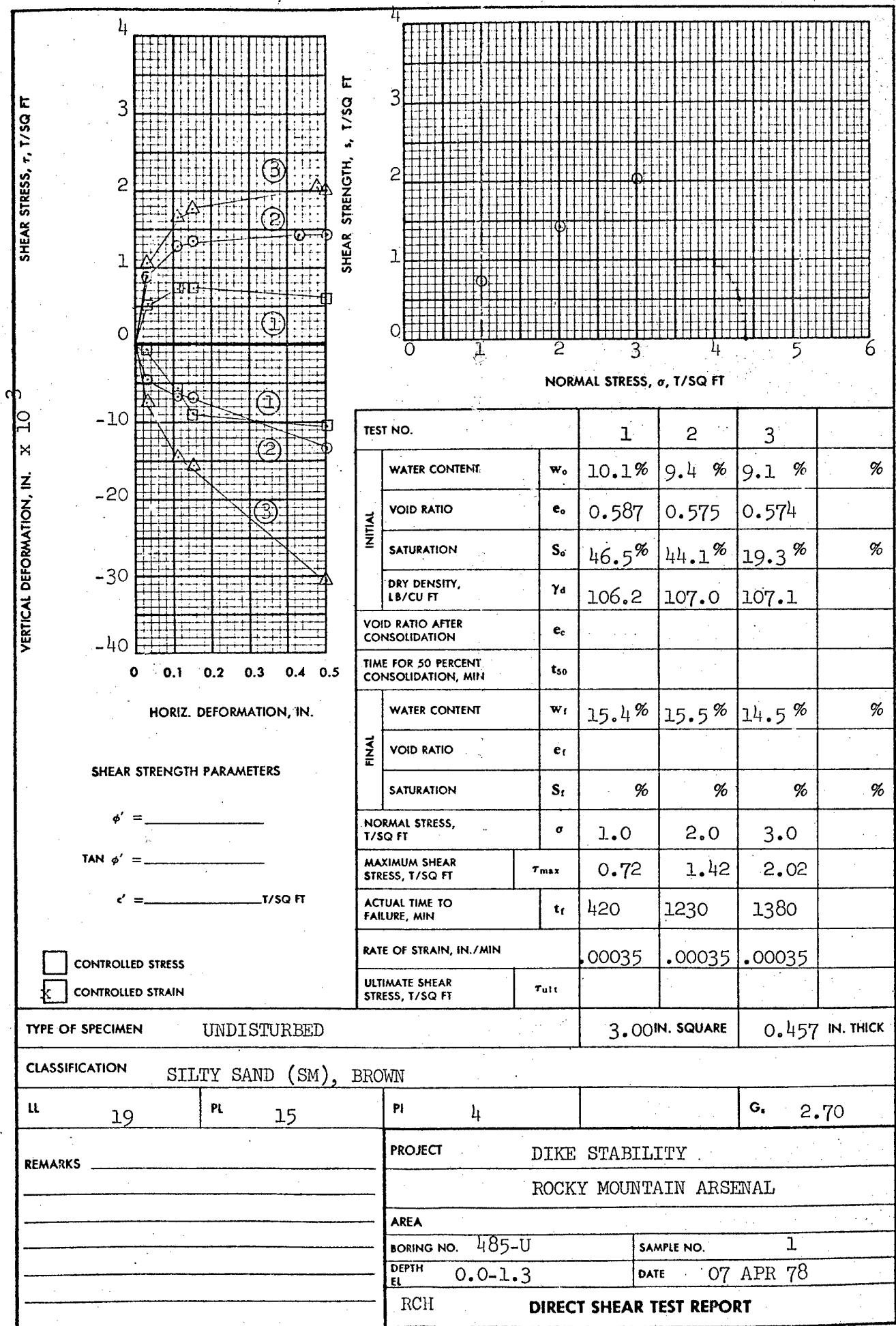
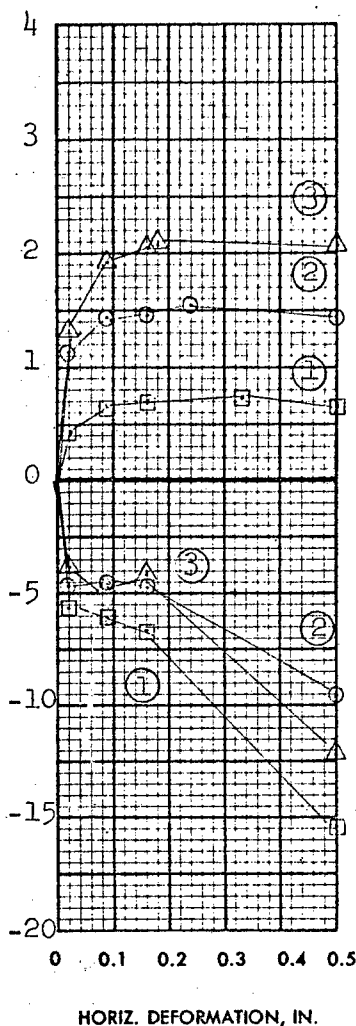


Figure 71



SHEAR STRESS, τ , T/SQ FT

VERTICAL DEFORMATION, IN. $\times 10^{-3}$

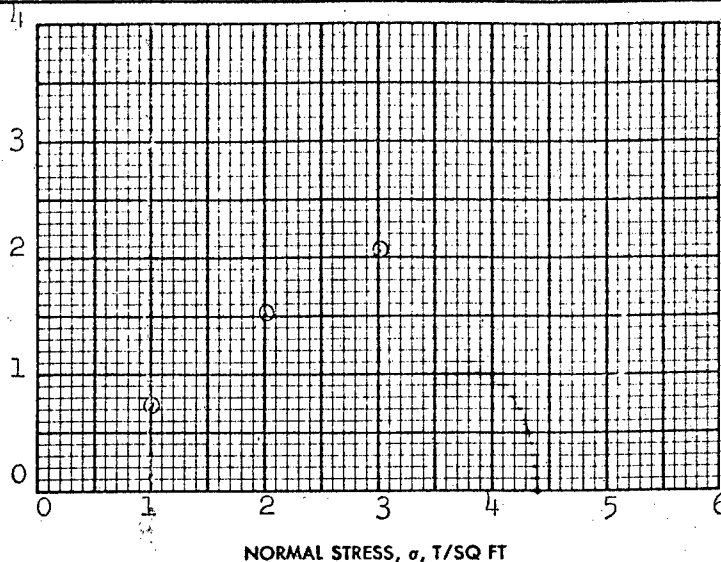


SHEAR STRENGTH PARAMETERS

$\phi' =$ _____
 $\tan \phi' =$ _____
 $c' =$ _____ T/SQ FT

☐ CONTROLLED STRESS
☒ CONTROLLED STRAIN

SHEAR STRENGTH, s , T/SQ FT



TEST NO.		1	2	3	
INITIAL	WATER CONTENT	w_o 8.8 %	9.8 %	9.1 %	%
	VOID RATIO	e_o 0.467	0.467	0.472	
	SATURATION	S_o 50.9 %	56.6 %	52.0 %	%
	DRY DENSITY, LB/CU FT	γ_d 114.9	114.9	114.5	
VOID RATIO AFTER CONSOLIDATION		e_c			
TIME FOR 50 PERCENT CONSOLIDATION, MIN		t_{50}			
FINAL	WATER CONTENT	w_f 14.3 %	14.8 %	14.6 %	%
	VOID RATIO	e_f			
	SATURATION	S_f	%	%	%
NORMAL STRESS, T/SQ FT		σ	1.0	2.0	3.0
MAXIMUM SHEAR STRESS, T/SQ FT		τ_{max}	0.73	1.51	2.06
ACTUAL TIME TO FAILURE, MIN		t_f	870	660	510
RATE OF STRAIN, IN./MIN			.00038	.00038	.00038
ULTIMATE SHEAR STRESS, T/SQ FT		τ_{ult}			

TYPE OF SPECIMEN UNDISTURBED 3.00 IN. SQUARE 0.544 IN. THICK

CLASSIFICATION SILTY SAND (SM), BROWN

LL 18 PL 14 PI 4 G. 2.70

REMARKS _____

PROJECT DIKE STABILITY

ROCKY MOUNTAIN ARSENAL

AREA

BORING NO. 485-U

SAMPLE NO. 2

DEPTH EL 5.0-6.0

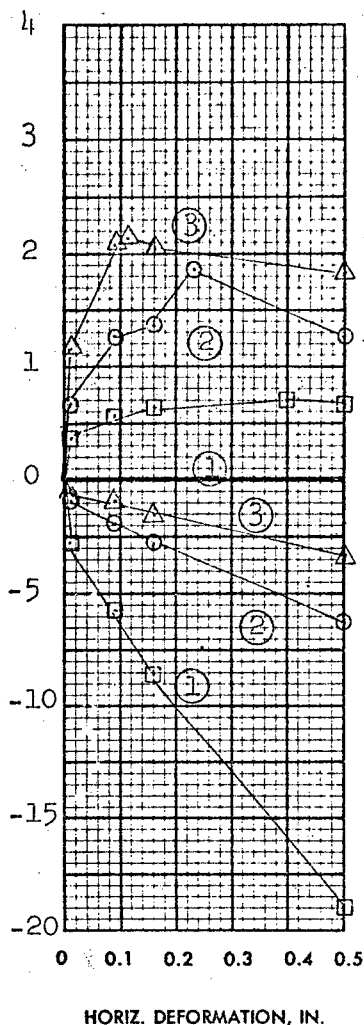
DATE 08 APR 78

RCH

DIRECT SHEAR TEST REPORT

-3
VERTICAL DEFORMATION, IN. $\times 10^{-3}$

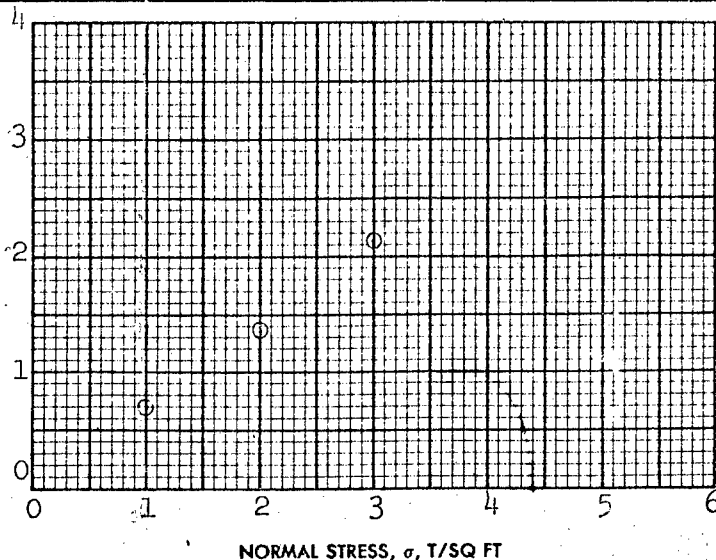
SHEAR STRESS, τ , T/SQ FT



SHEAR STRENGTH PARAMETERS

$\phi' =$ _____
 $\tan \phi' =$ _____
 $c' =$ _____ T/SQ FT

- ☐ CONTROLLED STRESS
☒ CONTROLLED STRAIN



TEST NO.			1	2	3	
INITIAL	WATER CONTENT	w _o	13.0%	12.9 %	13.0%	%
	VOID RATIO	e _o	0.497	0.500	0.504	
	SATURATION	S _o	70.6%	70.0 %	69.6 %	%
	DRY DENSITY, LB/CU FT	γ _d	112.6	112.3	112.1	
VOID RATIO AFTER CONSOLIDATION		e _c				
TIME FOR 50 PERCENT CONSOLIDATION, MIN		t ₅₀				
FINAL	WATER CONTENT	w _f	14.9%	14.6%	15.0%	%
	VOID RATIO	e _f				
	SATURATION	S _f	%	%	%	%
NORMAL STRESS, T/SQ FT		σ	1.0	2.0	3.0	
MAXIMUM SHEAR STRESS, T/SQ FT		τ _{max}	0.70	1.38	2.11	
ACTUAL TIME TO FAILURE, MIN		t _f	1050	630	360	
RATE OF STRAIN, IN./MIN			.00040	.00040	.00040	
ULTIMATE SHEAR STRESS, T/SQ FT		τ _{ult}				

TYPE OF SPECIMEN UNDISTURBED

3.00 IN. SQUARE 0.544 IN. THICK

CLASSIFICATION SILTY SAND (SM), BROWN

LL 20 PL 16 PI 4 G_s 2.70

REMARKS _____

PROJECT DIKE STABILITY

ROCKY MOUNTAIN ARSENAL

AREA

BORING NO. 485-U

SAMPLE NO. 3

DEPTH EL 6.0-7.0

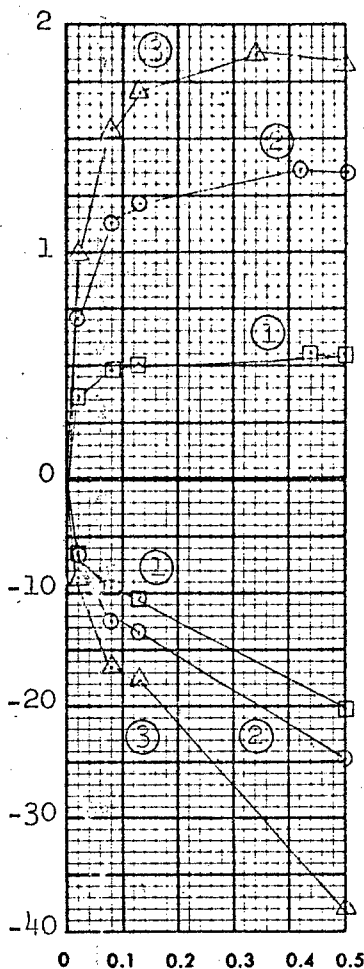
DATE 09 APR 78

RCH

DIRECT SHEAR TEST REPORT

SHEAR STRESS, τ , T/SQ FT

VERTICAL DEFORMATION, IN. $\times 10^{-3}$



HORIZ. DEFORMATION, IN.

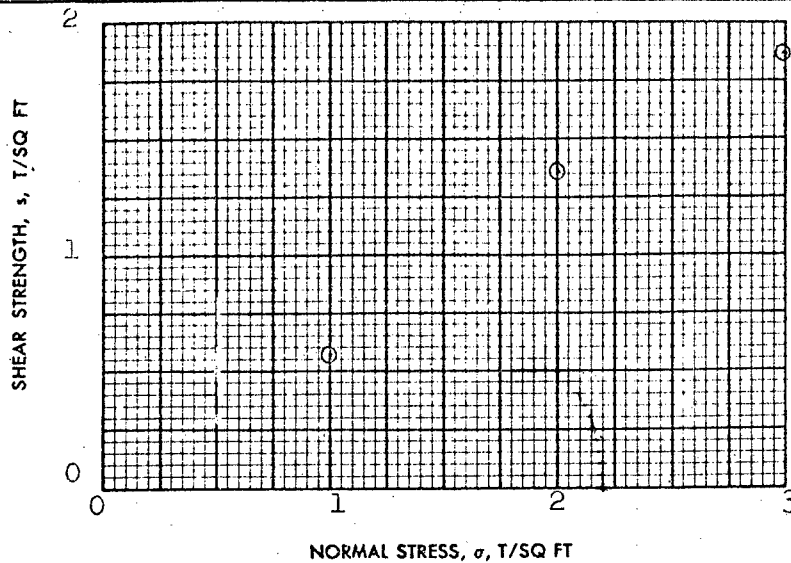
SHEAR STRENGTH PARAMETERS

$\phi' =$ _____

$\tan \phi' =$ _____

$c' =$ _____ T/SQ FT

- ☐ CONTROLLED STRESS
☒ CONTROLLED STRAIN



NORMAL STRESS, σ , T/SQ FT

TEST NO.		1	2	3	
INITIAL	WATER CONTENT	w_o 6.1 %	7.0 %	7.1 %	%
	VOID RATIO	e_o 0.694	0.697	0.706	
	SATURATION	S_o 23.7 %	27.1 %	27.2 %	%
	DRY DENSITY, LB/CU FT	γ_d 99.5	99.3	98.8	
VOID RATIO AFTER CONSOLIDATION		e_c			
TIME FOR 50 PERCENT CONSOLIDATION, MIN		t_{50}			
FINAL	WATER CONTENT	w_f 14.7 %	14.7 %	14.1 %	%
	VOID RATIO	e_f			
	SATURATION	S_f	%	%	%
NORMAL STRESS, T/SQ FT		σ	1.0	2.0	3.0
MAXIMUM SHEAR STRESS, T/SQ FT		τ_{max}	0.56	1.36	1.87
ACTUAL TIME TO FAILURE, MIN		t_f	1230	1200	960
RATE OF STRAIN, IN./MIN			.00036	.00036	.00036
ULTIMATE SHEAR STRESS, T/SQ FT		τ_{ult}			

TYPE OF SPECIMEN **UNDISTURBED** **3.00 IN. SQUARE** **0.544 IN. THICK**

CLASSIFICATION **SILTY SAND (SM), BROWN**

LL **19** PL **16** PI **2** G. **2.70**

REMARKS _____

PROJECT **DIKE STABILITY**
ROCKY MOUNTAIN ARSENAL

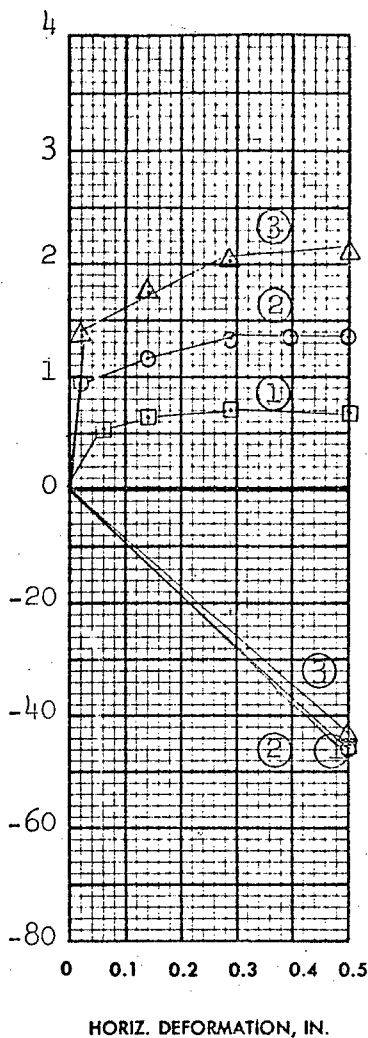
AREA

BORING NO. **485-U** SAMPLE NO. **4**
 DEPTH **10.0-11.0** DATE **12 APR 78**

RCH **DIRECT SHEAR TEST REPORT**

SHEAR STRESS, τ , T/SQ FT

VERTICAL DEFORMATION, IN. $\times 10^3$



SHEAR STRENGTH PARAMETERS

$\phi' =$ _____

$\tan \phi' =$ _____

$c' =$ _____ T/SQ FT

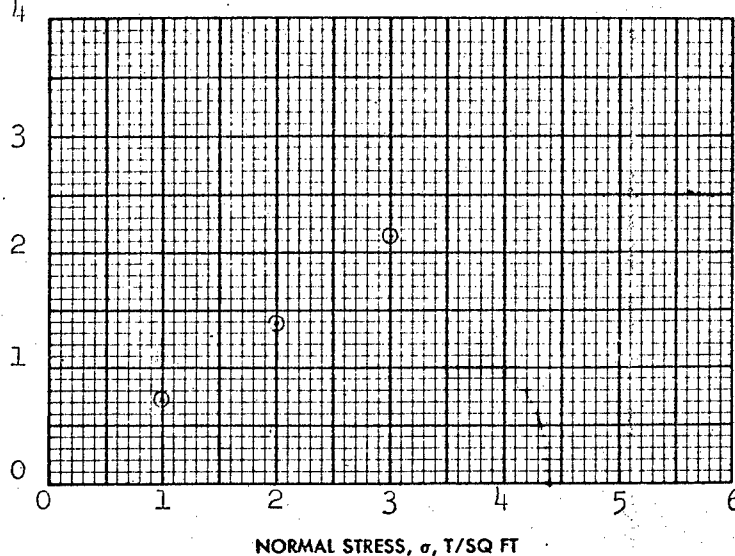


CONTROLLED STRESS



CONTROLLED STRAIN

SHEAR STRENGTH, s , T/SQ FT



TEST NO.		1	2	3	
INITIAL	WATER CONTENT	w_o	7.3 %	7.1 %	7.3 %
	VOID RATIO	e_o	0.630	0.614	0.599
	SATURATION	S_o	31.2 %	31.2 %	32.9 %
	DRY DENSITY, LB/CU FT	γ_d	103.4	104.4	105.4
VOID RATIO AFTER CONSOLIDATION		e_c			
TIME FOR 50 PERCENT CONSOLIDATION, MIN		t_{50}			
FINAL	WATER CONTENT	w_f	16.9 %	16.5 %	14.8 %
	VOID RATIO	e_f			
	SATURATION	S_f	%	%	%
NORMAL STRESS, T/SQ FT		σ	1.0	2.0	3.0
MAXIMUM SHEAR STRESS, T/SQ FT		τ_{max}	0.71	1.39	2.12
ACTUAL TIME TO FAILURE, MIN		t_f	1020	1020	1200
RATE OF STRAIN, IN./MIN			.00032	.00032	.00032
ULTIMATE SHEAR STRESS, T/SQ FT		τ_{ult}			

TYPE OF SPECIMEN **UNDISTURBED** **3.00 IN. SQUARE** **0.584 IN. THICK**

CLASSIFICATION **SILTY SAND (SM), RED**

LL **21** PL **17** PI **4** **G_s 2.70**

REMARKS _____

PROJECT **DIKE STABILITY**

ROCKY MOUNTAIN ARSENAL

AREA

BORING NO. **485-U**

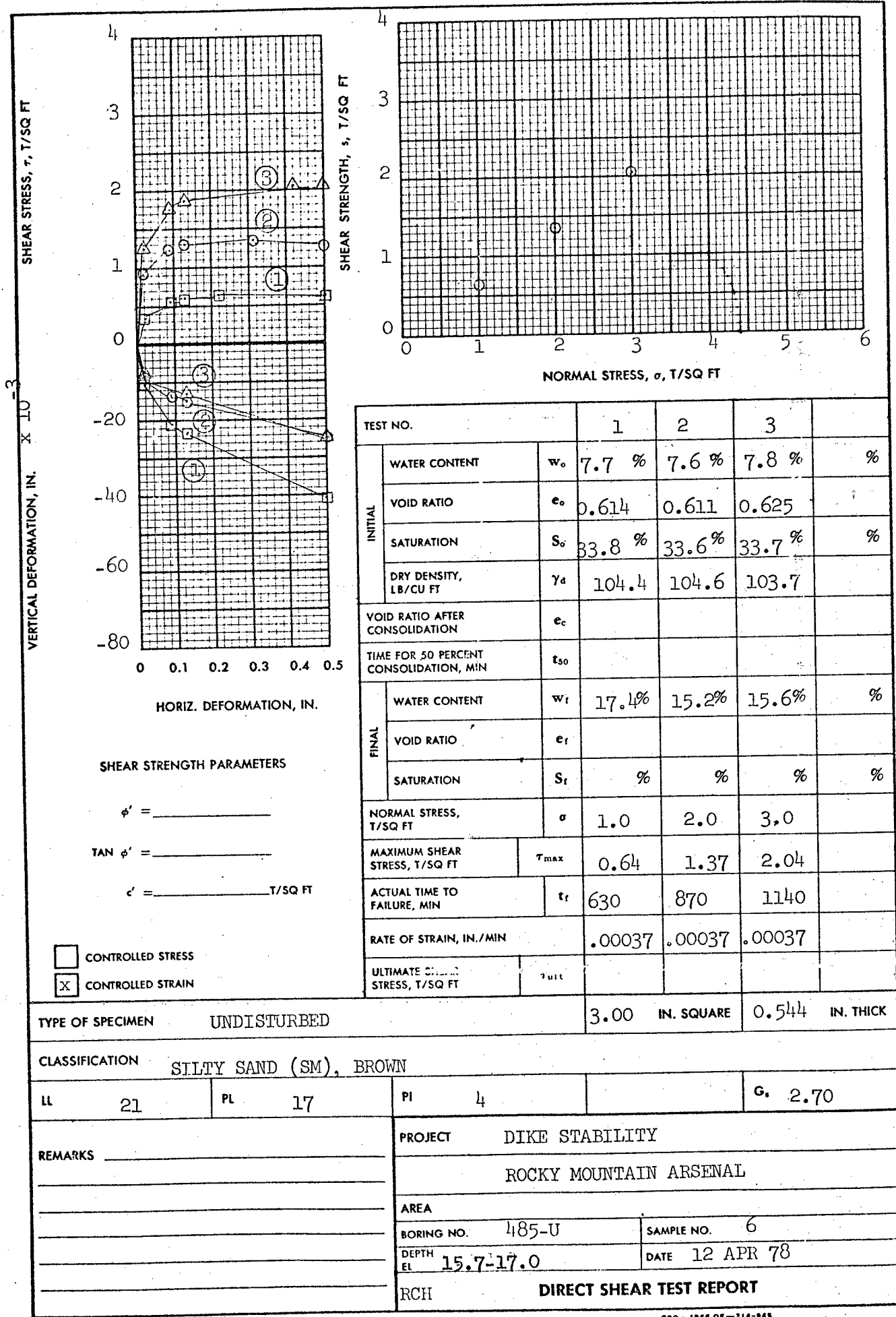
SAMPLE NO. **5**

DEPTH EL **11.0-12.0**

DATE **11 APR 78**

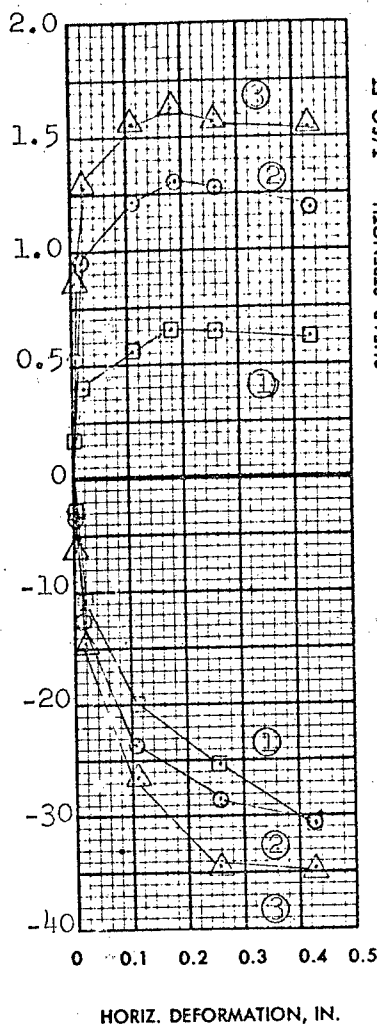
BWG

DIRECT SHEAR TEST REPORT



SHEAR STRESS, τ , T/SQ FT

VERTICAL DEFORMATION, IN. $\times 10^{-3}$



SHEAR STRENGTH PARAMETERS

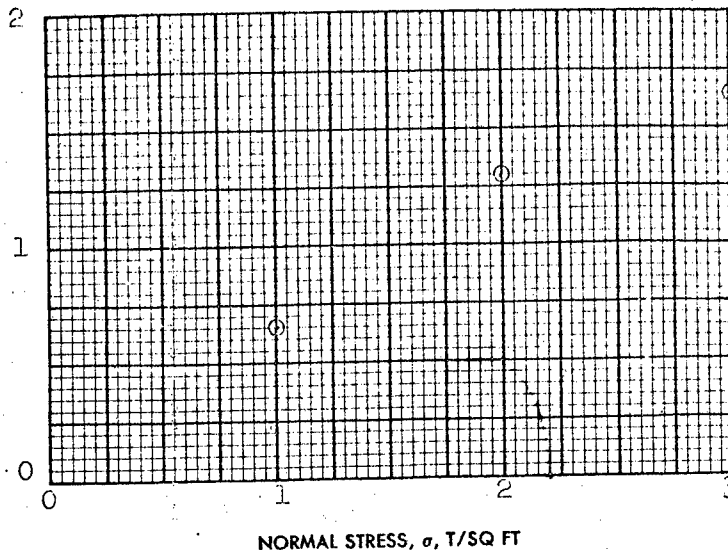
$\phi' =$ _____

$\tan \phi' =$ _____

$c' =$ _____ T/SQ FT



SHEAR STRENGTH, s , T/SQ FT



NORMAL STRESS, σ , T/SQ FT

TEST NO.		1	2	3	
INITIAL	WATER CONTENT	w_o	17.1%	17.3%	17.9%
	VOID RATIO	e_o	0.752	0.706	0.743
	SATURATION	S_o	62.1%	66.9%	65.7%
	DRY DENSITY, LB/CU FT	γ_d	97.3	99.9	97.8
VOID RATIO AFTER CONSOLIDATION		e_c			
TIME FOR 50 PERCENT CONSOLIDATION, MIN		t_{50}	10	4	4
FINAL	WATER CONTENT	w_f	24.3%	23.6%	22.2%
	VOID RATIO	e_f			
	SATURATION	S_f	%	%	%
NORMAL STRESS, T/SQ FT		σ	1.0	2.0	3.0
MAXIMUM SHEAR STRESS, T/SQ FT		τ_{max}	0.65	1.30	1.64
ACTUAL TIME TO FAILURE, MIN		t_f	1890	1260	1170
RATE OF STRAIN, IN./MIN			.00016	.00016	.00016
ULTIMATE SHEAR STRESS, T/SQ FT		τ_{ult}			

TYPE OF SPECIMEN **UNDISTURBED** **3.00 IN. SQUARE** **0.584 IN. THICK**

CLASSIFICATION **SANDY SILTY CLAY(CL), TAN AND RED MARBLED**

LL **40** PL **15** PI **25** **G_s 2.73**

REMARKS

PROJECT **DIKE STABILITY**

ROCKY MOUNTAIN ARSENAL

AREA

BORING NO. **485-U**

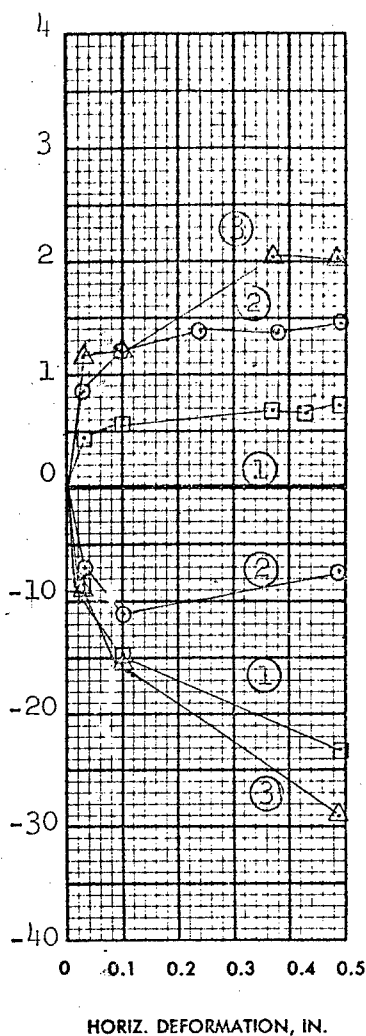
SAMPLE NO. **7**

DEPTH EL **20.35-21.6**

DATE **12 APR 78**

BWG

DIRECT SHEAR TEST REPORT

SHEAR STRESS, τ , T/SQ FTVERTICAL DEFORMATION, IN. $\times 10^{-3}$ 

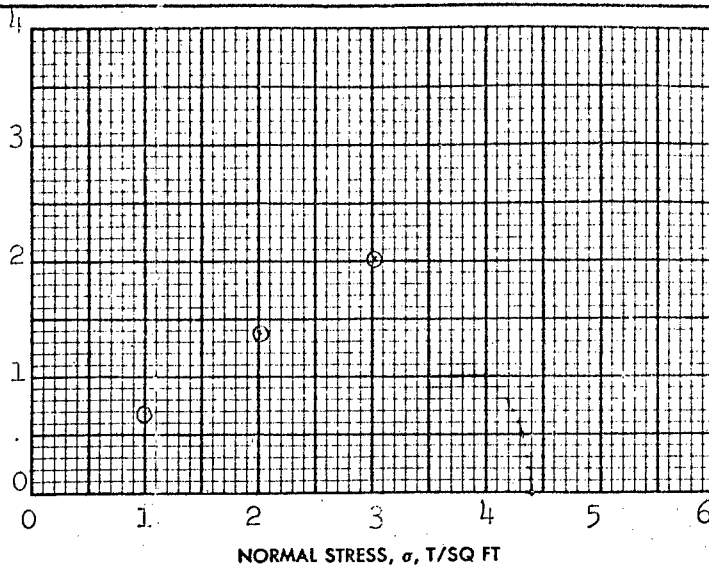
SHEAR STRENGTH PARAMETERS

 $\phi' =$ _____TAN $\phi' =$ _____ $c' =$ _____ T/SQ FT

CONTROLLED STRESS



CONTROLLED STRAIN

SHEAR STRENGTH, s , T/SQ FT

TEST NO.		1	2	3	
INITIAL	WATER CONTENT	w_o	16.4%	16.7%	15.6%
	VOID RATIO	e_o	0.561	0.564	0.551
	SATURATION	S_o	79.5%	80.5%	77.0%
	DRY DENSITY, LB/CU FT	γ_d	108.8	108.6	109.5
VOID RATIO AFTER CONSOLIDATION		e_c			
TIME FOR 50 PERCENT CONSOLIDATION, MIN		t_{50}			
FINAL	WATER CONTENT	w_f	16.2%	14.5%	13.1%
	VOID RATIO	e_f			
	SATURATION	S_f	%	%	%
NORMAL STRESS, T/SQ FT		σ	1.0	2.0	3.0
MAXIMUM SHEAR STRESS, T/SQ FT		τ_{max}	0.69	1.39	2.02
ACTUAL TIME TO FAILURE, MIN		t_f	1080	1080	1080
RATE OF STRAIN, IN./MIN			.00031	.00031	.00031
ULTIMATE SHEAR STRESS, T/SQ FT		τ_{ult}			

TYPE OF SPECIMEN

UNDISTURBED

3.00 IN. SQUARE

0.544 IN. THICK

CLASSIFICATION

CLAYEY SANDY GRAVEL (GC), BROWN

LL

36

PL

14

PI

22

G. 2.72

REMARKS

PROJECT

DIKE STABILITY

ROCKY MOUNTAIN ARSENAL

AREA

BORING NO.

485-U

SAMPLE NO.

8

DEPTH

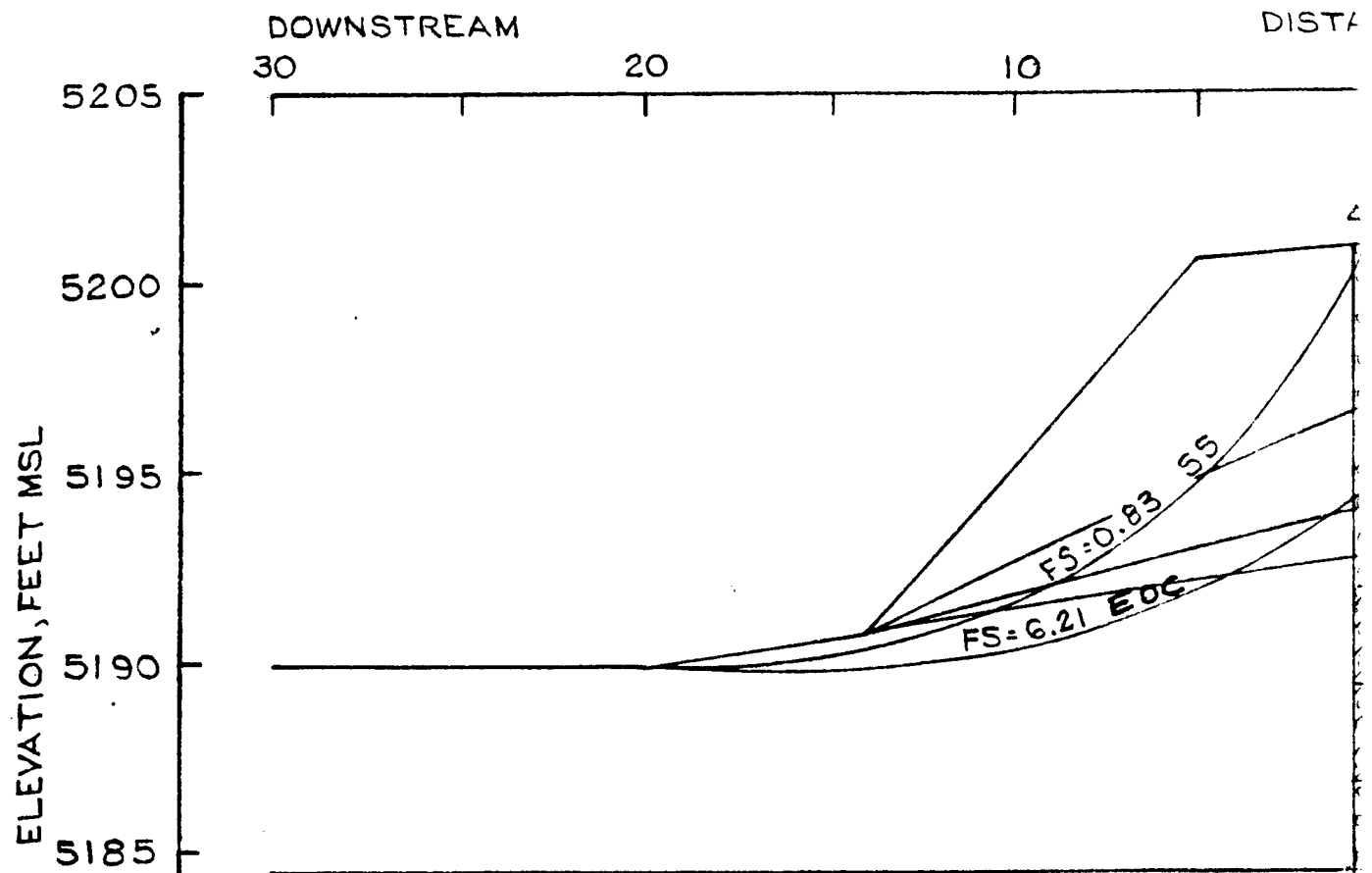
25.3-26.1

DATE

13 APR 78

RCH

DIRECT SHEAR TEST REPORT



ARC CENTER (X, Y)	SAFETY FACTOR (w/ EARTHQUAKE)	
	Q TEST	S TEST
-15.0, 5210	6.30	-
-15.0, 5215	6.21*	-
-15.0, 5220	6.44	-
-20.0, 5220	7.42	-
-20.0, 5225	7.07	-
-10.0, 5215	6.91	-
-17.5, 5209	-	0.83*
-12.5, 5207.5	-	1.10
-10.0, 5207.5	-	1.38
-15.0, 5210	-	0.97
-12.5, 5210	-	1.15

* MINIMUM

DISTANCE IN FEET FROM BORING

10

0

10

20

482

▽ HW 5199.0

▽ HW 5197.0

FS=0.83 SS

FS=6.21 EOC

SOIL #1

SOIL #2

OR
E)
ST
33*
0
38
37
5

30

40

UPSTREAM

50

SELECTED MEASURED SOIL PARAMETERS

SOIL	DENSITY, PCF	Q TEST		S TEST	
		ϕ	C	ϕ	C
1	132.0	32	900	34	0
2	115.0	15	840	32	0

 ∇ HW 5195

ASSUMED G.W 5190

5205

5200

5195

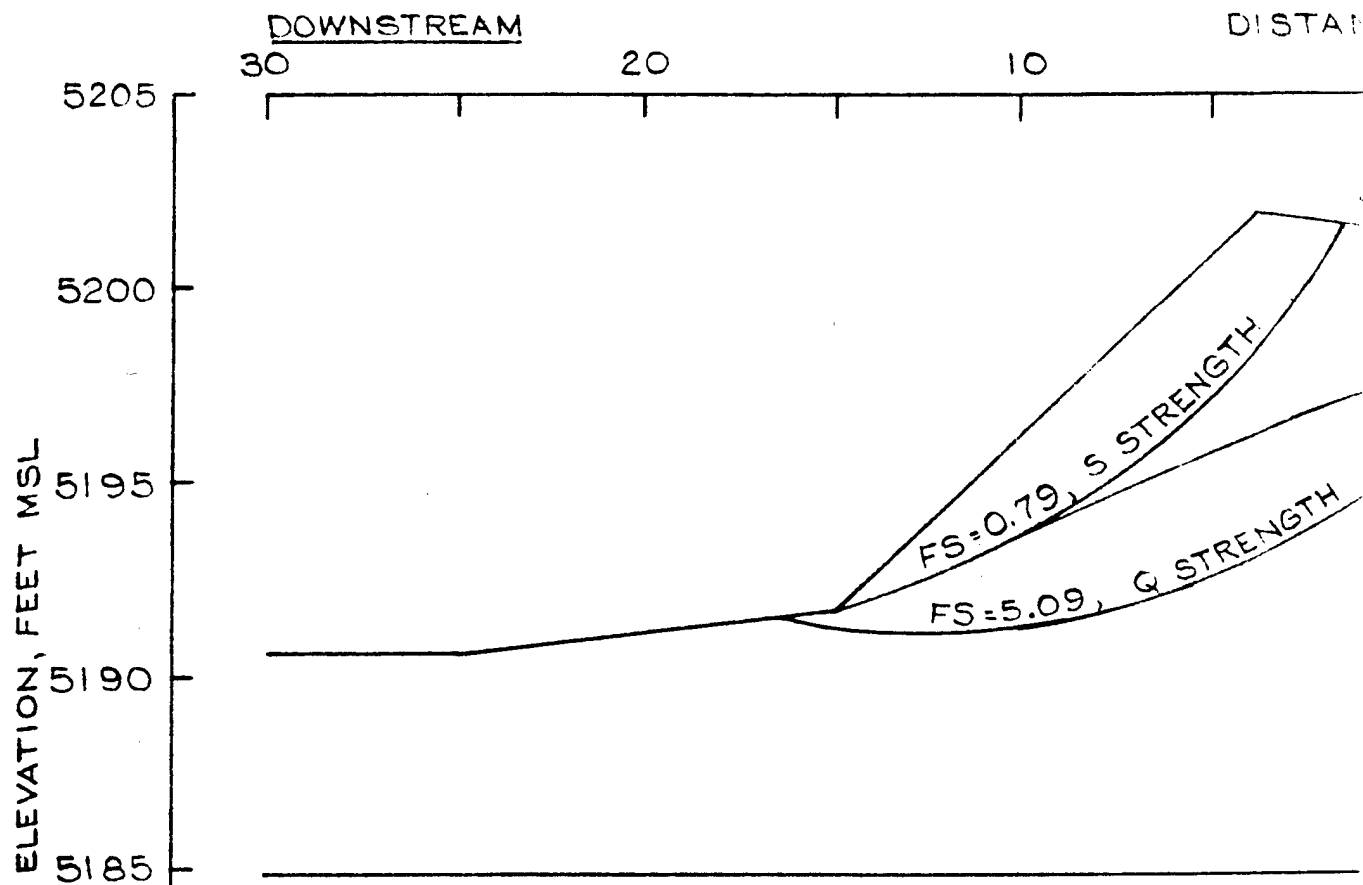
5190

5185

5180

ELEVATION, FEET MSL

DIKE STABILITY ANALYSIS
BASIN F
ROCKY MOUNTAIN ARSENAL
DENVER, COLORADO



ARC CENTER (X, Y)	SAFETY FACTOR (w/EARTHQUAKE)	
	Q TEST	S TEST
-20.0, 5212.5	8.60	0.79*
-17.5, 5212.5	6.26	0.94
-20.0, 5215.0	7.64	0.88
-17.5, 5215.0	6.05	1.00
-20.0, 5217.5	7.11	0.90
-12.5, 5210.0	5.10	-
-12.5, 5212.5	5.09*	-
-12.5, 5215.0	5.12	-
-15.0, 5212.5	5.41	-
-10.0, 5212.5	5.14	-

*MINIMUM

①

DISTANCE IN FEET FROM BORING

10

0

10

20

483

▽ HW 5199.5

FS=0.79, S STRENGTH

FS=5.09, Q STRENGTH

SOIL #1

SOIL #2

1

2

3*

4

3

2

2

②

UPSTREAM
50

20

30

40

SELECTED MEASURED SOIL PARAMETERS

SOIL	DENSITY, PCF	Q TEST		S TEST	
		ϕ	C	ϕ	C
1	132	30	900	34	0
2	115	15	840	32	0

V 5199.5

EL. 5190.5

EL. 5185.0

DIKE STABILITY
BASIN F
ROCKY MOUNTAIN
DENVER, COLO

30

40

UPSTREAM

50

SELECTED MEASURED SOIL PARAMETERS					
SOIL	DENSITY, PCF	Q TEST		S TEST	
		ϕ	C	ϕ	C
1	132	30	900	34	0
2	115	15	840	32	0

5205

5200

5195

5190

5185

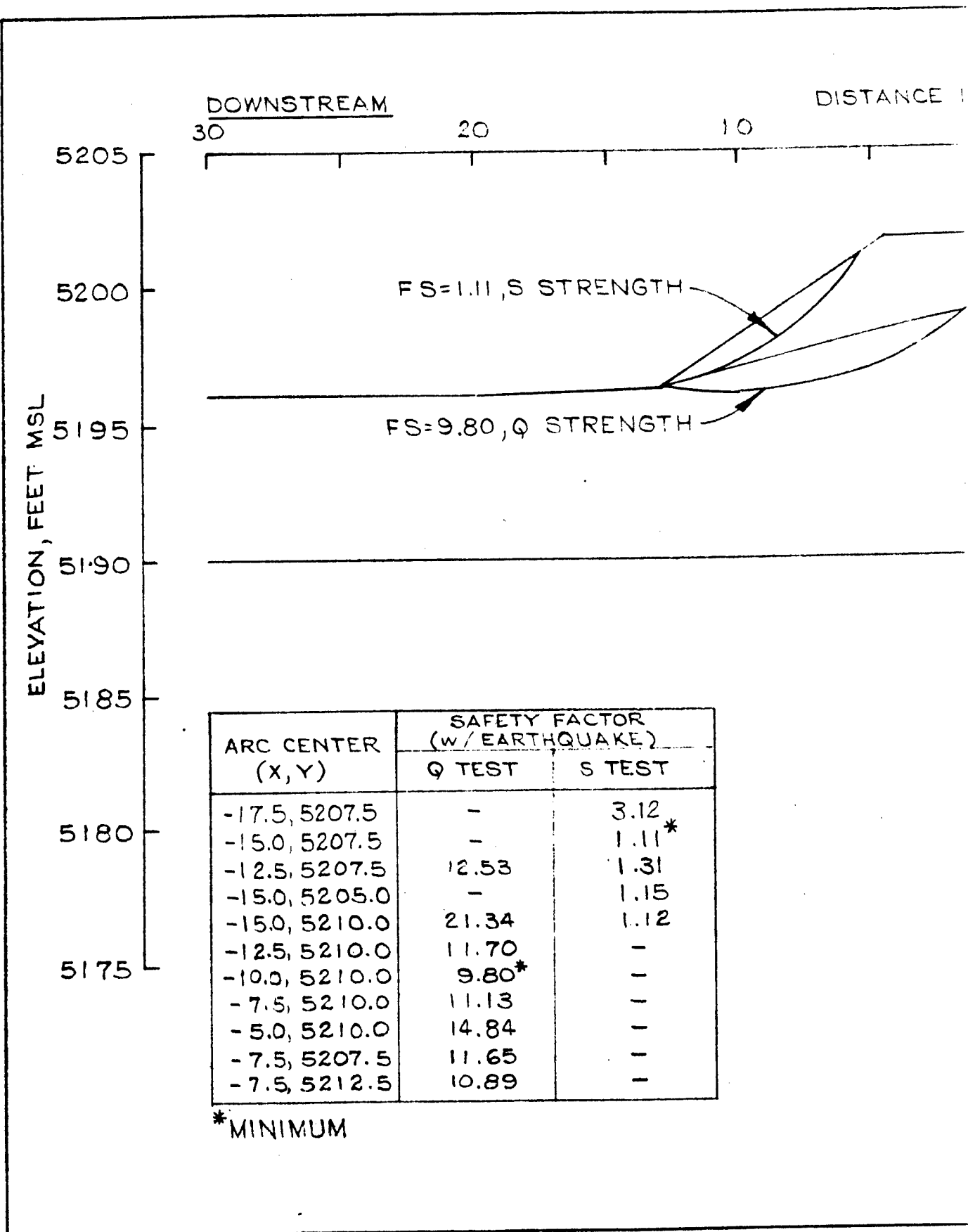
5180

ELEVATION, FEET MSL

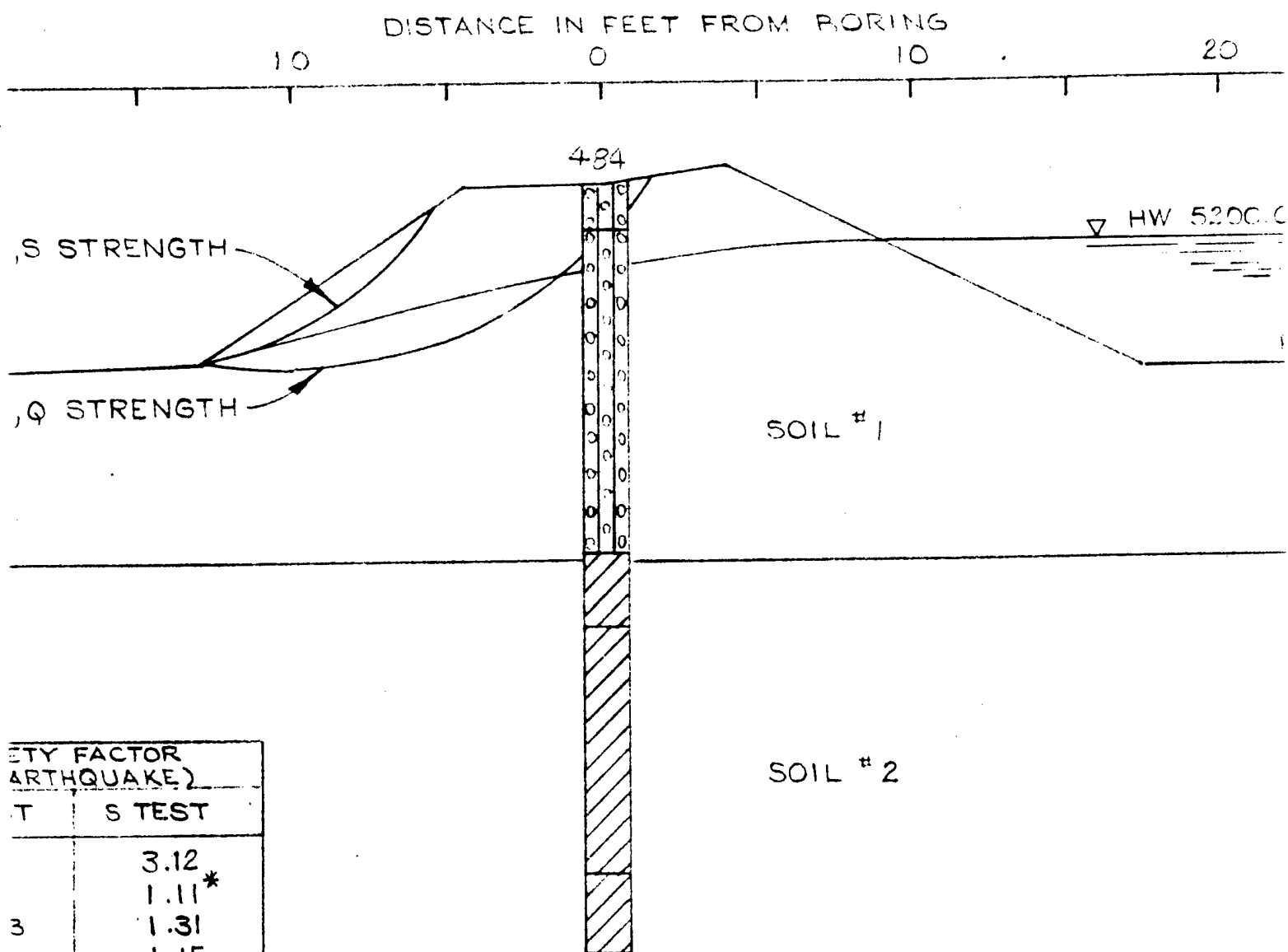
EL. 5190.5

EL. 5185.0

DIKE STABILITY ANALYSIS
BASIN F
ROCKY MOUNTAIN ARSENAL
DENVER, COLORADO



①



SEISMIC FACTOR (EARTHQUAKE)	
T	S TEST
	3.12
	1.11*
3	1.31
4	1.15
0	1.12
0*	-
3	-
4	-
5	-
9	-

IRING
10

20

30

40

5

▽ HW 5200.0

EL 5196.0

SELECTED MEASURED SOIL PARAM			
SOIL	DENSITY, PCF	Q TEST	
		φ	C
1	132	31.3	860
2	115	15.0	840

EL 51

" 2

3

30

40

UPSTREAM
50

SELECTED MEASURED SOIL PARAMETERS

SOIL	DENSITY, PCF	Q TEST		S TEST	
		ϕ	C	ϕ	C
1	132	31.3	860	34	0
2	115	15.0	840	32	0

36.0

EL 5190.0

5205

5200

5195

5190

5185

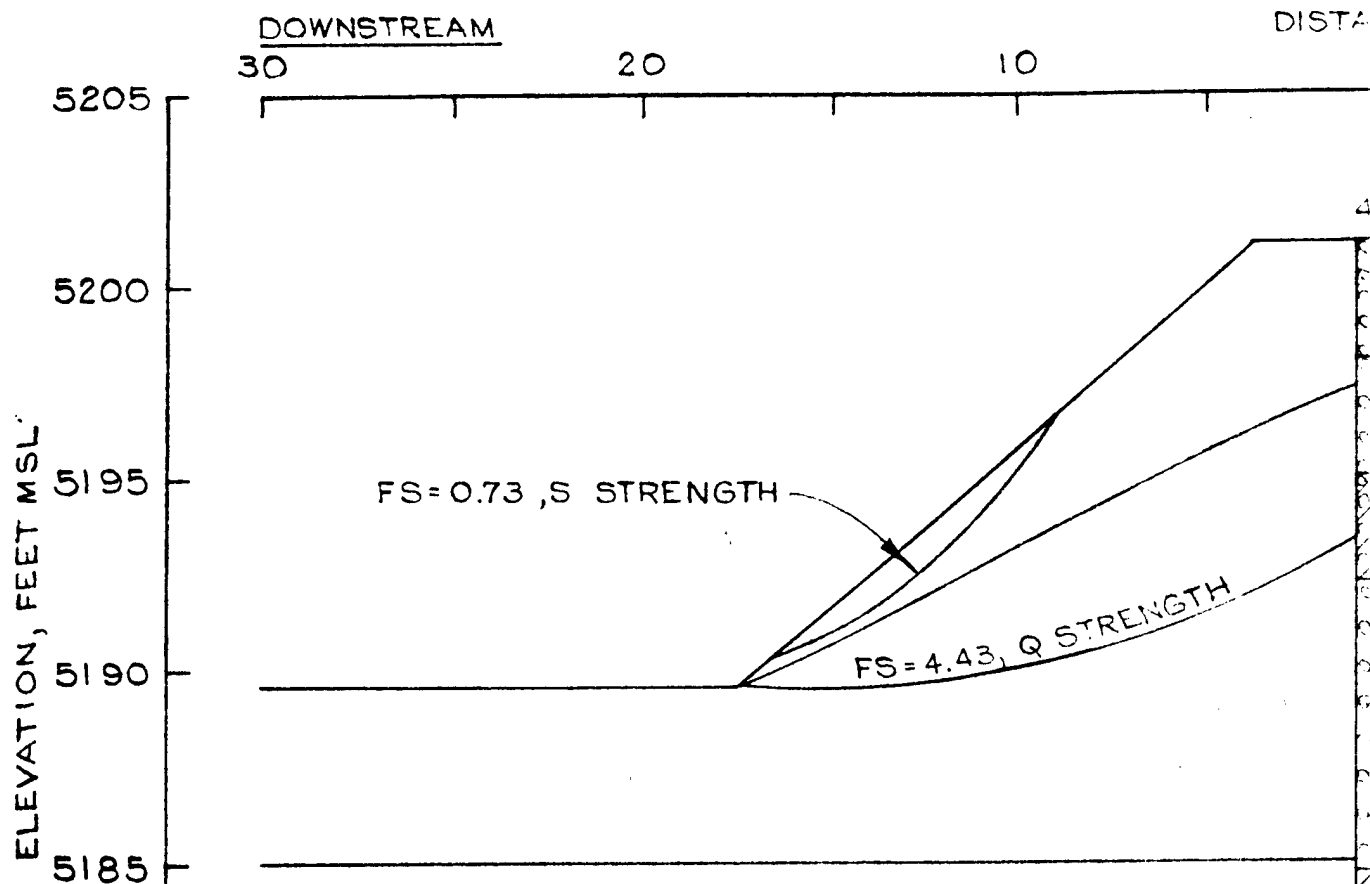
5180

ELEVATION, FEET MSL

DIKE STABILITY ANALYSIS
BASIN F
ROCKY MOUNTAIN ARSENAL
DENVER, COLORADO

Figure 22

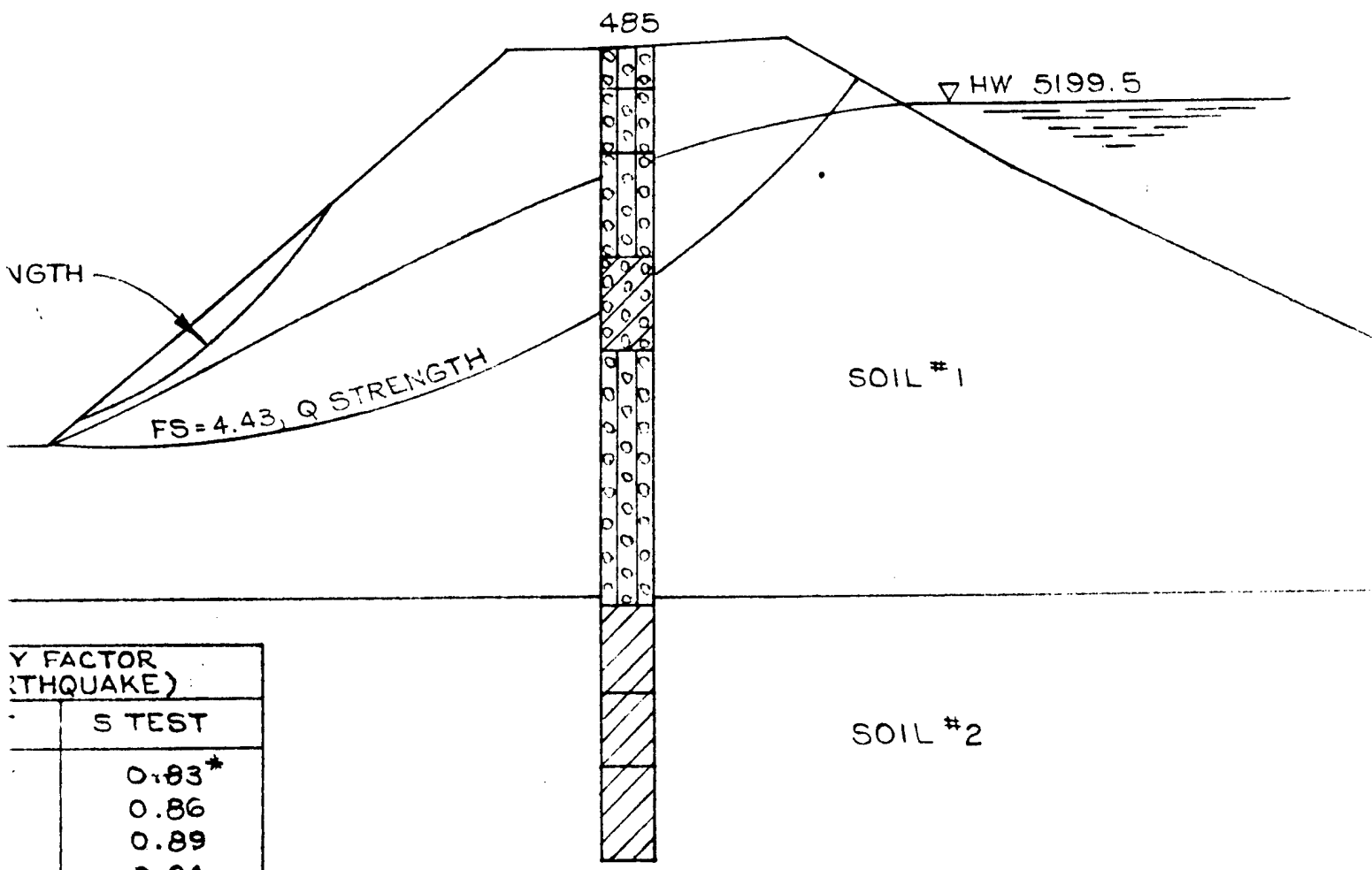
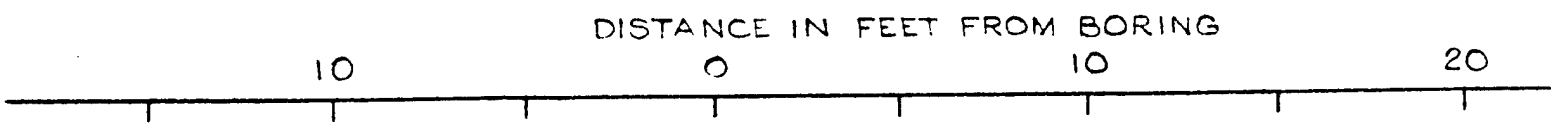
4



ARC CENTER (X, Y)	SAFETY FACTOR (w/ EARTHQUAKE)	
	Q TEST	S TEST
-22.5, 5205.0	-	0.83*
-20.0, 5205.0	-	0.86
-17.5, 5205.0	5.88	0.89
-20.0, 5200.0	-	0.84
-20.0, 5202.5	-	0.88
17.5, 5217.5	4.61	-
15.0, 5217.5	4.43*	-
12.5, 5217.5	4.59	-
15.0, 5215.0	4.44	-
15.0, 5220.0	4.45	-

* MINIMUM

①



Y FACTOR (EARTHQUAKE)	
	S TEST
	0.83*
	0.86
	0.89
	0.84
	0.88
*	-
	-
	-
	-
	-

OM BORING
10

20

30

40

▽ HW 5199.5

SELECTED MEASURED SOIL PARA

SOIL	DENSITY, PCF	Q TEST	
		ϕ	c
1	132	31.3	860
2	115	15.0	840

IL #1

▽ GW = 5184.5

EL 5185

IL #2

3

30

40

50

UPSTREAM

SELECTED MEASURED SOIL PARAMETERS

SOIL	DENSITY, PCF	Q TEST		S TEST	
		ϕ	c	ϕ	c
1	132	31.3	860	34.0	0
2	115	15.0	840	32.0	0

5205

5200

5195

5190

5185

5180

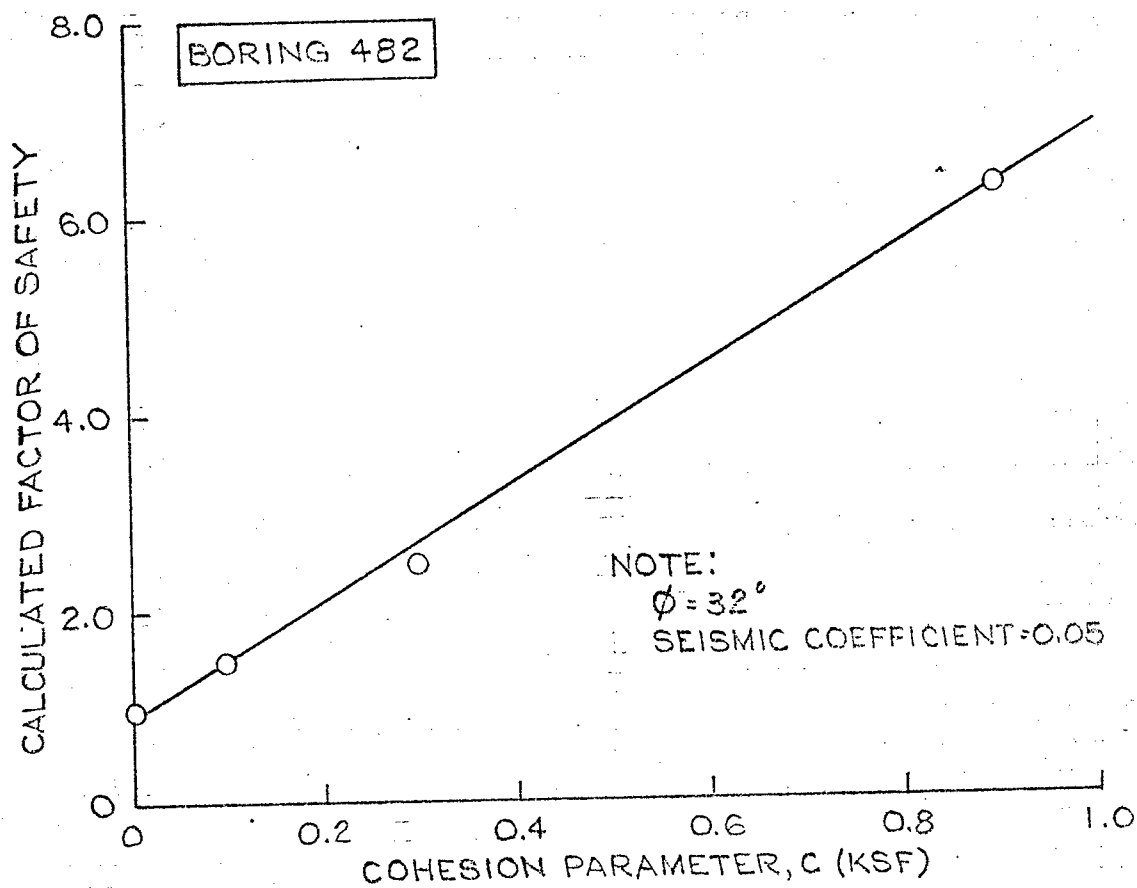
ELEVATION, FEET MSL

▽ GW = 5184.5

EL 5185

DIKE STABILITY ANALYSIS
BASIN F
ROCKY MOUNTAIN ARSENAL
DENVER, COLORADO

4



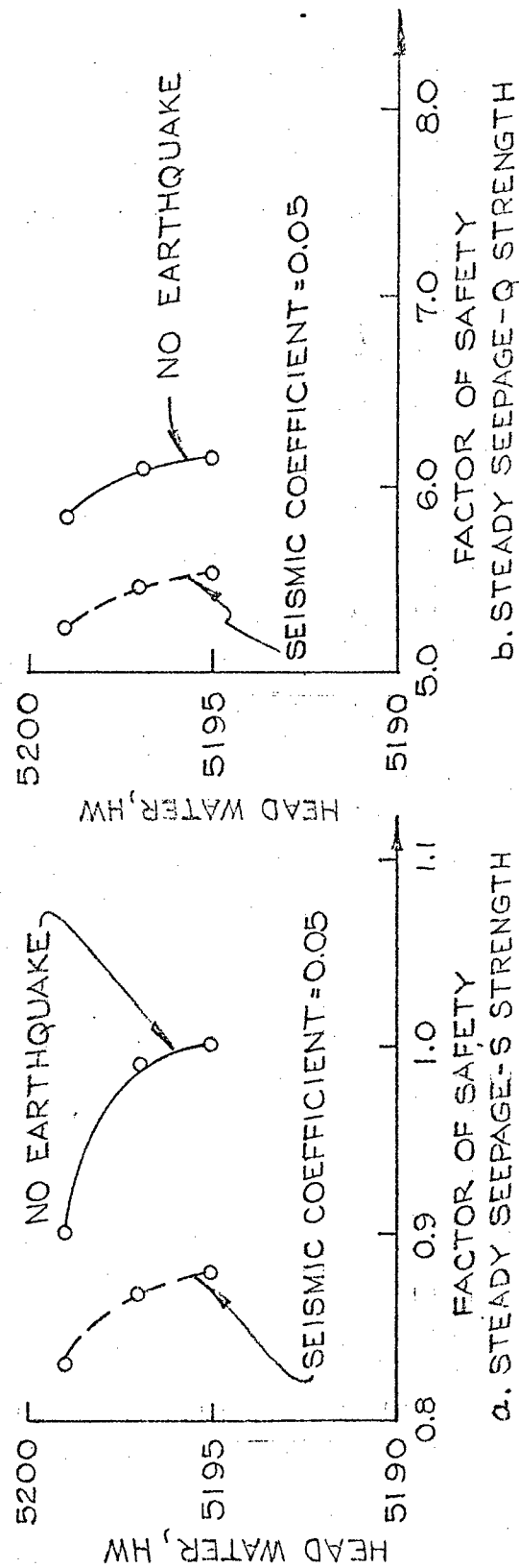
COHESION SENSITIVITY
DIKE STABILITY ANALYSIS
BASIN F
ROCKY MOUNTAIN ARSENAL
DENVER, COLORADO

Figure 84

Boring	Shear Strength Source	Minimum Safety Factors		
		Upstream Slope	Downstream Slope	
		Q-test	Q-test	S-test
482	Estimated Measured	1.87 -	- 5.21*	0.87 0.83*
483	Estimated Measured	1.97 -	- 5.09*	1.02 0.79*
484	Estimated Measured	1.78 -	- 9.80*	1.25 1.11*
485	Estimated Measured	1.79 -	- 4.43*	0.93 0.73*

* seismic coefficient - 0.05

SUMMARY OF FACTORS OF SAFETY
 DIKE STABILITY ANALYSIS
 BASIN F
 ROCKY MOUNTAIN ARSENAL
 DENVER, COLORADO



POOL ELEVATION VS FACTOR OF SAFETY
DIKE STABILITY ANALYSIS
BASIN F
ROCKY MOUNTAIN ARSENAL
DENVER, COLORADO

Figure 86