

64-F-230 C

W.P. #130-61

WELLAND CANAL

TUNNEL

H. Q. GOLDER & ASSOCIATES LTD.

CONSULTING CIVIL ENGINEERS

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REPORT

TO

DEPARTMENT OF HIGHWAYS, ONTARIO

ON

SOIL CONDITIONS

(AS DISCLOSED FROM BORINGS AT THE SITE 1963-64)

PROPOSED WELLAND CANAL TUNNEL

W.P. 130-61

Distribution:

- 11 copies - Department of Highways, Ontario,
Toronto, Ontario.
- 5 copies - Gibb, Underwood, McLellan,
Toronto, Ontario.
- 2 copies - H. Q. Golder & Associates Ltd.,
Toronto, Ontario.

November, 1964

6375
(Addit'l Canal BH's-64005)

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ABSTRACT

The results of borings put down at the site of the proposed Welland Canal tunnel, in the City of Welland, Ontario, in 1963-64 are reported, together with the results of in situ tests and laboratory tests carried out on the samples.

It was found that the undrained shear strength of the clay deposits at the site differed markedly, depending whether in situ tests or laboratory tests were employed. The results of such tests are discussed and reference is made to the need for more detailed examination of the deposits by means of a test shaft, the results of which were presented in our report 6375, dated July, 1964.

INTRODUCTION

H. Q. Golder & Associates Ltd. were retained by the Department of Highways, Ontario to carry out a soils investigation in conjunction with the Department for a proposed open-cut vehicular tunnel beneath the Welland Canal in the City of Welland, Ontario.

The purpose of the investigation was to determine the detailed soil conditions along the line of the proposed tunnel and to define the shear strength of the known clay deposits at the site for use in the design of permanent and temporary cut slopes.

This report presents the data obtained in both the field and the laboratory from boreholes 24, 28, 29, 30, 31, 33 and 34 and supplements our previous reports of December, 1960; July, 1961; and July, 1964.

PROCEDURE

The field work was supervised jointly by the Department of Highways, Ontario and H. Q. Golder & Associates Ltd. The first nine boreholes were put down between July 8, 1963 and September 6, 1963 with a further two boreholes being put down between the 15th and 30th of January, 1964. During the first period, four detailed continuously sampled borings were made to rock under the supervision of the Department of Highways, Ontario. Five boreholes with samples every 5 feet were also supervised by H. Q. Golder & Associates Ltd.;

during this period a total of 44 auger probings were also made to determine the top of the till stratum. The latter two boreholes, made between the 15th and 30th of January, were augered from the top of the ice cover over the Welland Canal and were supervised by H. Q. Golder & Associates Ltd.

The sampling work was carried out using a Penndrill power auger and a standard machine drillrig owned and operated by Canadian Longyear Ltd. The auger probings were carried out using two Penndrill power augers owned and operated by F. E. Johnston Drilling Co. Ltd. Bedrock was cored in BX size for 15 to 29 ft. in the four sampled holes and pressure packer tests were carried out. A separate hole for in situ vane shear testing was put down adjacent to the four detailed holes.

The locations of all borings and probings put down during the investigation are shown on Figure 1; a section showing the inferred soil stratigraphy along the proposed centre line is given on Figure 2.

The soil samples obtained during the investigation were returned to the Materials and Research laboratory of the Department of Highways, Ontario and to our laboratory for examination and testing. The results of the laboratory testing carried out on the

samples brought to our laboratory are plotted on the Records of Boreholes and on the figures.

The borings are located with reference to the centre line of the proposed tunnel and were staked out by Gibb, Underwood and McLellan who also supplied the elevations. The probings are also located with reference to the centre line; they were located and the elevations supplied by the Department of Highways, Ontario. The datum for the borings and probings is Geodetic.

SOIL CONDITIONS AT THE SITE

The site for the proposed Welland Canal Tunnel is located in the City of Welland between the Main Street and Lincoln Street bridges. The ground surface is relatively flat; the main drainage in the area is to the canal and the Welland River which flows in a slight depression.

The site is underlain by deep lacustrine deposits of silty clay laid down in glacial Lake Whittlesey and overlying a dense glacial till which blankets Paleozoic shales and dolomites. The sequence of the clay deposits is relatively uniform (Fig. 2) whereas the upper surface of the glacial till shows considerable variation across the site as shown in Figure 3.

The boreholes put down from the original ground surface

show that there is about 45 feet of hard to stiff reddish-brown very silty clay with occasional granular particles which ranged in size from large boulders to sand. Most frequently they were found to be cobble to gravel size and the majority angular in shape (Fig. 4, a to f).

From 45 feet to about 55 feet the clays were more plastic and distinctly layered. From 45 feet to 50 feet approximately, there were occasional grey more plastic layers, about 1/2 inch to 1 inch thick, in the reddish-brown silty clay (Fig. 4, g), but from 50 feet to 55 feet approximately the soil consisted of a sequence of soft to firm reddish-brown, grey, red and dark brown very plastic silty clay layers, 1/4 inch to 3/4 inch thick (Fig. 4, h, i.) These layered clays contained little or no granular material.

From 55 ft. to about 70 ft. there was another deposit of stiff reddish-brown silty clay, similar to that in the upper 30 ft., but slightly more clayey. It contained occasional grey layers and a few angular cobbles and gravel. (Fig. 4, j to o).

Below approximately 70 ft. to the upper surface of the glacial till, there was another sequence of firm to soft reddish-brown, grey, red, dark brown and grey brown plastic silty clays. These layers were about 1/2 inch to 1 inch thick, becoming thicker

with depth with interspersed layers of silt. (Fig. 4, p.)

The depth of the upper surface of the till varied between 75 ft. and 97 ft. below ground surface. It was a very stiff to hard reddish-brown sandy silty clay with many angular gravel and cobble size particles.

The bedrock was found to be about 100 ft. below ground surface. It was a relatively intact grey sedimentary rock with occasional zones of white secondary minerals.

Photographs of samples taken from Borehole 28 are presented as Fig. 4. The grain-size and plasticity characteristics of the soil are presented in summary form as Figs. 5, 6 and 7. A plot showing the variation in plasticity and moisture content with elevation is given on Fig. 8.

DISCUSSION OF SOIL PROPERTIES

In 1960 and 1961 preliminary soils investigations had been carried out at the site of the proposed Welland Canal Tunnel (Reports by H. Q. Golder & Associates Ltd. December, 1960 and July, 1961). These investigations established the general soil conditions in the area and provided information on the soil conditions in connection with feasibility studies for the tunnel and its approaches.

The previous investigations had shown a marked deviation in the undrained shear strength as measured by in situ vane tests from that measured in the laboratory on thin wall tube samples. (Fig. 9). In this investigation, the sampling and in situ tests were again carried out using careful sampling and test techniques with the intent of defining the degree of variation between in situ shear test results and laboratory shear test values. In order to minimize disturbance of the soil prior to sampling, power augers were used wherever possible, to advance the borings rather than driving casing.

The results of the undrained triaxial, the unconfined compression tests and the vane tests are plotted on the borehole logs and are summarized on Figs. 10 and 11.

Despite the careful execution of the work, there was again a difference in the shear strength properties of the layered clays below 45 ft. from ground surface, as measured by the in situ tests from the laboratory strengths measured. The results of the vane tests invariably showed higher shear strengths than those from the unconfined compression tests. The strengths obtained from the undrained triaxial tests were intermediate between the vane and the unconfined results. It was not possible from the results of the borings to determine if the difference between the vane and com-

pression test results was due to the presence of fine seams of sand or silt increasing the vane shear strength or due to sample disturbance and relief of stress decreasing the unconfined compressive strength. (Typical stress-strain curves are shown in Figs. 18 to 32 inclusive and exhibit a wide range of stress-strain characteristics.)

It was therefore decided, in view of the critical importance of the properties of these layered clays in relation to the safety and economy of the cut slopes for the temporary and permanent excavations, to put down a trial shaft which would permit direct examination of the clay, the taking of large 'undisturbed' block samples and the testing of the clay in situ.

The trial shaft was subsequently put down to a depth of 77 ft. and the results reported in "Trial Shaft at Proposed Tunnel Site; Execution, Sampling and Test Results, Welland, Ontario", H. Q. Golder & Associates Ltd. Report 6375, July, 1964. This report contains a complete discussion of the engineering properties of the soil and recommendations for the engineering design of the cut slopes for the tunnel.

The results of consolidated drained triaxial compression tests are presented on Figs. 12, 13 and 14. In general, the angle of drained shear resistance, ϕ_d , is about 28° . This value for ϕ_d agrees quite well with the results of similar tests on previous

borehole or "vertical" samples. (Reports 6022, 6108 of 1960-61). The tests on samples from relatively shallow depths (50 ft. or less) exhibited signs of some degree of over-consolidation, and in one set of tests a cohesion intercept, c' , of about 400 lb/sq.ft. was obtained. (Fig. 13). Samples from a greater depth (70 ft. or more) were apparently normally consolidated, as would be expected from the consolidation test results (Refer to summary, Fig. 68. Report of July, 1964); the cohesion intercept for these tests was zero. It is of interest to contrast the results of these tests with those carried out on samples of the same material taken in the test shaft but trimmed at an angle of 45° to the horizontal layerings (Figs. 69, 70. Report of July, 1964). For these tests (45° samples) the value of c' was generally zero, but ϕ' or ϕ_d was of the order of 20° rather than 28° , thus demonstrating the marked directional shear strength properties of the material.

The results of consolidation tests are presented on Figs. 15, 16 and 17, and should be read with reference to Fig. 68. (Report of July, 1964).

for *H*
B. E. W. Dowse, P. Eng.

H
V. Milligan, P. Eng.

BEWD:IMB
6375
(Addt'l Canal BH's-64005)

LIST OF ABBREVIATIONS

The abbreviations commonly employed on each "Record of Borehole," on the figures and in the text of the report, are as follows:

I. SAMPLE TYPES

AS auger sample
CS chunk sample
DO drive open
DS Denison type sample
FS foil sample
RC rock core
ST slotted tube
TO thin-walled, open
TP thin-walled, piston
WS wash sample

II. PENETRATION RESISTANCES

Dynamic Penetration Resistance: The number of blows by a 140-pound hammer dropped 30 inches required to drive a 2-inch diameter, 60 degree cone one foot, where the cone is attached to 'A' size drill rods and casing is not used.

Standard Penetration Resistance, *N*: The number of blows by a 140-pound hammer dropped 30 inches required to drive a 2-inch drive open sampler one foot.

WH sampler advanced by static weight—weight, hammer
PH sampler advanced by pressure—pressure, hydraulic
PM sampler advanced by pressure—pressure, manual

III. SOIL DESCRIPTION

(a) Cohesionless Soils

Relative Density	<i>N</i> , blows/ft.
Very loose	0 to 4
Loose	4 to 10
Compact	10 to 30
Dense	30 to 50
Very dense	over 50

(b) Cohesive Soils

Consistency	<i>c_u</i> , lb./sq. ft.
Very soft	Less than 250
Soft	250 to 500
Firm	500 to 1,000
Stiff	1,000 to 2,000
Very stiff	2,000 to 4,000
Hard	over 4,000

IV. SOIL TESTS

C consolidation test
H hydrometer analysis
M sieve analysis
MH combined analysis, sieve and hydrometer¹
Q undrained triaxial²
R consolidated undrained triaxial²
S drained triaxial
U unconfined compression
V field vane test

NOTES:

¹Combined analyses when 5 to 95 per cent of the material passes the No. 200 sieve.

²Undrained triaxial tests in which pore pressures are measured are shown as \bar{Q} or \bar{R} .

LIST OF SYMBOLS

I. GENERAL

π	= 3.1416
e	= base of natural logarithms 2.7183
$\log_e a$ or $\ln a$	natural logarithm of a
$\log_{10} a$ or $\log a$	logarithm of a to base 10
t	time
g	acceleration due to gravity
V	volume
W	weight
M	moment
F	factor of safety

II. STRESS AND STRAIN

u	pore pressure
σ	normal stress
σ'	normal effective stress ($\bar{\sigma}$ is also used)
τ	shear stress
ϵ	linear strain
ϵ_{xy}	shear strain
ν	Poisson's ratio (μ is also used)
E	modulus of linear deformation (Young's modulus)
G	modulus of shear deformation
K	modulus of compressibility
η	coefficient of viscosity

III. SOIL PROPERTIES

(a) Unit weight

γ	unit weight of soil (bulk density)
γ_s	unit weight of solid particles
γ_w	unit weight of water
γ_d	unit dry weight of soil (dry density)
γ'	unit weight of submerged soil
G_s	specific gravity of solid particles $G_s = \gamma_s / \gamma_w$
e	void ratio
n	porosity
w	water content
S_r	degree of saturation

(b) Consistency

w_L	liquid limit
w_P	plastic limit
I_P	plasticity index
w_S	shrinkage limit
I_L	liquidity index = $(w - w_P) / I_P$
I_C	consistency index = $(w_L - w) / I_P$
e_{max}	void ratio in loosest state
e_{min}	void ratio in densest state
D_r	relative density = $(e_{max} - e) / (e_{max} - e_{min})$

(c) Permeability

h	hydraulic head or potential
q	rate of discharge
v	velocity of flow
i	hydraulic gradient
k	coefficient of permeability
j	seepage force per unit volume

(d) Consolidation (one-dimensional)

m_v	coefficient of volume change = $-\Delta e / (1+e) \Delta \sigma'$
C_c	compression index = $-\Delta e / \Delta \log_{10} \sigma'$
c_p	coefficient of consolidation
T_v	time factor = $c_p t / d^2$ (d , drainage path)
U	degree of consolidation

(e) Shear strength

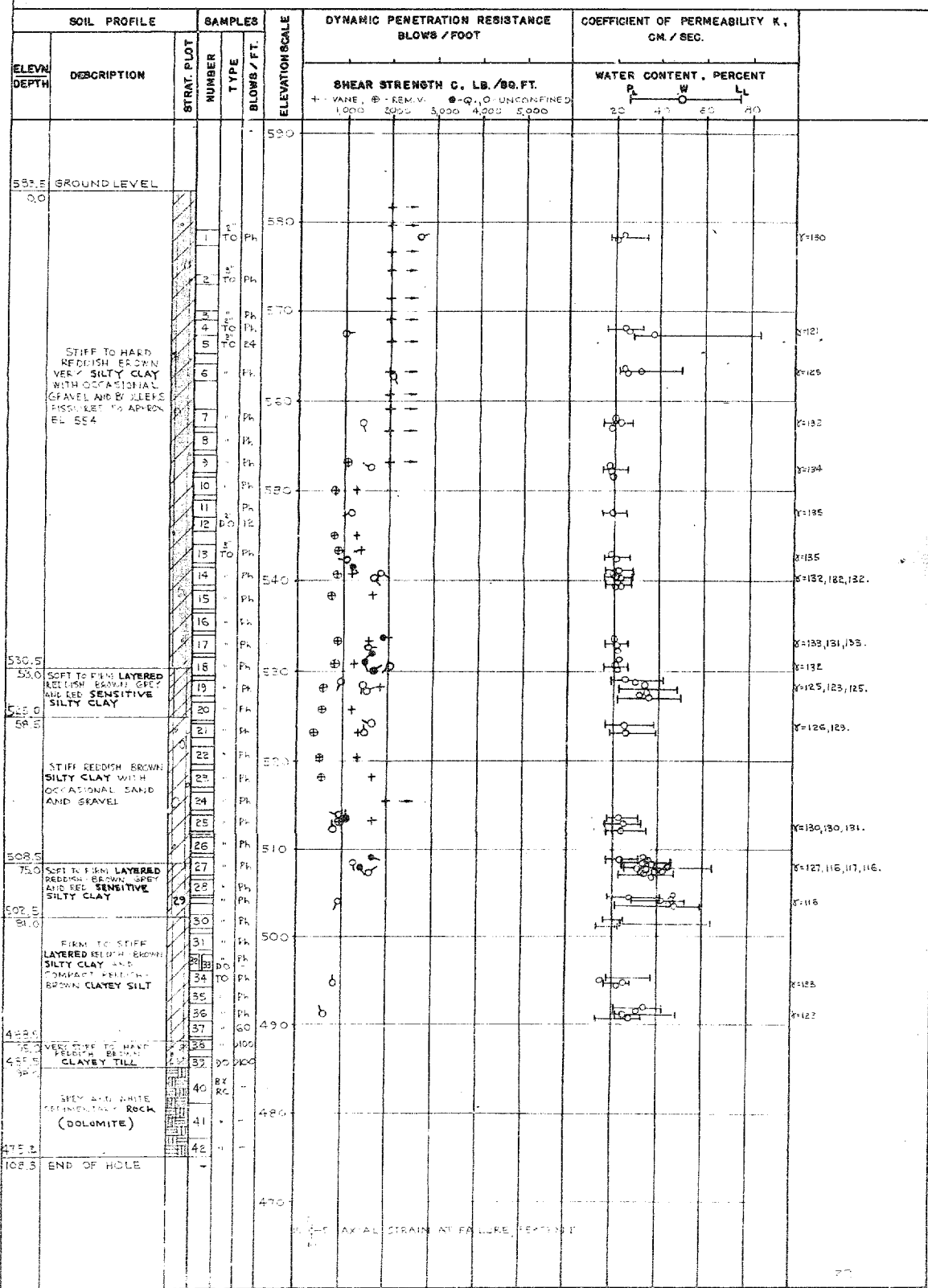
τ_f	shear strength
c'	effective cohesion
ϕ'	effective angle of shearing resistance, or friction
c_u	apparent cohesion*
ϕ_u	apparent angle of shearing resistance, or friction
μ	coefficient of friction
S_t	sensitivity

*For the case of a saturated cohesive soil, ϕ_u as half the undrained compressive strength.

and the undrained shear strength $\tau_f = c_u$ is taken

RECORD OF BOREHOLE 24

LOCATION SEE FIGURE 1 BORING DATE JULY 12-AUG. 2, 1963 DATUM GEODETIC
BOREHOLE TYPE POWER AUGER & WASH BORING BOREHOLE DIAMETER 4.5 INCHES & EX CASING
SAMPLER HAMMER WEIGHT 140 LB. DROP 30 INCHES PEN. TEST HAMMER WEIGHT - LB. DROP - INCHES



AXIAL STRAIN AT FAILURE, PERCENT

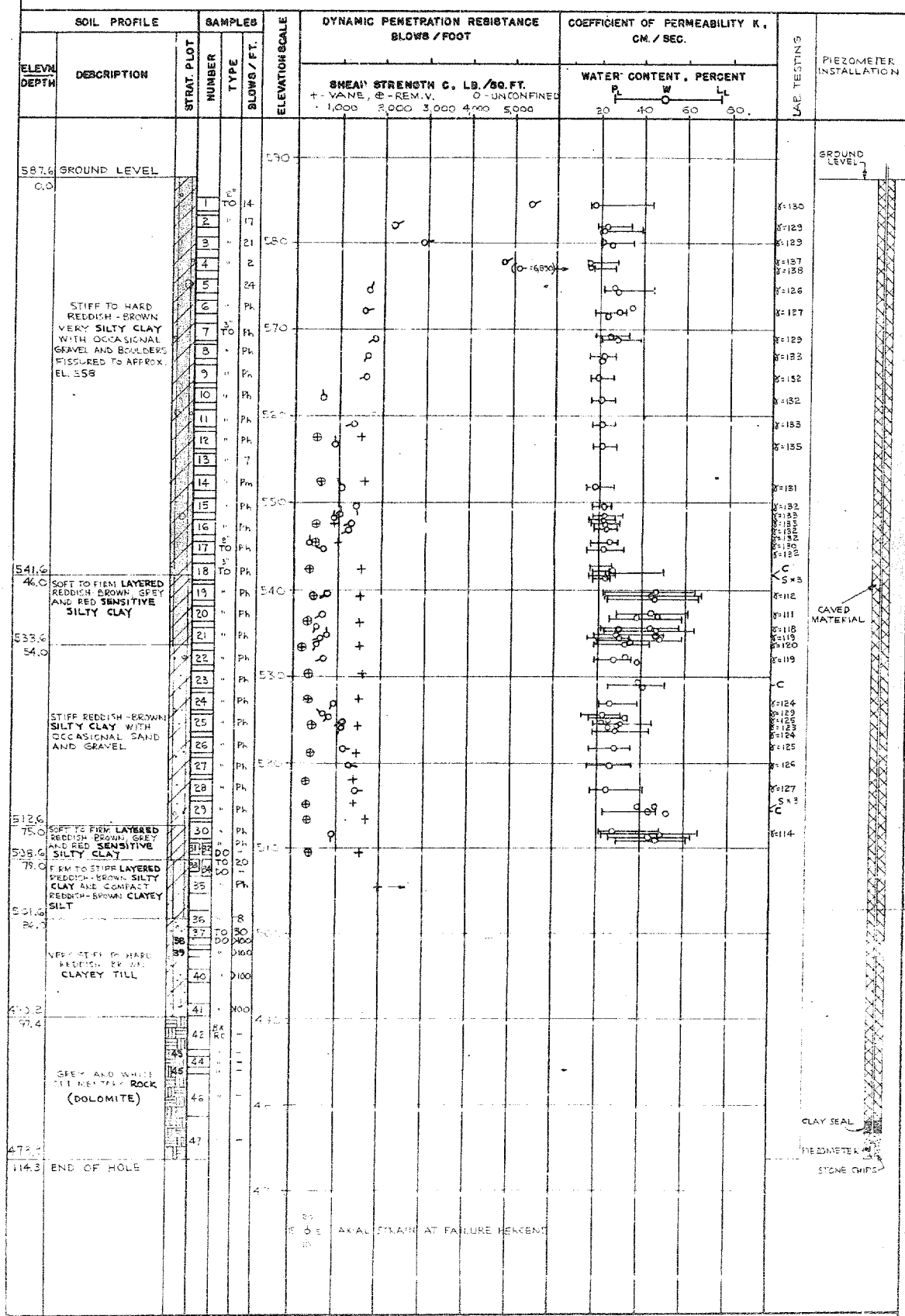
VERTICAL SCALE
1 INCH TO 10' - 0"

GOLDER & ASSOCIATES

DRAWN
CHECKED

RECORD OF BOREHOLE 28

LOCATION SEE FIGURE 1 BORING DATE JULY 23-AUG. 16, 1963 DATUM GEODETIC
BOREHOLE TYPE POWER AUGER & WASH BORING BOREHOLE DIAMETER 4.5 INCHES & BX CASING
SAMPLER HAMMER WEIGHT 140 LB. DROP 30 INCHES PEN. TEST HAMMER WEIGHT - LB. DROP - INCHES



RECORD OF BOREHOLE 29

LOCATION SEE FIGURE 1

BORING DATE AUG. 20-22, 1963

DATUM GEODETIC

BOREHOLE TYPE

POWER AUGER BORING

BOREHOLE DIAMETER 4.5"

SAMPLER HAMMER WEIGHT 140 LB. DROP 30 INCHES

PEN. TEST HAMMER WEIGHT - LB. DROP - INCHES

SOIL PROFILE		SAMPLES		ELEVATION SCALE	DYNAMIC PENETRATION RESISTANCE BLOWS / FOOT				COEFFICIENT OF PERMEABILITY K, CM. / SEC.			
ELEV. DEPTH	DESCRIPTION	STRAT. PLT	NUMBER TYPE		SHEAR STRENGTH C, LB. / SQ. FT.				WATER CONTENT, PERCENT			
				BLOWS / FT.								
588.1	GROUND LEVEL			530								
0.0												
			1	39								
			2	36								
			3	17								
			4	11								
			5	17								
			6	13								
			7	10								
			8	12								
			9	7								
538.6			10	7								
49.5			11	8								
530.1			12	9								
58.0			13	12								
518.1			14	9								
70.0			15	Wh								
517.3			16	14								
80.5			17	1000								
502.6												
68.5												

VERTICAL SCALE
1 INCH TO 10' - 0"

GOLDER & ASSOCIATES

DRAWN *W.D.*
CHECKED *W.D.*

RECORD OF BOREHOLE 30

LOCATION SEE FIGURE 1

BORING DATE AUG. 22 - 23, 1963

DATUM

GEODETIC

BOREHOLE TYPE

POWER AUGER BORING

BOREHOLE DIAMETER

4.5"

SAMPLER HAMMER WEIGHT 140 LB. DROP 30 INCHES

PEN. TEST HAMMER WEIGHT - LB. DROP - INCHES

ELEV. DEPTH	SOIL PROFILE DESCRIPTION	SOIL PROFILE STRAT. PLOT	SAMPLES		ELEVATION SCALE BLOWS / FT.	ELEVATION SCALE	DYNAMIC PENETRATION RESISTANCE BLOWS / FOOT				COEFFICIENT OF PERMEABILITY K, CM. / SEC.			
			NUMBER	TYPE			SHEAR STRENGTH C, LB. / SQ. FT.				WATER CONTENT, PERCENT			
587.0 0.0	GROUND LEVEL					590								
			1	DO	28	580								
			2	"	26									
			3	"	9	570								
			4	"	12									
			5	"	11	560								
			6	"	11									
			7	"	10	550								
			8	"	10									
			9	"	11	540								
538.0 49.0	SOFT TO FIRM LAYERED REDDISH-BROWN, GREY AND RED SENSITIVE SILTY CLAY		10	"	8									
529.5 57.5			11	"	11	530								
			12	"	12									
			13	"	18	500								
517.0 70.0	SOFT TO FIRM LAYERED REDDISH-BROWN, RED AND GREY SILTY CLAY BECOMING STIFFER WITH DEPTH WITH LAYERS OF COMPACT CLAYEY SILT		14	"	10									
			15	"	14	510								
505.0 82.0			16	"	1/4									
			17	"	89	500								
495.0 92.0	END OF HOLE		18	"	33									

VERTICAL SCALE

1 INCH TO 10' - 0"

GOLDER & ASSOCIATES

DRAWN J. G.

CHECKED J. G.

RECORD OF BOREHOLE 31

LOCATION SEE FIGURE 1

BORING DATE AUG. 26-27, 1963

DATUM

GEODETIC

BOREHOLE TYPE

POWER AUGER BORING

BOREHOLE DIAMETER 4.5"

SAMPLER HAMMER WEIGHT 140 LB. DROP 30 INCHES

PEN. TEST HAMMER WEIGHT - LB. DROP - INCHES

SOIL PROFILE		SAMPLES		ELEVATION SCALE	DYNAMIC PENETRATION RESISTANCE BLOWS / FOOT					COEFFICIENT OF PERMEABILITY K, CM. / SEC.				
ELEVATION DEPTH	DESCRIPTION	STRAT. PLOT NUMBER	TYPE		SHEAR STRENGTH C, LB./SQ. FT. + VANE, @ - REM. V. 1,000 2,000 3,000 4,000 5,000					WATER CONTENT, PERCENT P W L				
587.3 0.0	GROUND LEVEL			590										
		1	DO	29										
		2	"	26										
		3	"	24										
		4	"	21										
		5	"	18										
		6	"	15										
		7	"	12										
		8	"	9										
		9	"	6										
		10	"	3										
		11	"	0										
539.3 48.0	SOFT TO FIRM LAYERED REDDISH-BROWN SILTY CLAY WITH OCCASIONAL SAND AND GRAVEL	12	"	29										
		13	"	26										
		14	"	23										
		15	"	20										
		16	"	17										
		17	"	14										
		18	"	11										
		19	"	8										
		20	"	5										
		21	"	2										
		22	"	0										
506.3 81.0	SOFT TO FIRM LAYERED REDDISH-BROWN SILTY AND GREY SILTY CLAY BEING STIFFER WITH LAYERED OR JIL WITH DEPTH	23	"	29										
		24	"	26										
		25	"	23										
		26	"	20										
		27	"	17										
		28	"	14										
		29	"	11										
		30	"	8										
		31	"	5										
		32	"	2										
		33	"	0										
499.3 88.0	VERY STIFF TO HARD REDDISH-BROWN CLAYEY TILL	34	"	29										
		35	"	26										
		36	"	23										
		37	"	20										
		38	"	17										
		39	"	14										
		40	"	11										
		41	"	8										
		42	"	5										
		43	"	2										
		44	"	0										
494.3 93.0	END OF HOLE													

VERTICAL SCALE

1 INCH TO 10'-0"

GOLDER & ASSOCIATES

DRAWN M.W.

CHECKED H.S.

REGORD OF BOREHOLE 33

LOCATION See Figure 1

BORING DATE JAN. 15 - 22, 1964

DATUM GEOMETRIC

BOREHOLE TYPE WASH BORING

BOREHOLE DIAMETER 4" 5/8 EX CASING


SAMPLER HAMMER WEIGHT 140 LB. DROP 30 INCHES

PEN. TEST HAMMER WEIGHT - LB. DROP - INCHES

SOIL PROFILE		SAMPLES			ELEVATION SCALE	DYNAMIC PENETRATION RESISTANCE BLOWS / FT. -----		COEFFICIENT OF PERMEABILITY K, CM. / SEC.		ADDITIONAL LAB. TESTING	PIEZOMETER OR STANDPIPE INSTALLATION
ELEV. DEPTH	DESCRIPTION	STRAT. PLOT	NUMBER	TYPE		SHEAR STRENGTH C_u , LB. / SQ. FT.	WATER CONTENT, PERCENT <div>W_p W W_L</div>				
568.4	CANAL LEVEL				570						
0.0											
					560						
					550						
					540						
537.4	CANAL BOTTOM										
31.0	STIFF REDDISH-BROWN VERY SILTY CLAY WITH OCCASIONAL SAND AND GRAVEL		1	T.O.							
532.9			2	T.O.	530						
35.5	SOFT TO FIRM LAYERED REDDISH-BROWN, GREY AND M.D. SENSITIVE SILTY CLAY		3	T.O.							
527.4			4	T.O.							
41.0			5	T.O.							
			6	"							
			7	"							
	STIFF REDDISH-BROWN SILTY CLAY WITH OCCASIONAL SAND AND GRAVEL		8	"	520						
			9	"							
			10	"							
			11	"							
			12	"							
			13	"	510						
			14	"							
505.9			15	"							
62.5			16	"							
			17	"							
	SOFT TO FIRM LAYERED REDDISH-BROWN, RED AND GREY SILTY CLAY BECOMING STIFFER WITH DEPTH WITH LAYERS OF COMPACT CLAYEY SILT		18	"	500						
			19	"							
			20	"							
			21	T.O.	490						
			22	"							
			23	"							
483.4			24	"							
66.0	VERY STIFF TO HARD REDDISH-BROWN CLAYEY TILL		25	"							
478.4			26	"	480						
30.0	END OF HOLE		27	"							

15
10
5

Percent axial strain at failure


 5 Percent axial strain at failure

VERTICAL SCALE

1 INCH TO 10'-0"

GOLDER & ASSOCIATES

DRAWN *[Signature]*CHECKED *[Signature]*

RECORD OF BOREHOLE 34

LOCATION

See Figure 1

BORING DATE JAN. 22-30, 1964

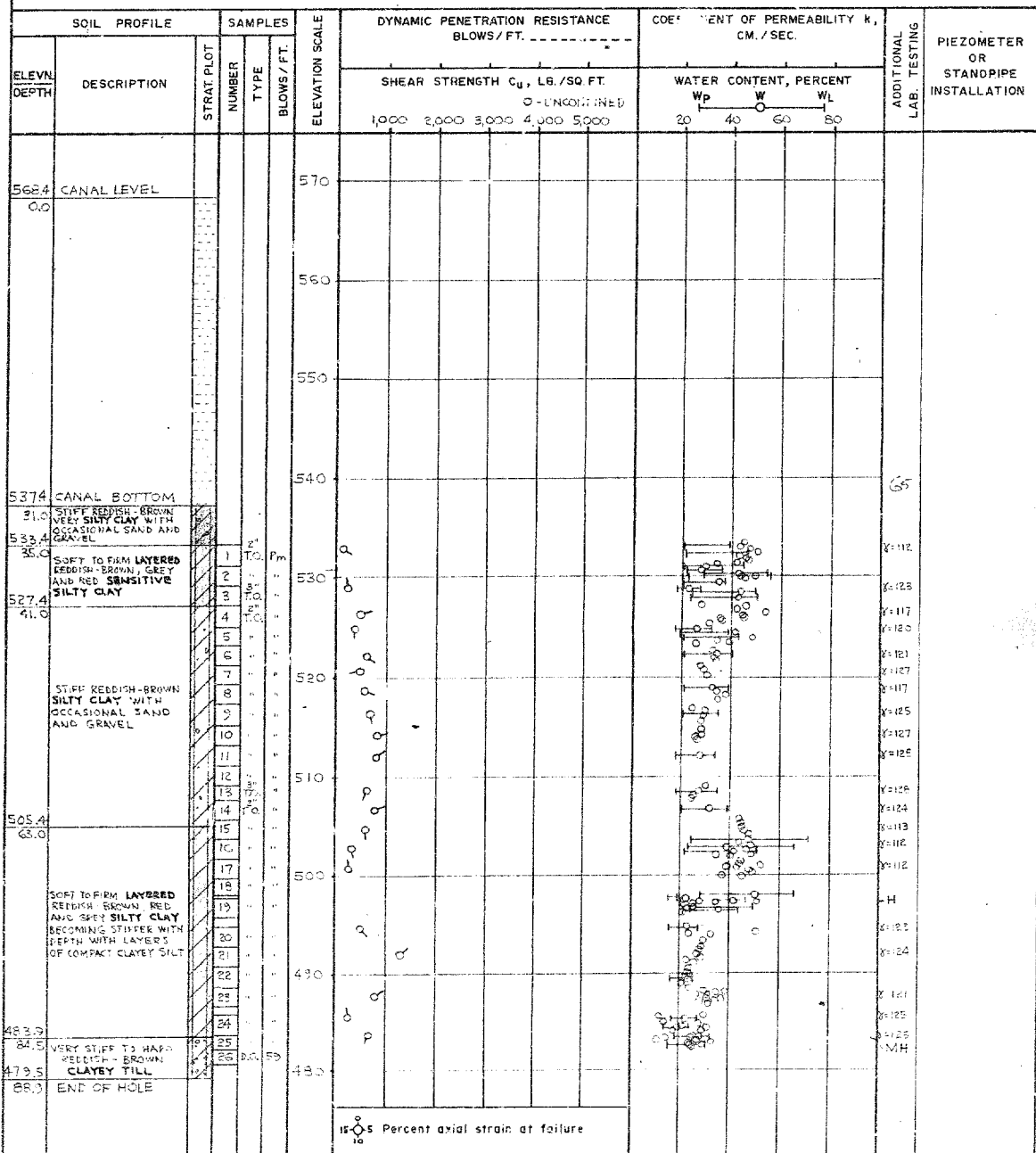
DATUM GEODETIC

BOREHOLE TYPE WASH BORING

BOREHOLE DIAMETER 4" 5/8" CASING

SAMPLER HAMMER WEIGHT 140 LB. DROP 30 INCHES

PEN. TEST HAMMER WEIGHT - LB. DROP - INCHES



VERTICAL SCALE

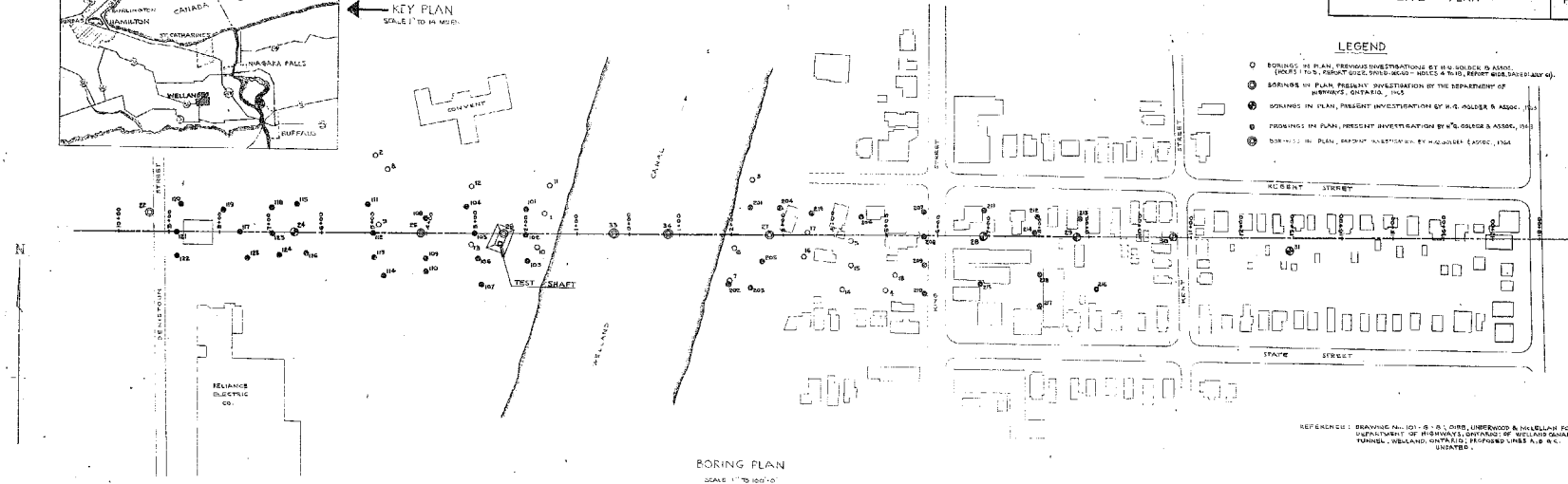
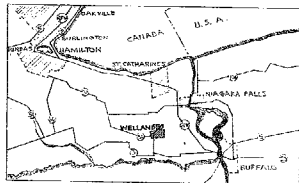
1 INCH TO 10'-0"

GOLDER & ASSOCIATES

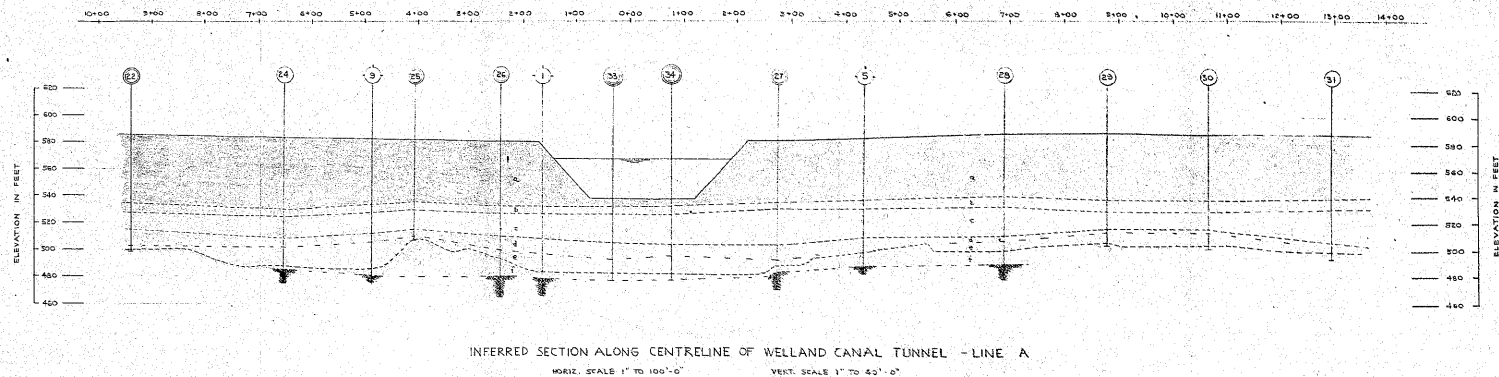
DRAWN *hsh*CHECKED *hsh*

LEGEND

- BORINGS IN PLAN, PREVIOUS INVESTIGATIONS BY H.W. GOLDER & ASSOC. (HOLE 1 TO 3, REPORT 5022, 1950-5050 - HOLES 4 TO 10, REPORT 5058, DATED JULY 61).
- BORINGS IN PLAN, PRESENT INVESTIGATION BY THE DEPARTMENT OF HIGHWAYS, ONTARIO, 1945
- ⊙ BORINGS IN PLAN, PRESENT INVESTIGATION BY H.W. GOLDER & ASSOC., 1943
- ⊖ BORINGS IN PLAN, PRESENT INVESTIGATION BY H.W. GOLDER & ASSOC., 1943
- ⊕ BORINGS IN PLAN, PRESENT INVESTIGATION BY H.W. GOLDER & ASSOC., 1944



REFERENCE: DRAWING No. 101 - S & S, CHAS. UNDERWOOD & McLELLAN FOR DEPARTMENT OF HIGHWAYS, ONTARIO; OF WELLAND CANAL TUNNEL, WELLAND, ONTARIO; PROPOSED LINES A, B & C, UNDATED.



LEGEND

- SITE INVESTIGATION 1960, 1961 - H.G. GOLDBER & ASSOC.
- SITE INVESTIGATION 1963 - H.G. GOLDBER & ASSOC.
- SITE INVESTIGATION 1963 - DEPARTMENT OF HIGHWAYS, ONTARIO
- SITE INVESTIGATION 1964 - H.G. GOLDBER & ASSOC.

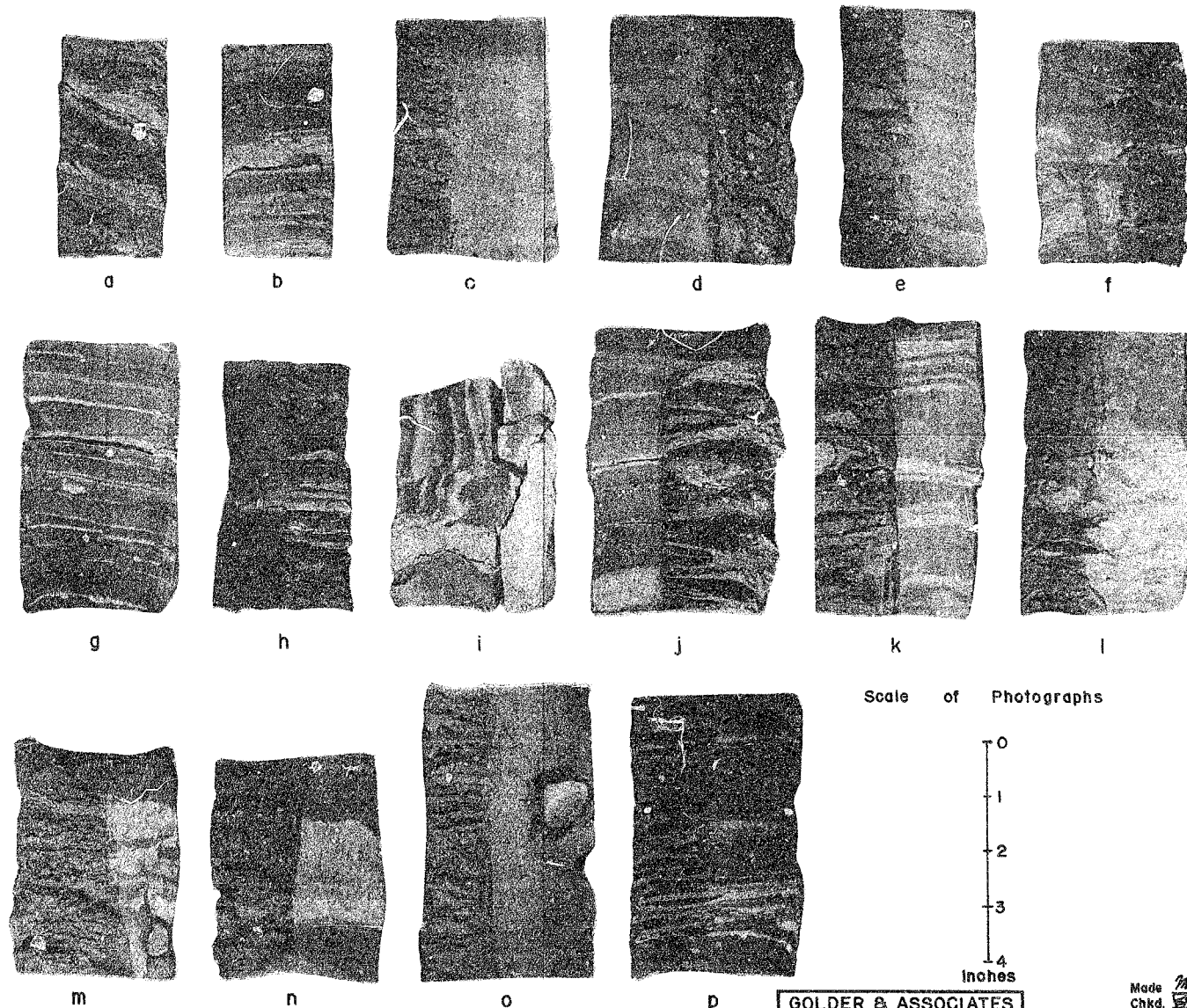
STRATIGRAPHY

- a STIFF TO HARD RED-BROWN VERY SILTY CLAY WITH OCCASIONAL GRAVEL AND BOULDERS. FISSURES TO 30"
- b SOFT TO FIRM LAYERED RED-BROWN, GREY AND RED SENSITIVE SILTY CLAYS. LAYERS 1/8" TO 1" THICK.
- c STIFF RED-BROWN SILTY CLAY WITH OCCASIONAL SAND AND GRAVEL.
- d SOFT TO FIRM LAYERED RED-BROWN, GREY AND RED SENSITIVE SILTY CLAYS. LAYERS 1/8" TO 1" THICK.
- e FIRM TO STIFF LAYERED RED-BROWN SILTY CLAY AND LOOSE TO COMPACT RED-BROWN CLAYEY SILT. LAYERS 1" TO 4" THICK.
- f VERY STIFF TO HARD RED-BROWN CLAYEY TILL WITH ANGULAR SAND AND GRAVEL.
- GREY AND WHITE SEDIMENTARY ROCK

SOIL PROFILE		
ELEV. DEPTH	DESCRIPTION	STRAT. PLOT PHOTOGRAPH
587.6 0.0	GROUND LEVEL	
	Stiff to hard reddish-brown very Silty Clay with occasional gravel and boulders	a b c d
	fissured to approx. elev. 558	e f g h i j k l m n o p
541.6 46.0	Soft to firm layered reddish-brown, grey and red sensitive Silty Clay	
533.6 54.0		
	Stiff reddish-brown Silty Clay with occasional sand and gravel	
512.6 75.0	Soft to firm layered reddish-brown, grey and red sensitive Silty Clay	
508.6 79.0	Firm to stiff layered reddish-brown Silty Clay and compact reddish-brown Clayey Silt	
501.6 86.0	Scale 1" to 10'	

PHOTOGRAPHS OF SAMPLES BOREHOLE No. 28

FIGURE 4



Scale of Photographs



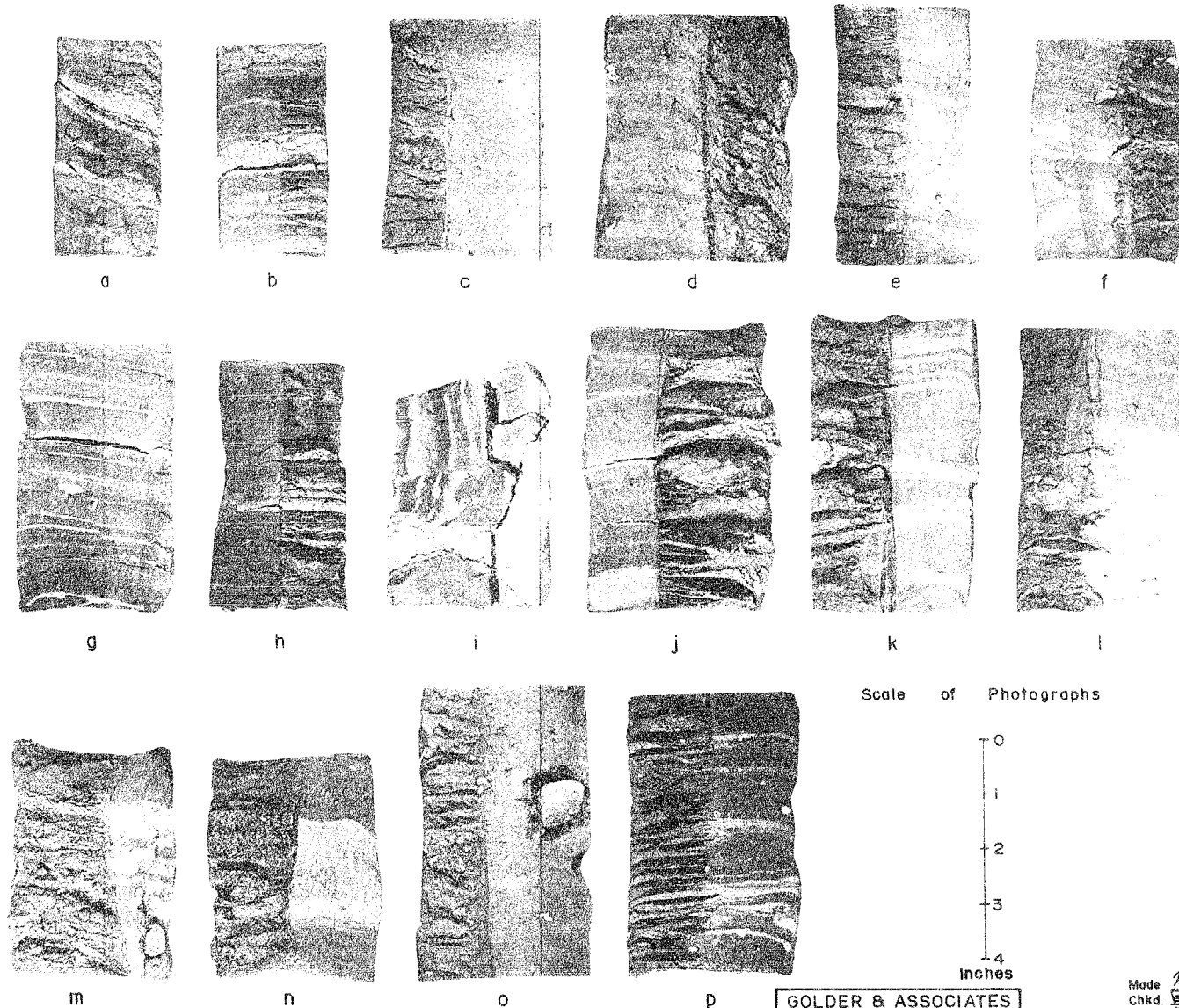
GOLDER & ASSOCIATES

Made
Chkd.
Appd.

PHOTOGRAPHS OF SAMPLES BOREHOLE No. 28

FIGURE 4

SOIL PROFILE		STRAT. PLT	PHOTOGRAPH
ELEV. DEPTH	DESCRIPTION		
567.6 0.0	GROUND LEVEL		
	Stiff to hard reddish-brown very Silty Clay with occasional gravel and boulders	(a) (b) (c) (d)	a b c d
	fissured to approx elev. 558	(e) (f)	e f
541.6 46.0	Soft to firm layered reddish-brown, grey and red sensitive Silty Clay	(g) (h) (i) (j)	g h i j
533.6 54.0	Stiff reddish-brown Silty Clay with occasional sand and gravel	(k) (l) (m) (n) (o) (p)	k l m n o p
512.6 75.0	Soft to firm layered reddish-brown, grey and red sensitive Silty Clay		
508.6 79.0	Firm to stiff layered reddish-brown Silty Clay and compact reddish-brown Clayey Silt		
501.6 86.0	Scale 1" to 10'		



Scale of Photographs

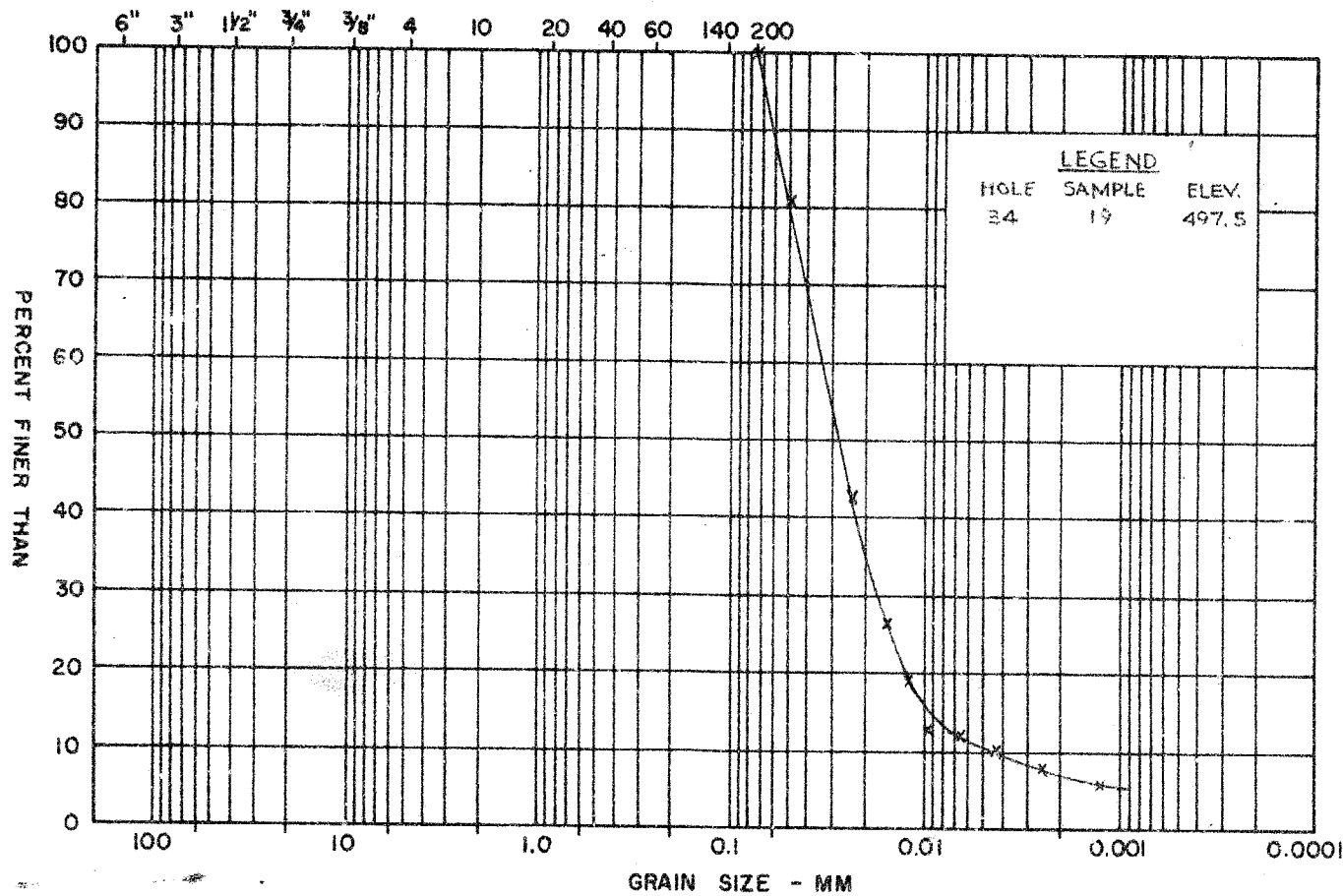
0
1
2
3
4
Inches

GOLDER & ASSOCIATES

Made
Chkd
Appd

M.I.T. GRAIN SIZE SCALE

SIZE OF OPENING - INS. U.S.S. SIEVE SIZE - MESHES/IN.



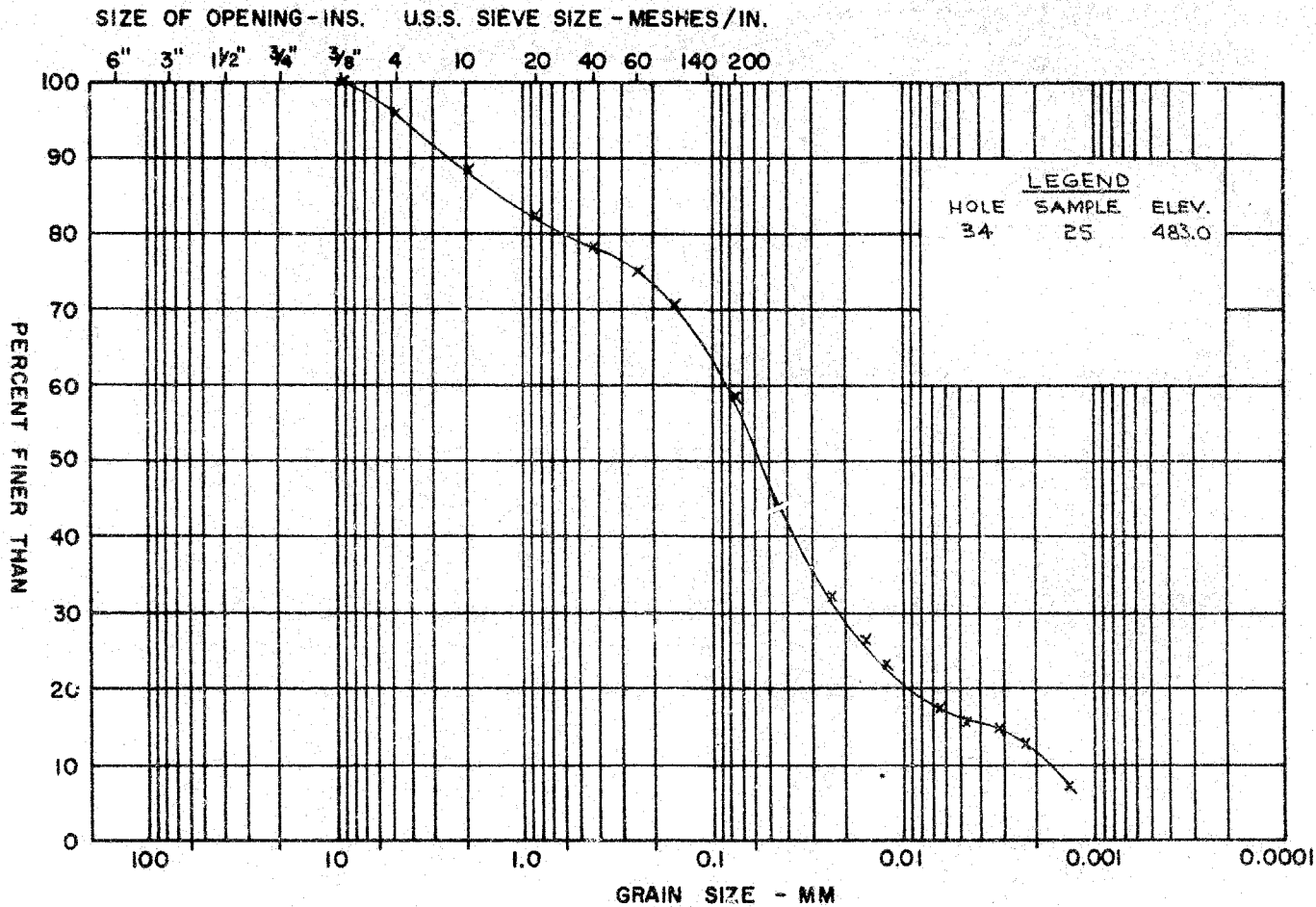
GOLDER & ASSOCIATES

GRAIN SIZE DISTRIBUTION
LAYERED SILTY CLAY

FIGURE 5

COBBLE SIZE	COARSE	MEDIUM	FINE	COARSE	MEDIUM	FINE	SILT SIZE	CLAY SIZE
	GRAVEL SIZE			SAND SIZE			FINE GRAINED	

M.I.T. GRAIN SIZE SCALE

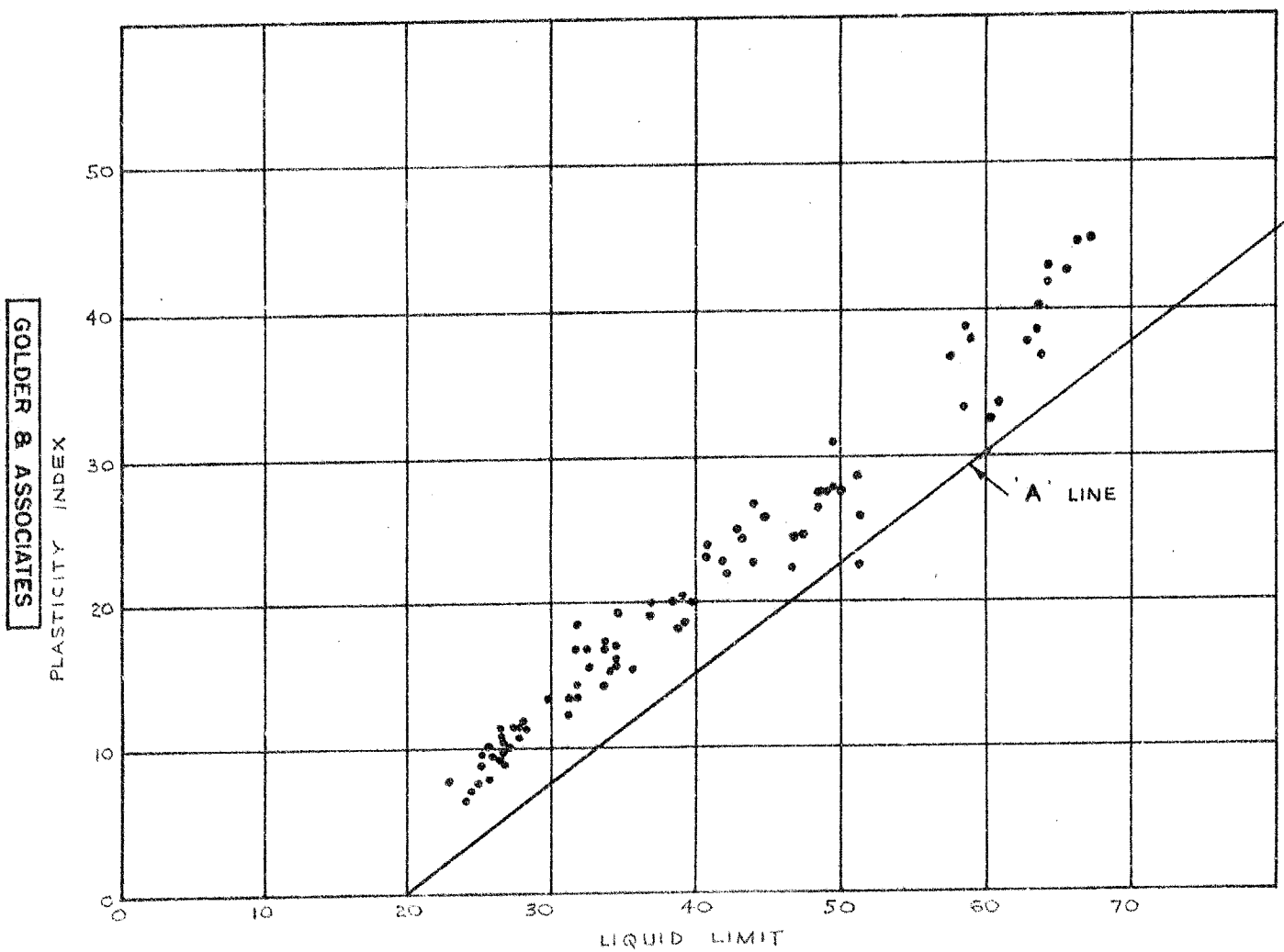


GOLDER & ASSOCIATES

GRAIN SIZE DISTRIBUTION
CLAYEY TILL

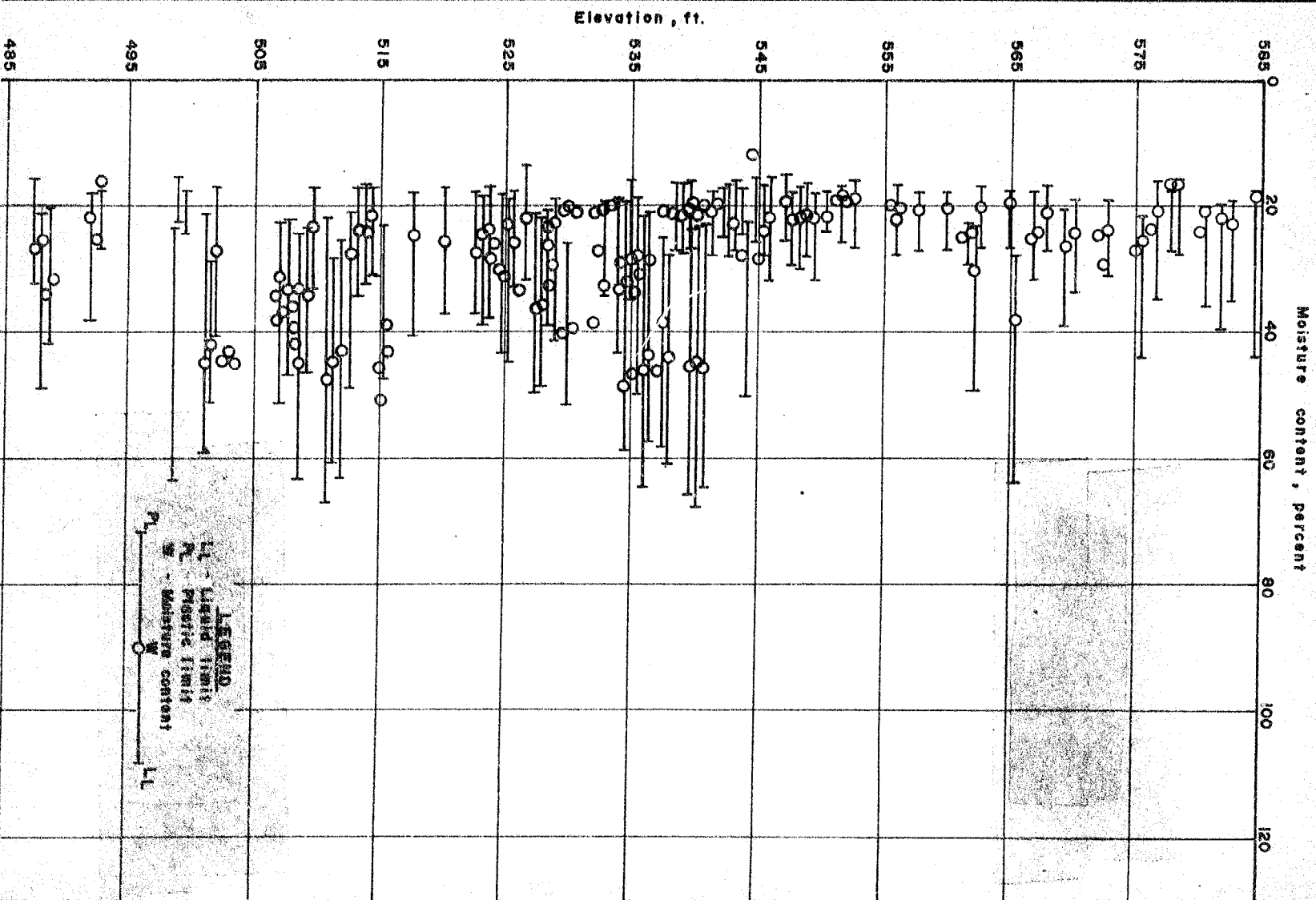
FIGURE

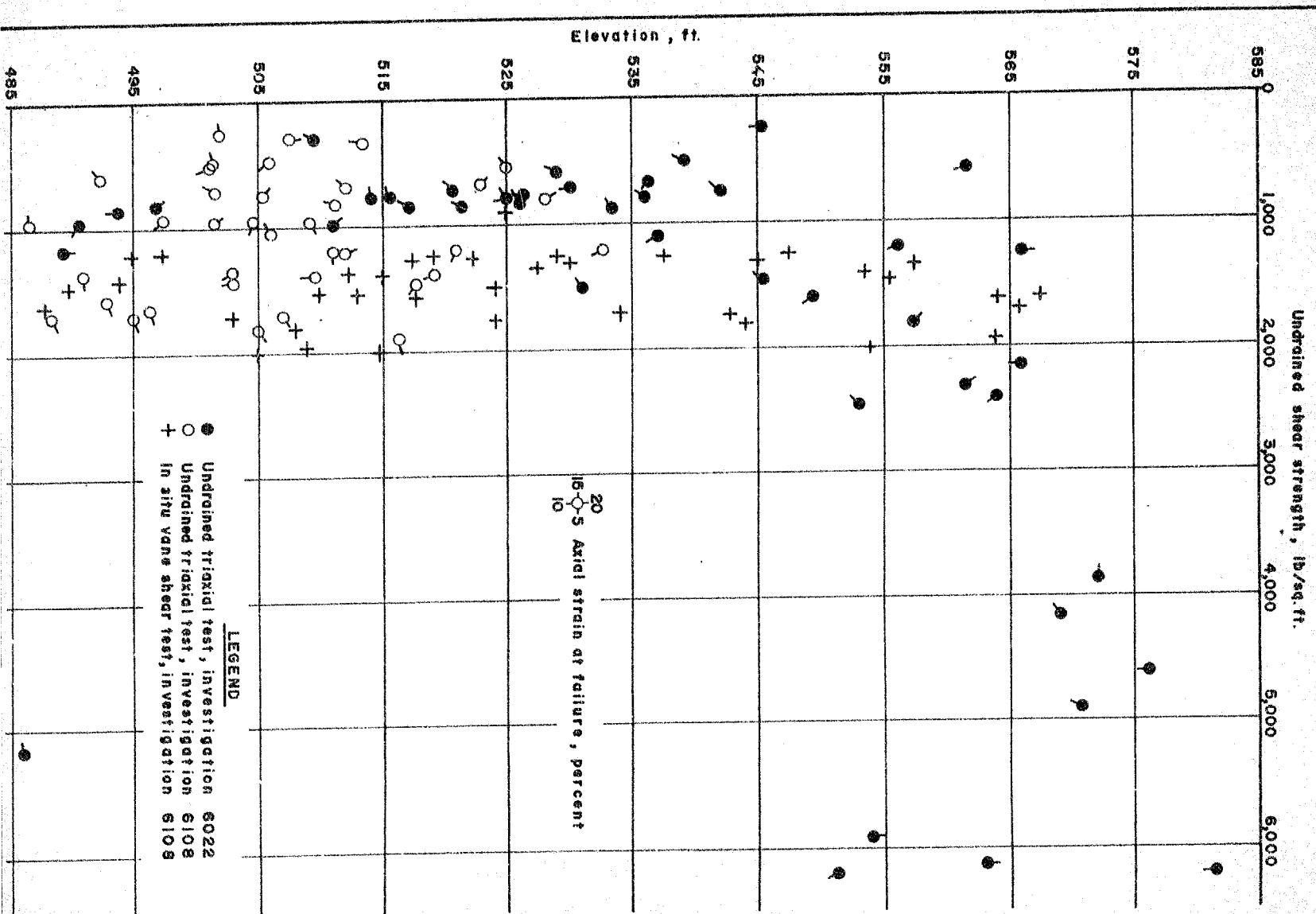
6



PLASTICITY CHART

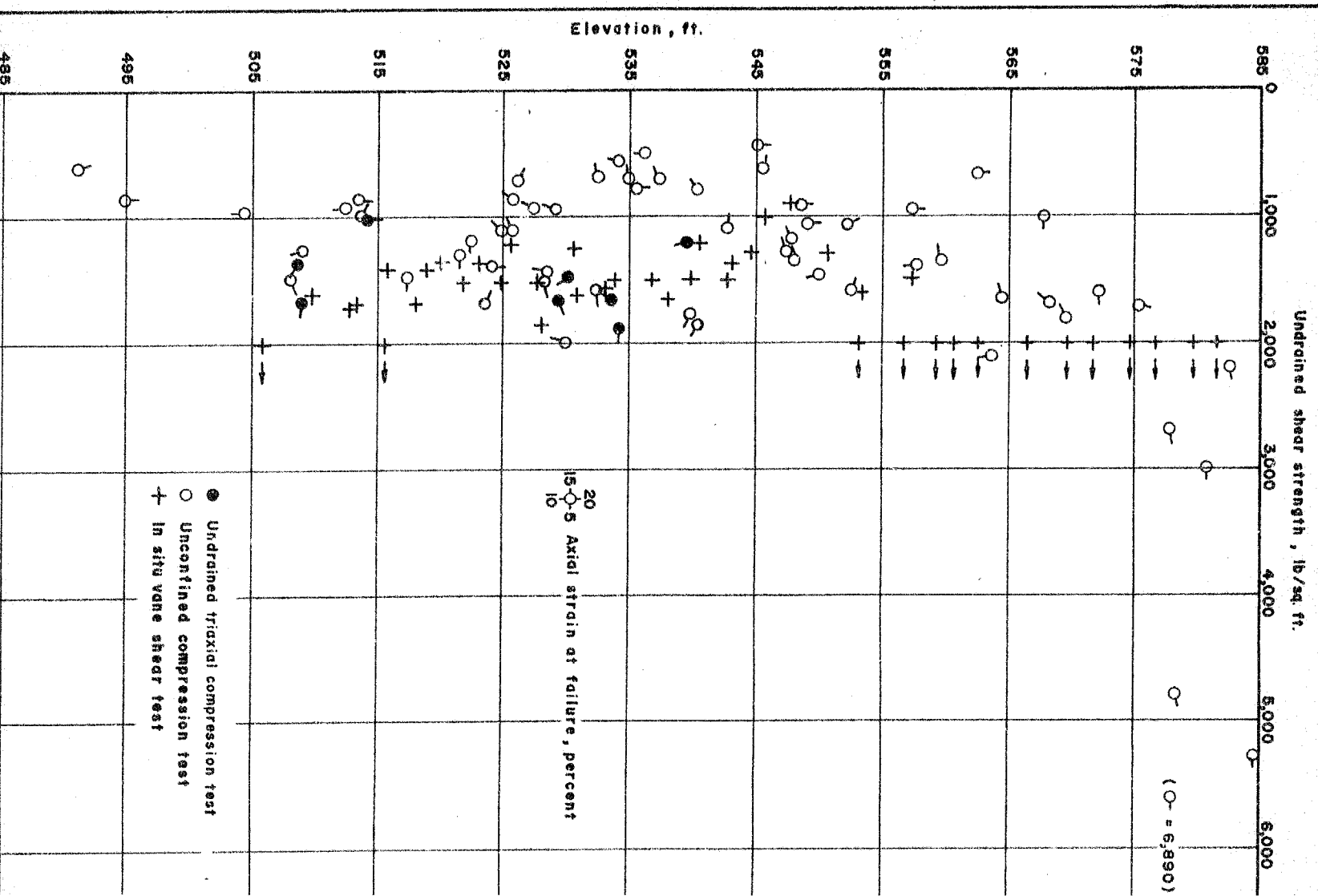
FIGURE 7

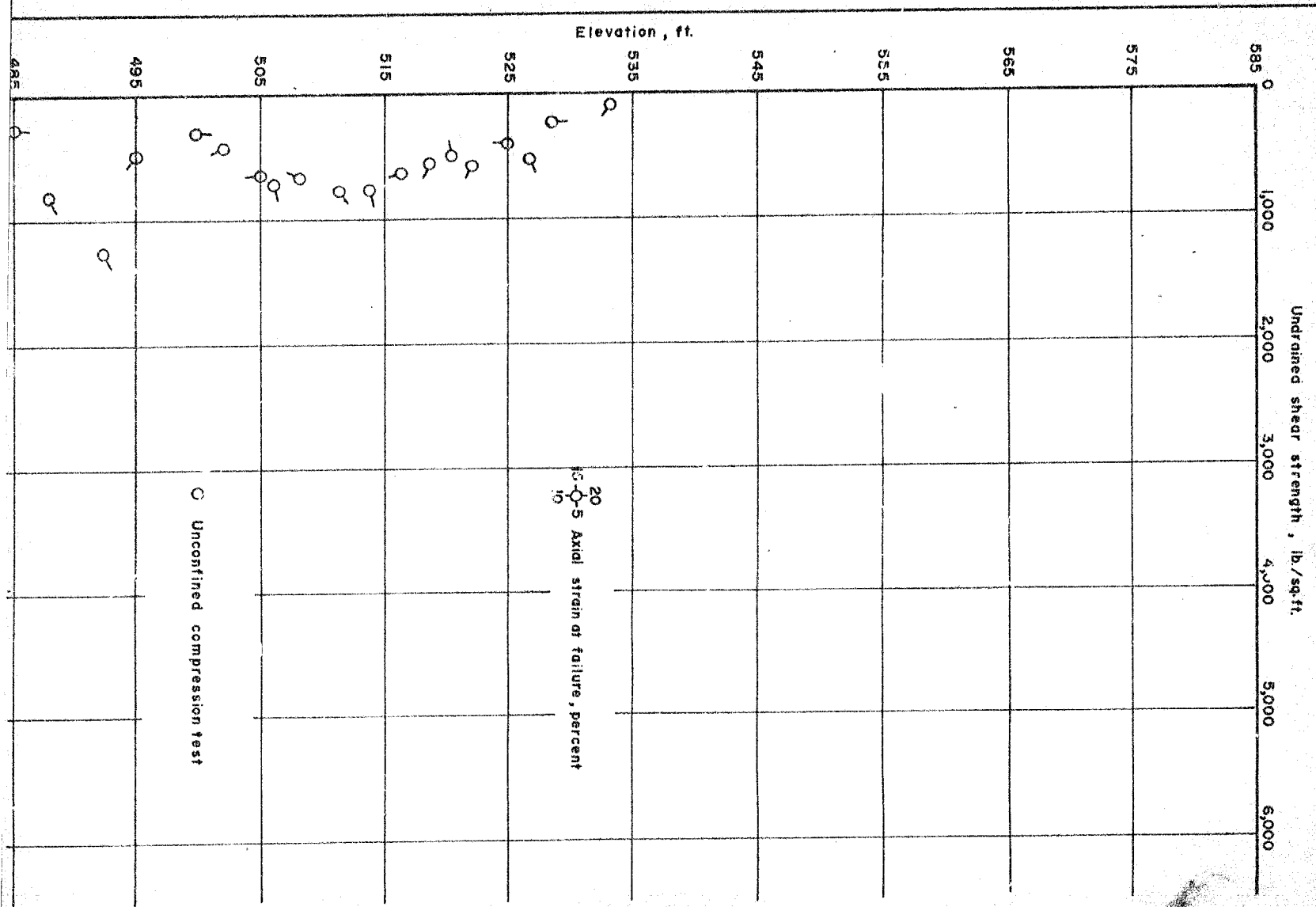


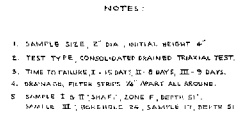
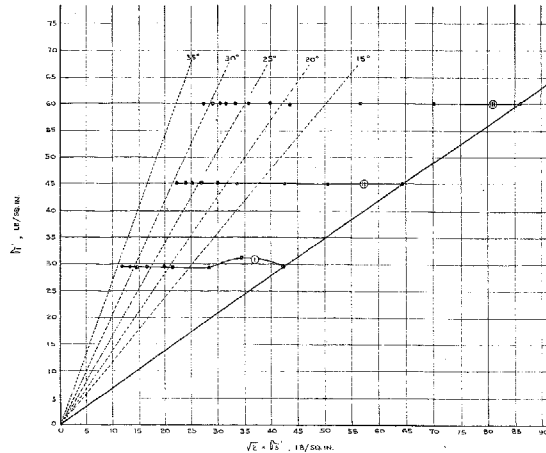


SUMMARY - UNDRAINED SHEAR STRENGTHS MEASURED, 1963

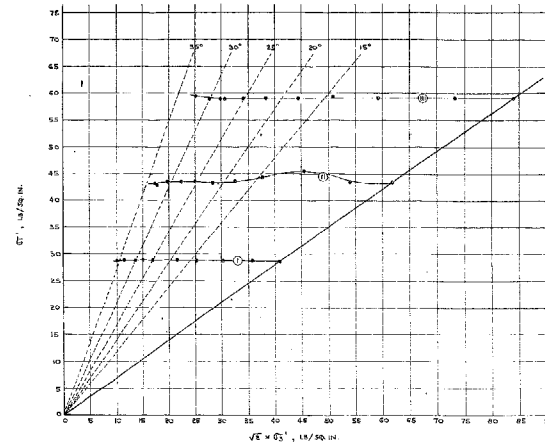
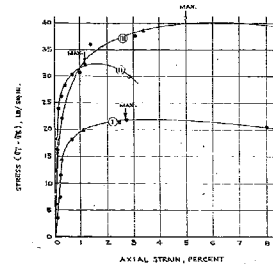
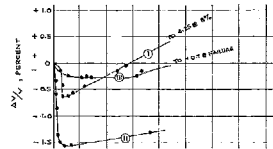
FIGURE 10





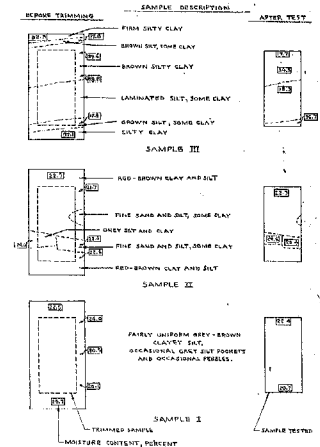
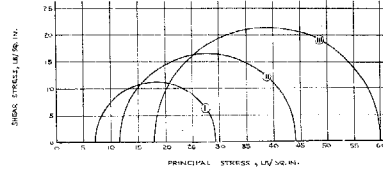


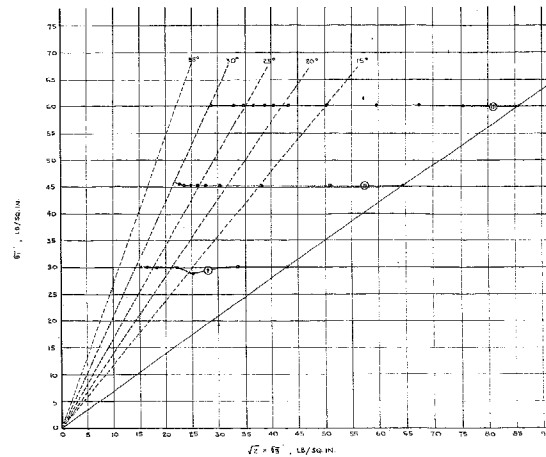
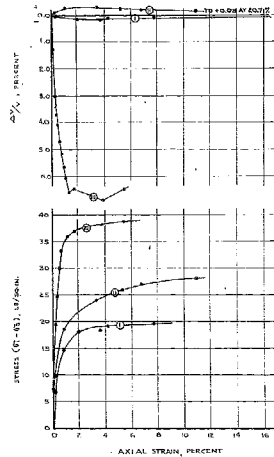
GOLDER & ASSOCIATES



NOTES:

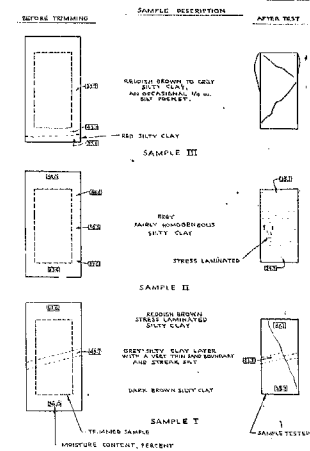
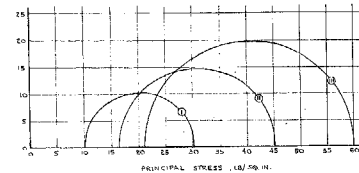
1. SAMPLE SIZE, 2" DIA., INITIAL HEIGHT 4"
2. TEST TYPE, CONSOLIDATED DRAINED TRIAXIAL TEST
3. TIME TO FAILURE, I - 14 DAYS, II - 10 DAYS, III - 12 DAYS
4. DRAINAGE, FILTER STRIPS 1/2" APART ALL AROUND
5. BOARDHOLE OR, SAMPLE 18, DRAIN 45°





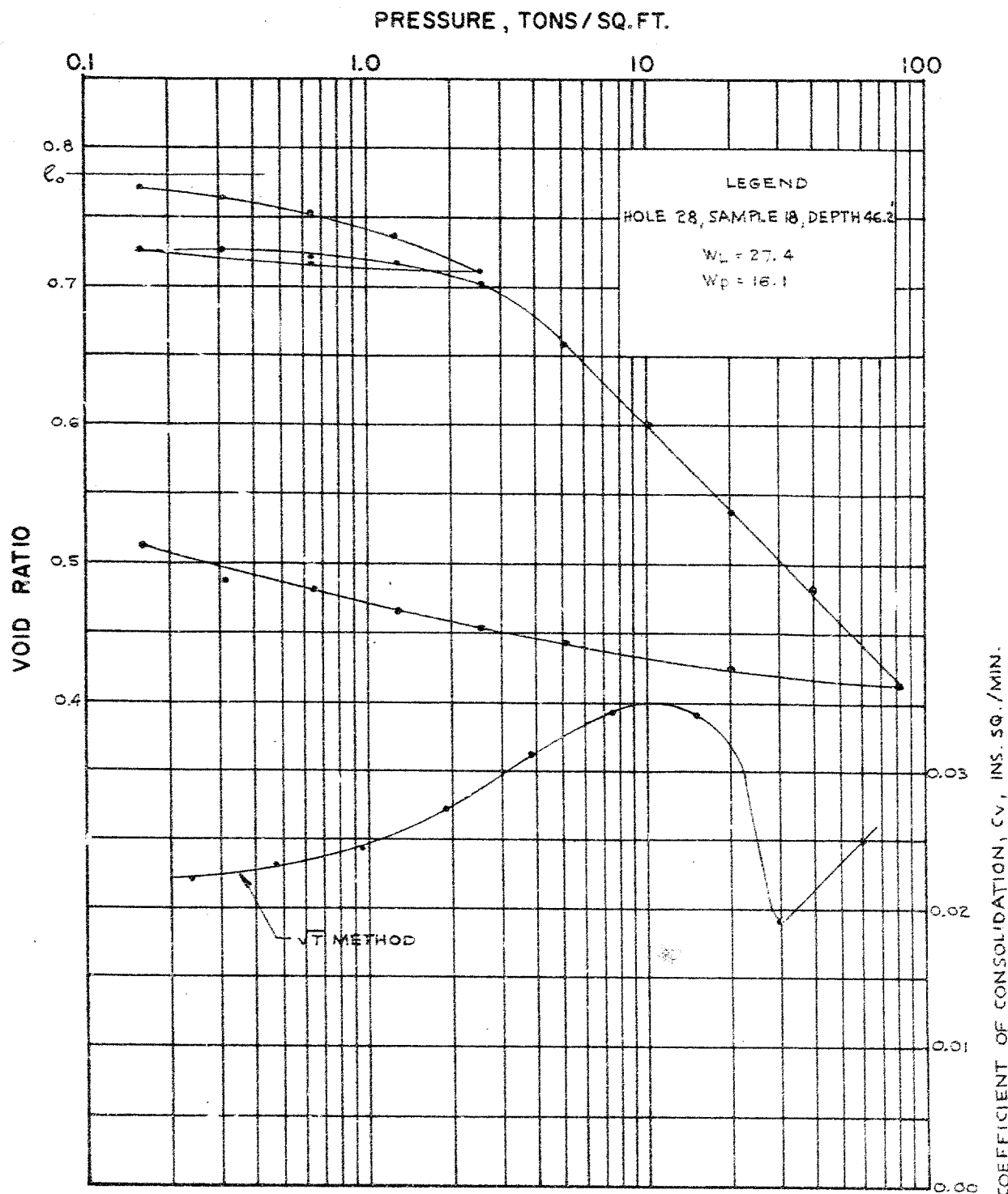
NOTES:

1. SAMPLE SIZE, 2" DIA., INITIAL HEIGHT 9"
2. TEST TYPE, CONSOLIDATED DRAINED TRIAXIAL TEST
3. TIME TO FAILURE: I - 12 DAYS, II - 11 DAYS, III - 20 DAYS
4. DRAINAGE, FILTER STRIPS, 1/2" APART ALL AROUND
5. BOREHOLE NO., SAMPLE NO., DEPTH 73'



VOID RATIO - PRESSURE CURVES CONSOLIDATION TEST

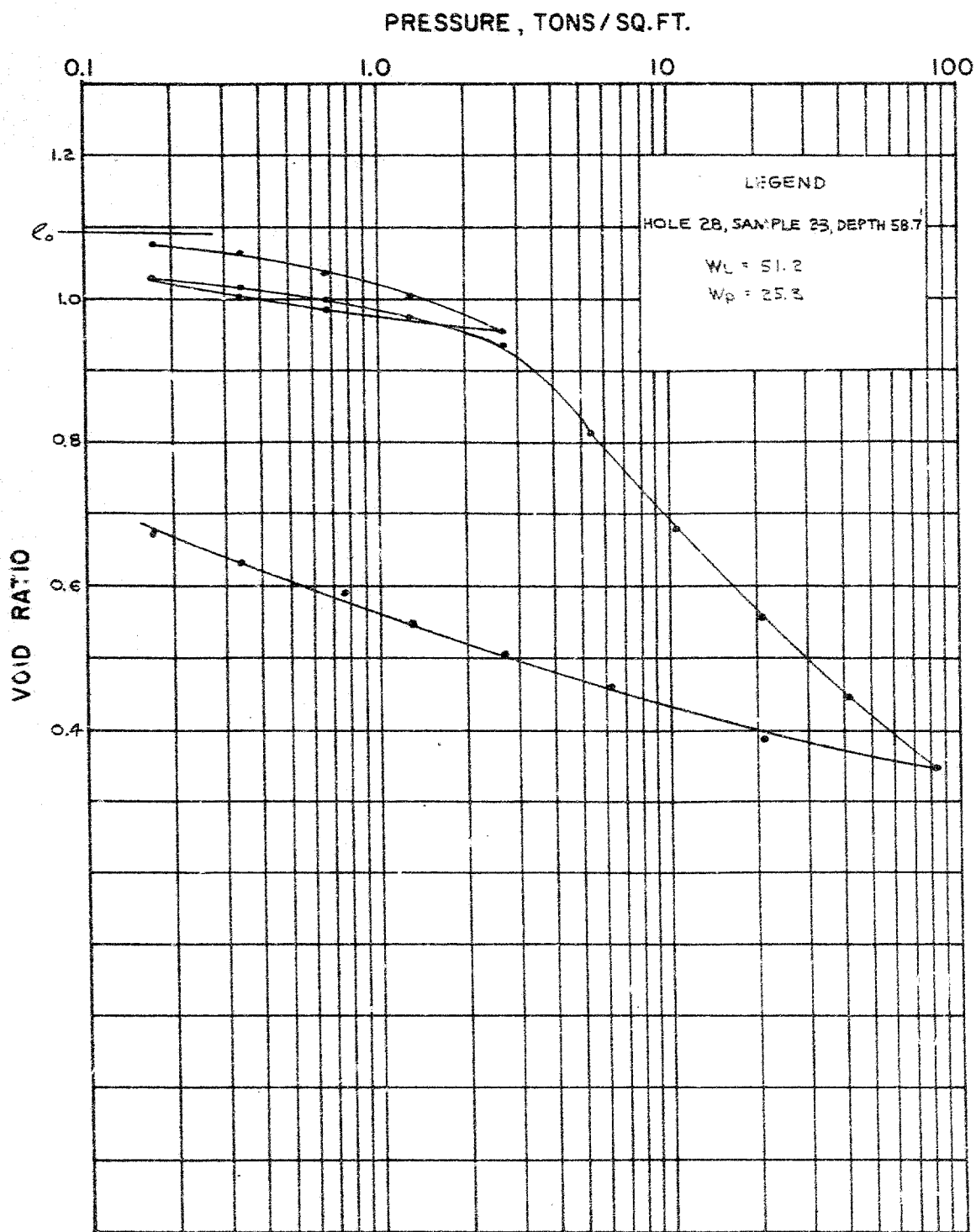
FIGURE 15



GOLDER & ASSOCIATES

VOID RATIO - PRESSURE CURVES
CONSOLIDATION TEST

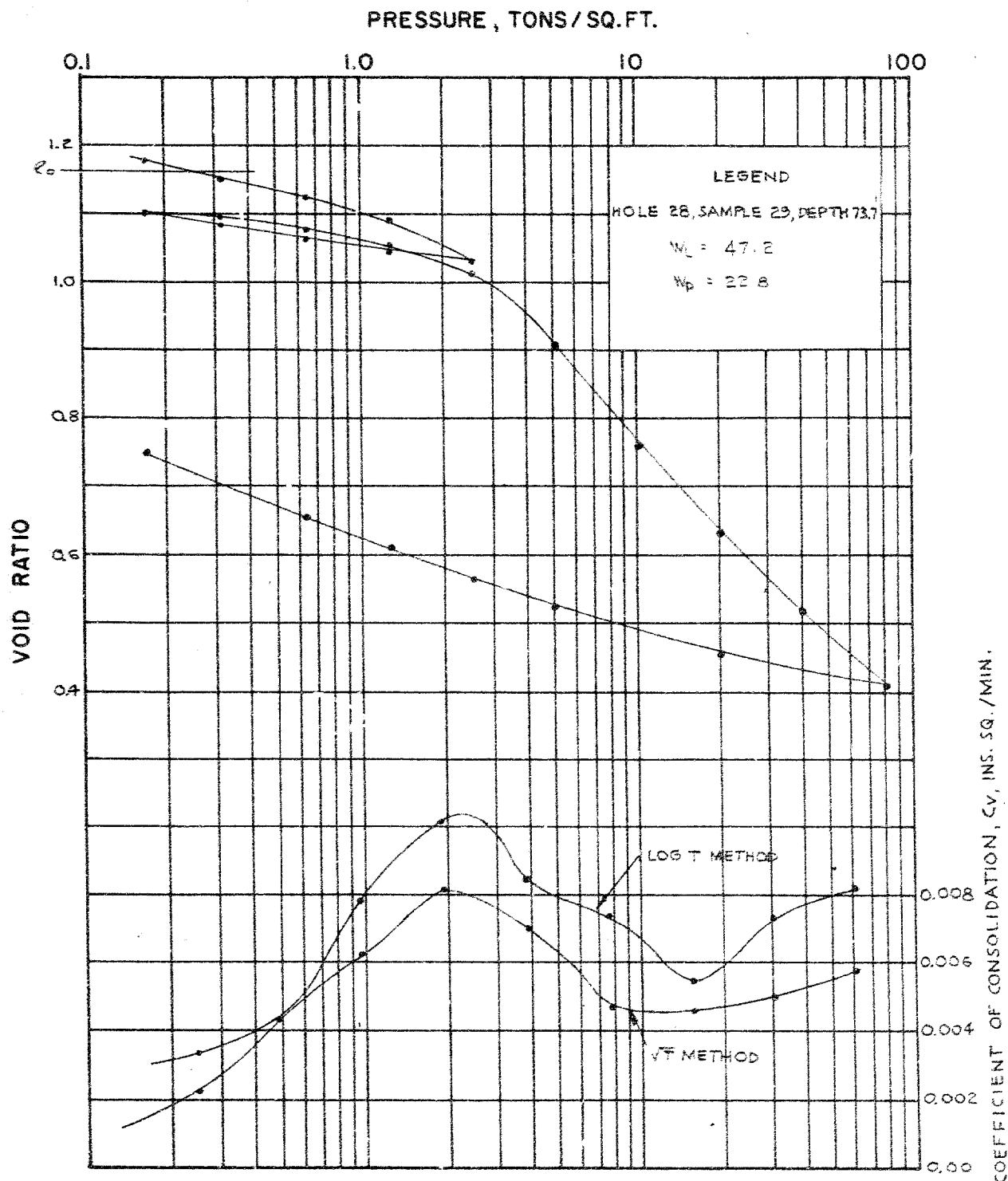
FIGURE 16



GOLDER & ASSOCIATES

VOID RATIO - PRESSURE CURVES CONSOLIDATION TEST

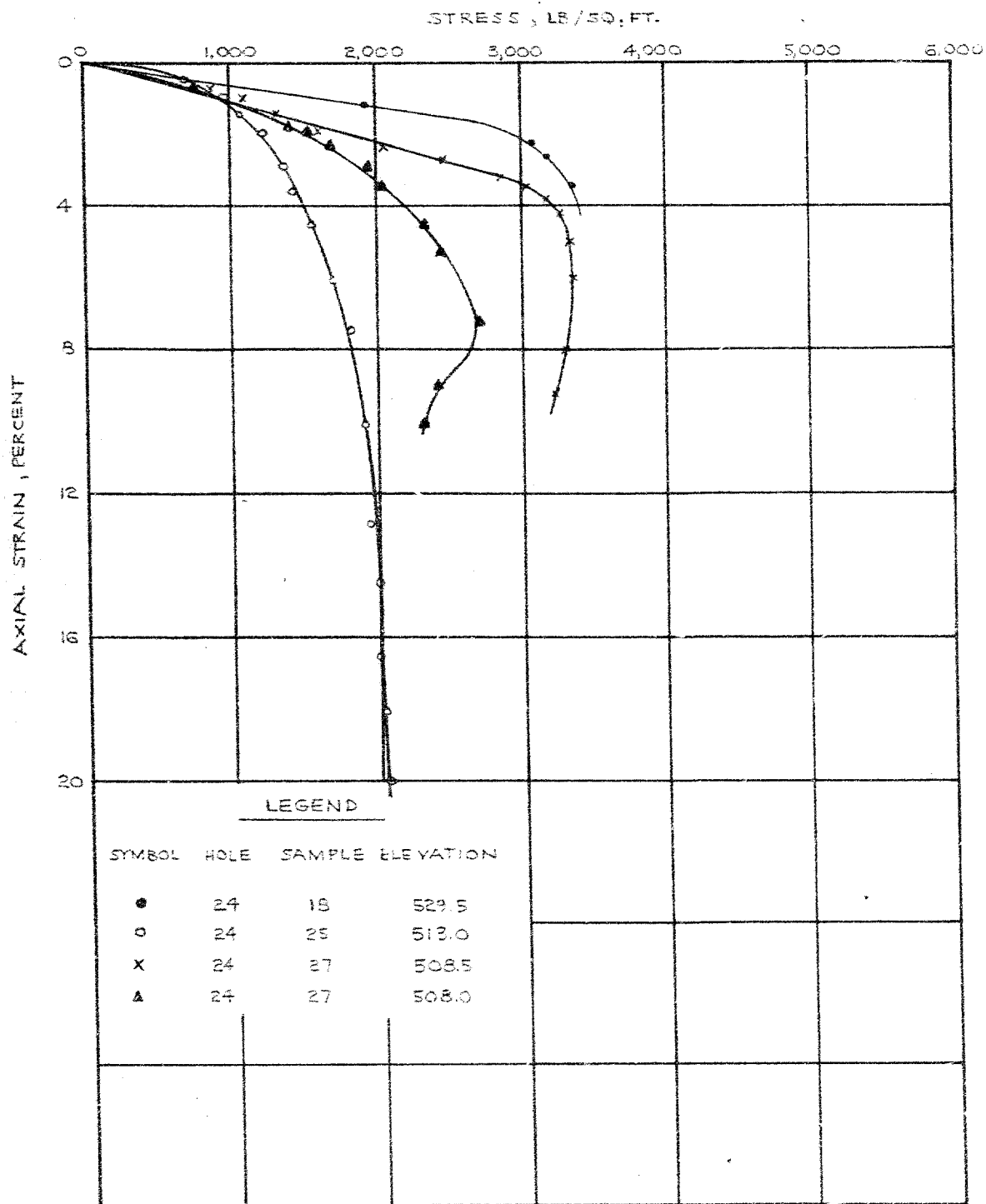
FIGURE 17



GOLDER & ASSOCIATES

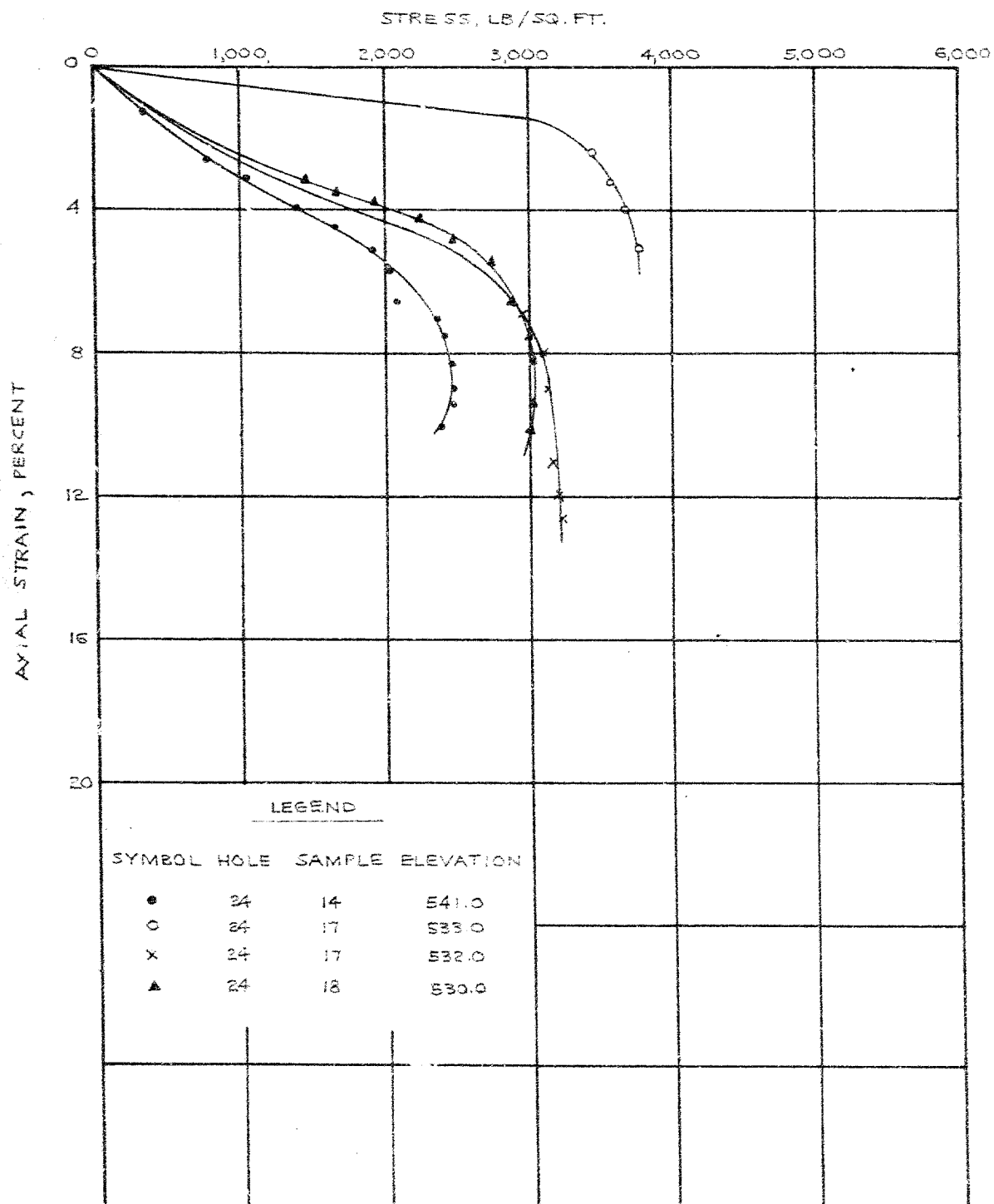
UNDRAINED TRIAXIAL TESTS STRESS-STRAIN CURVES

FIGURE 18



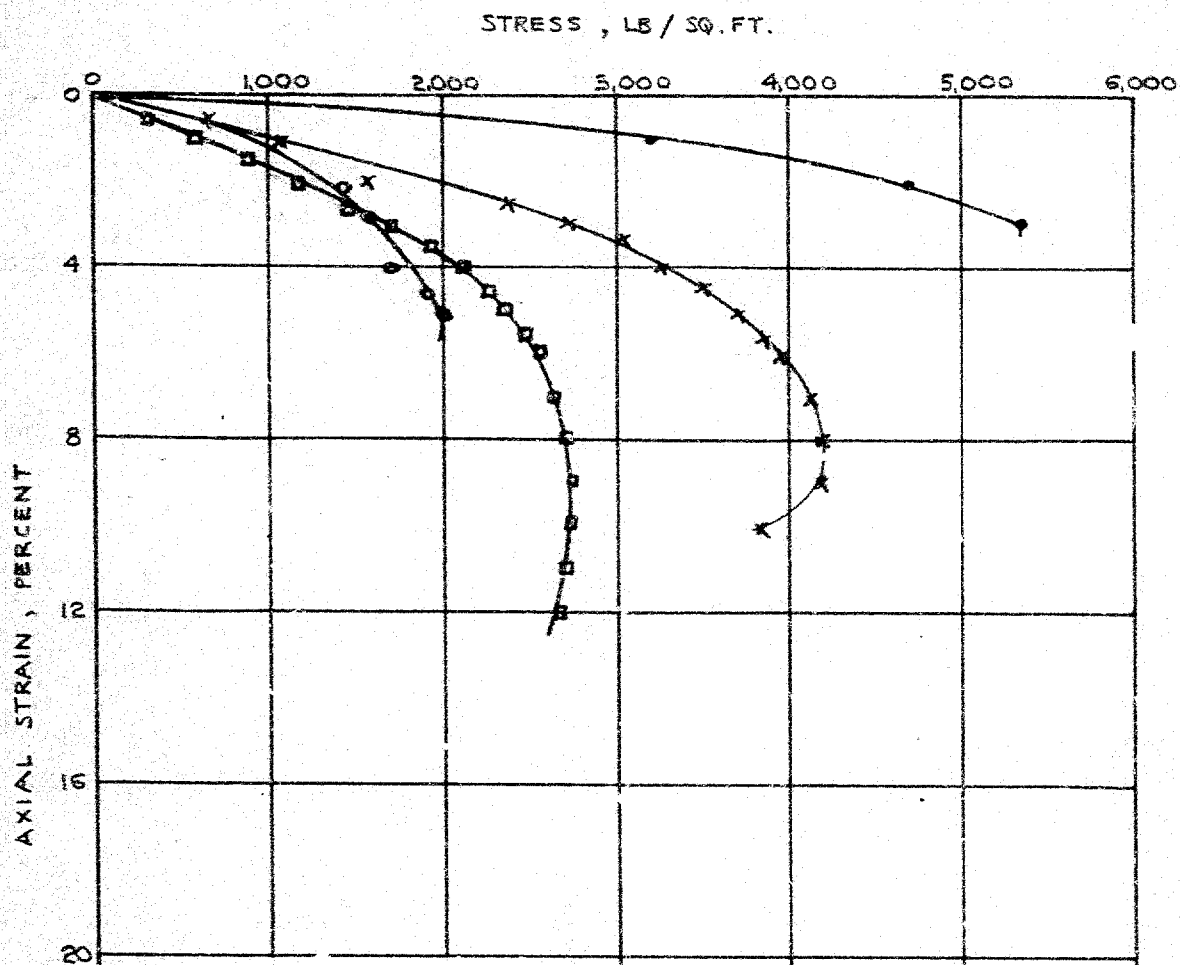
UNDRAINED TRIAXIAL TESTS STRESS - STRAIN CURVES

FIGURE 19



UNCONFINED COMPRESSION TESTS STRESS-STRAIN CURVES

FIGURE 20



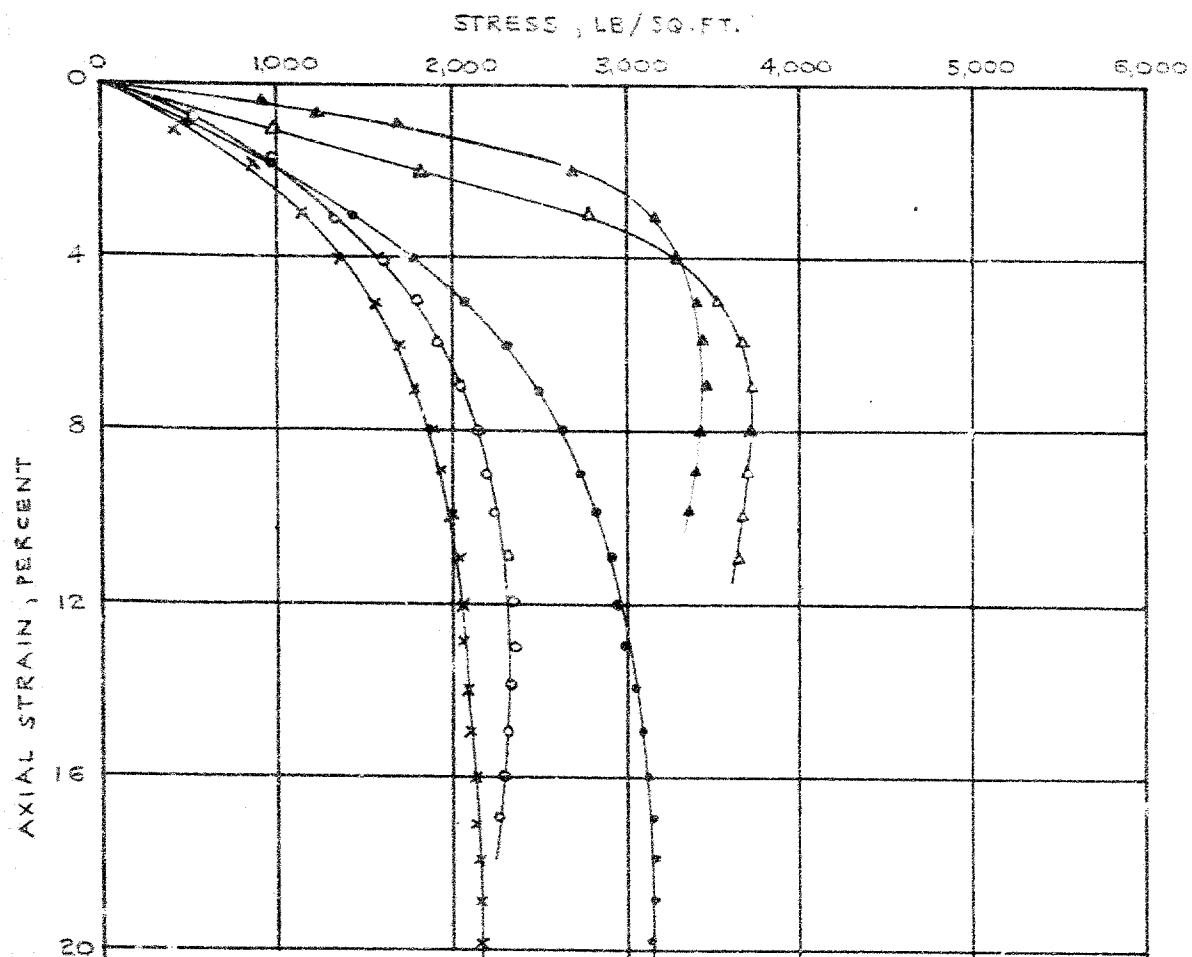
LEGEND

SYMBOL HOLE SAMPLE ELEVATION

•	24	1	578.3
○	24	4	567.5
×	24	6	563.5
□	24	7	558.3

UNCONFINED COMPRESSION TESTS STRESS-STRAIN CURVES

FIGURE 21



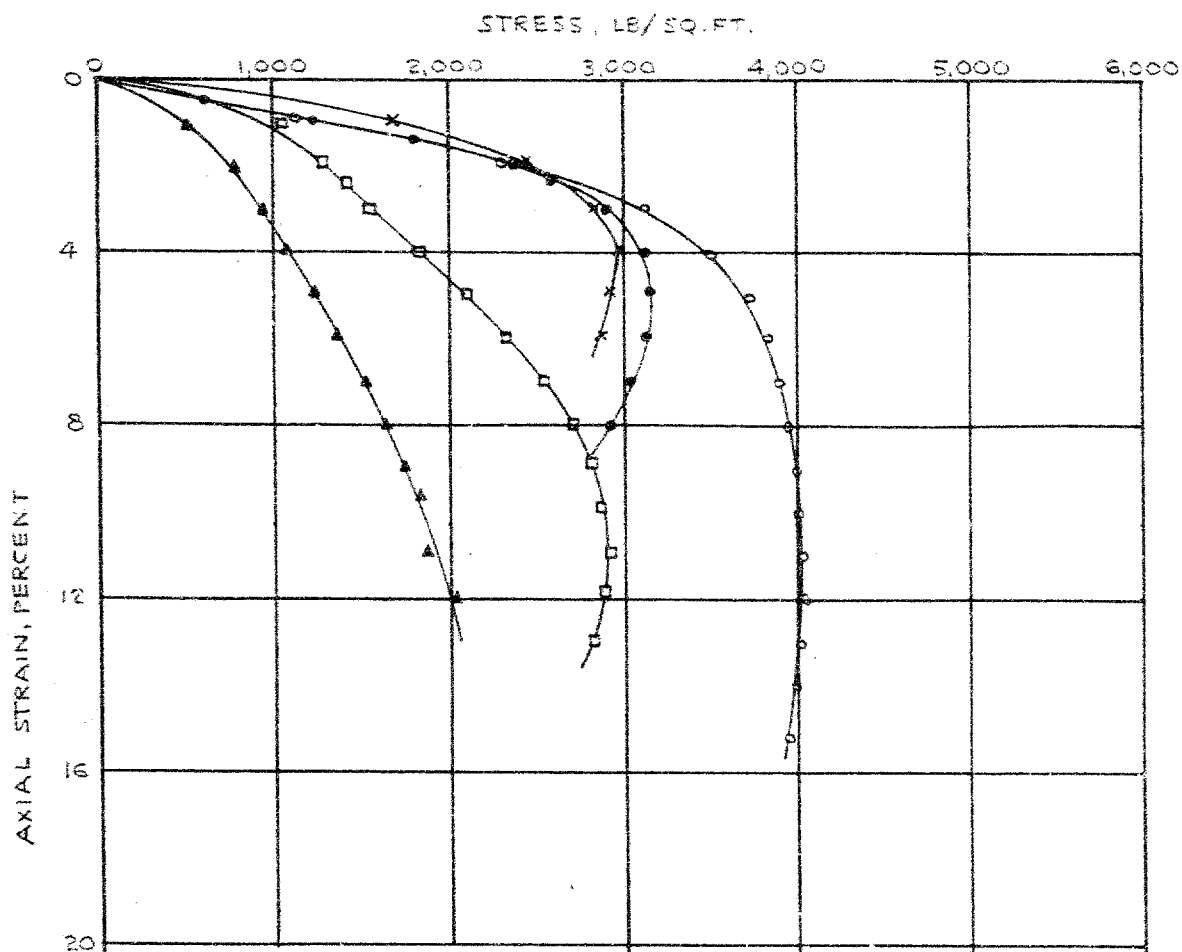
LEGEND

SYMBOL HOLE SAMPLE ELEVATION

●	24	9	552.5
○	24	11	548.0
x	24	13	542.0
△	24	14	540.5
▲	24	14	540.0

UNCONFINED COMPRESSION TESTS STRESS-STRAIN CURVES

FIGURE 22



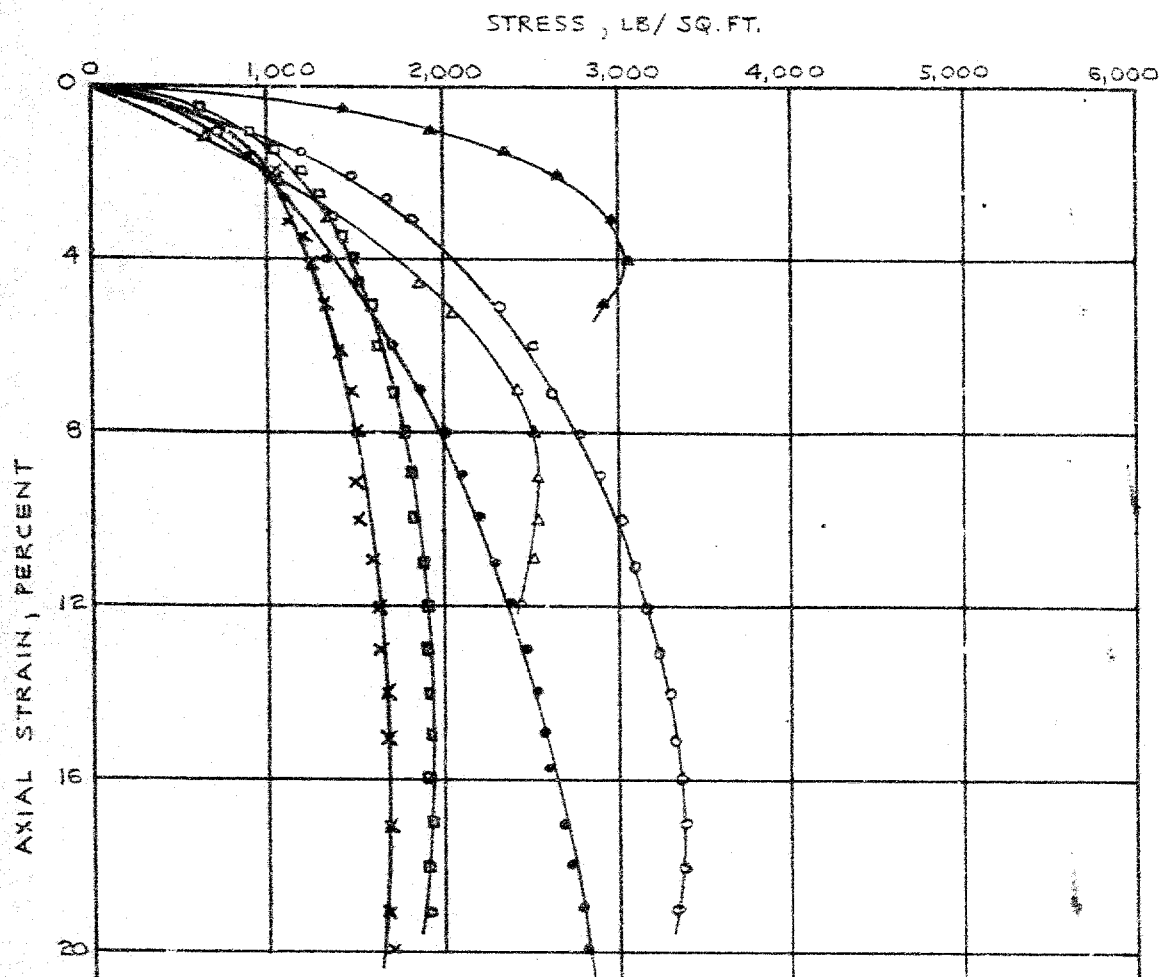
LEGEND

SYMBOL HOLE SAMPLE ELEVATION

●	24	17	532.7
○	24	18	530.5
X	24	19	529.0
□	24	19	528.5
▲	24	19	528.0

UNCONFINED COMPRESSION TESTS STRESS-STRAIN CURVES

FIGURE 23



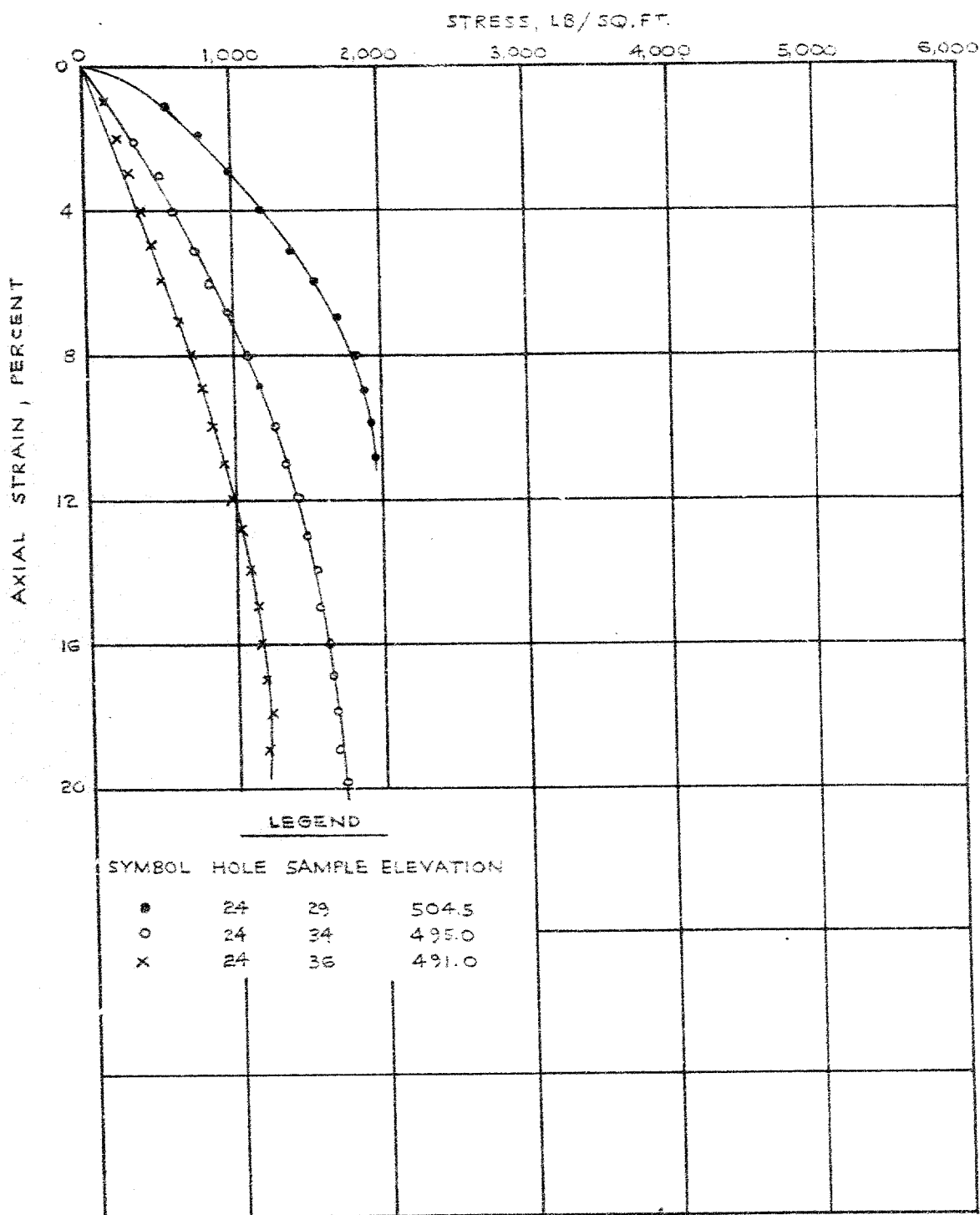
LEGEND

SYMBOL HOLE SAMPLE ELEVATION

○	24	21	523.0
●	24	21	523.5
□	24	25	513.0
x	24	25	513.5
▲	24	27	508.0
△	24	27	508.5

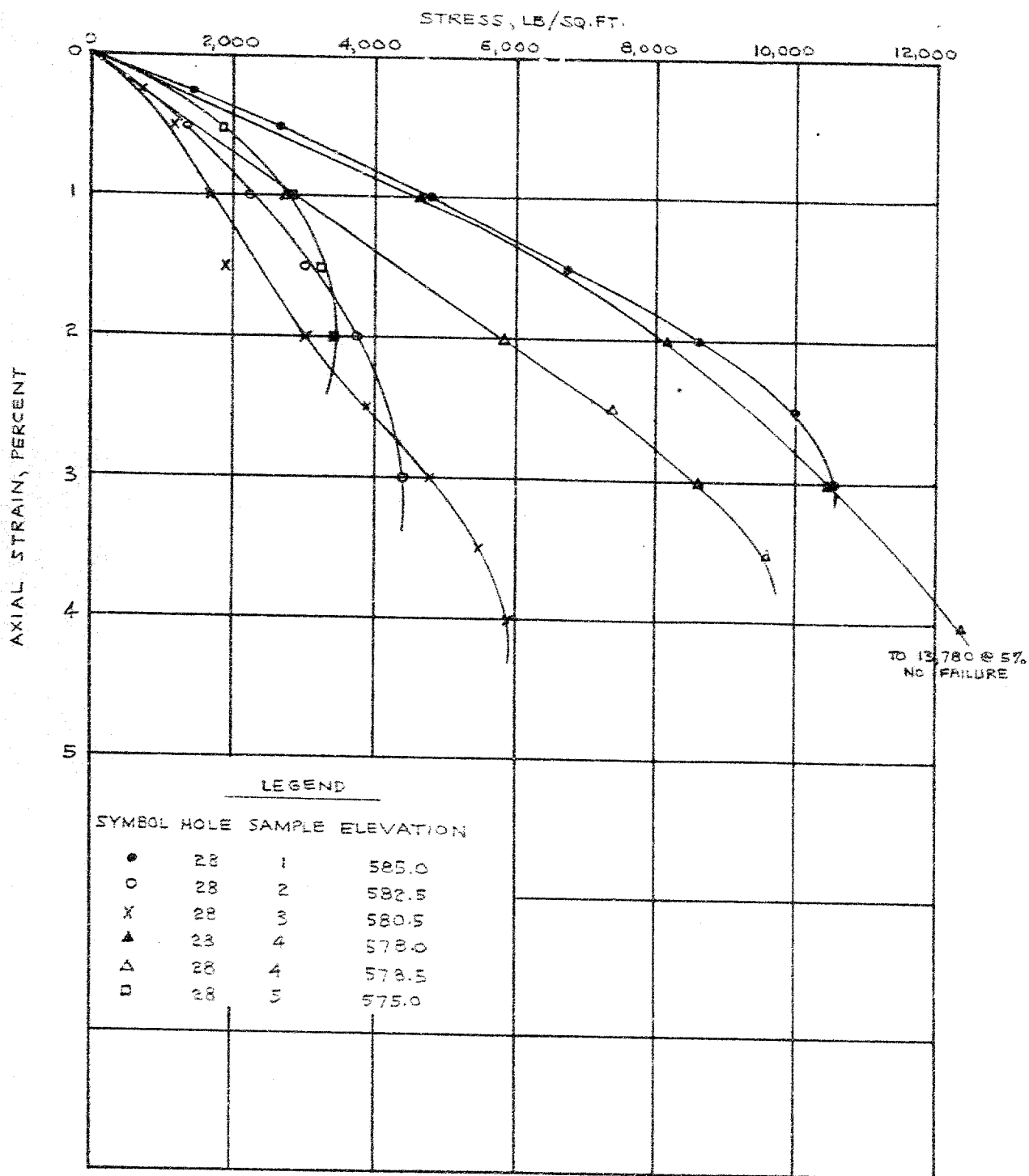
UNCONFINED COMPRESSION TESTS STRESS - STRAIN CURVES

FIGURE 24



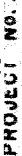
UNCONFINED COMPRESSION TESTS STRESS-STRAIN CURVES

FIGURE 25



PROJECT NO.

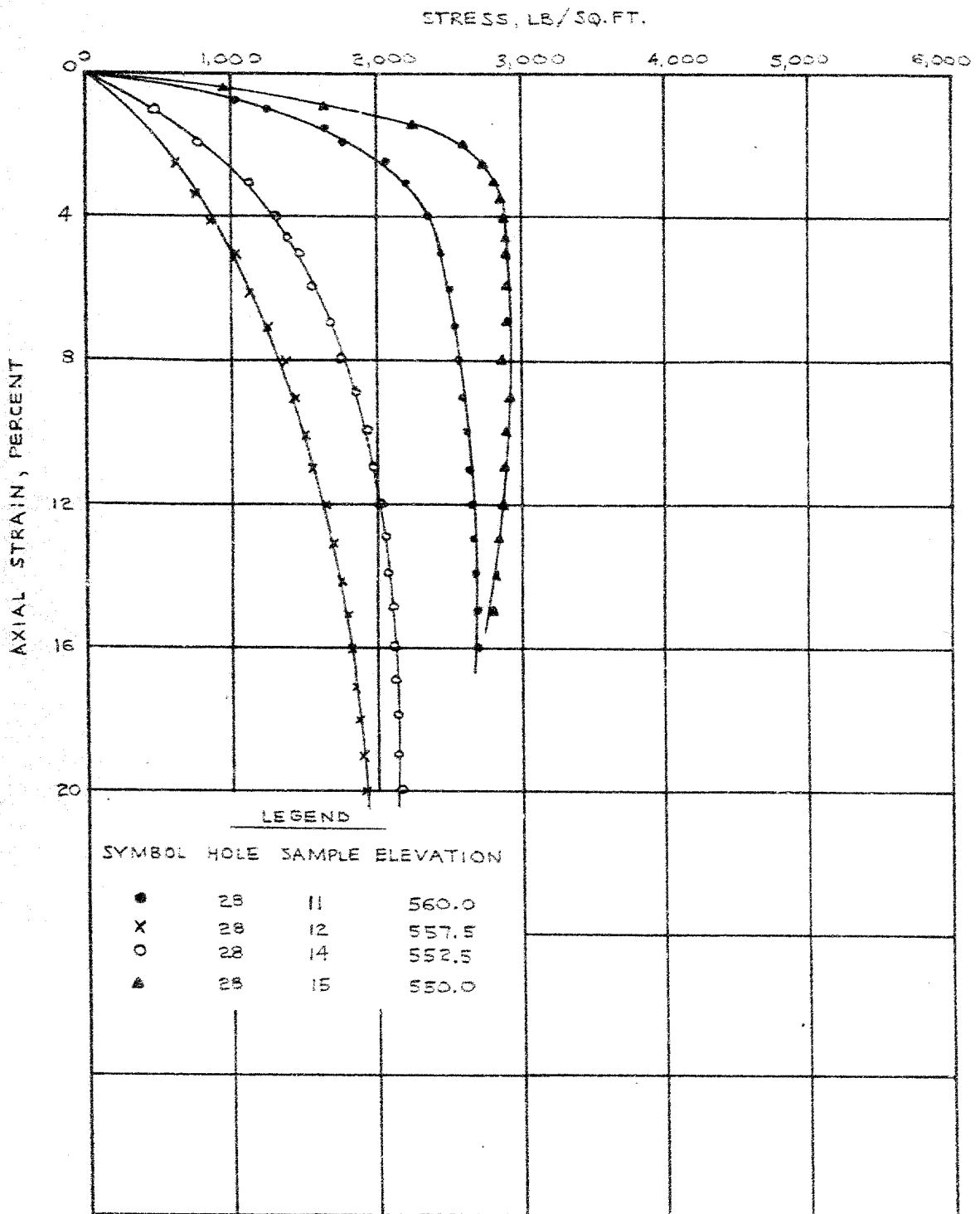
PROJECT NO.



PROJECT NO.

UNCONFINED COMPRESSION TESTS STRESS-STRAIN CURVES

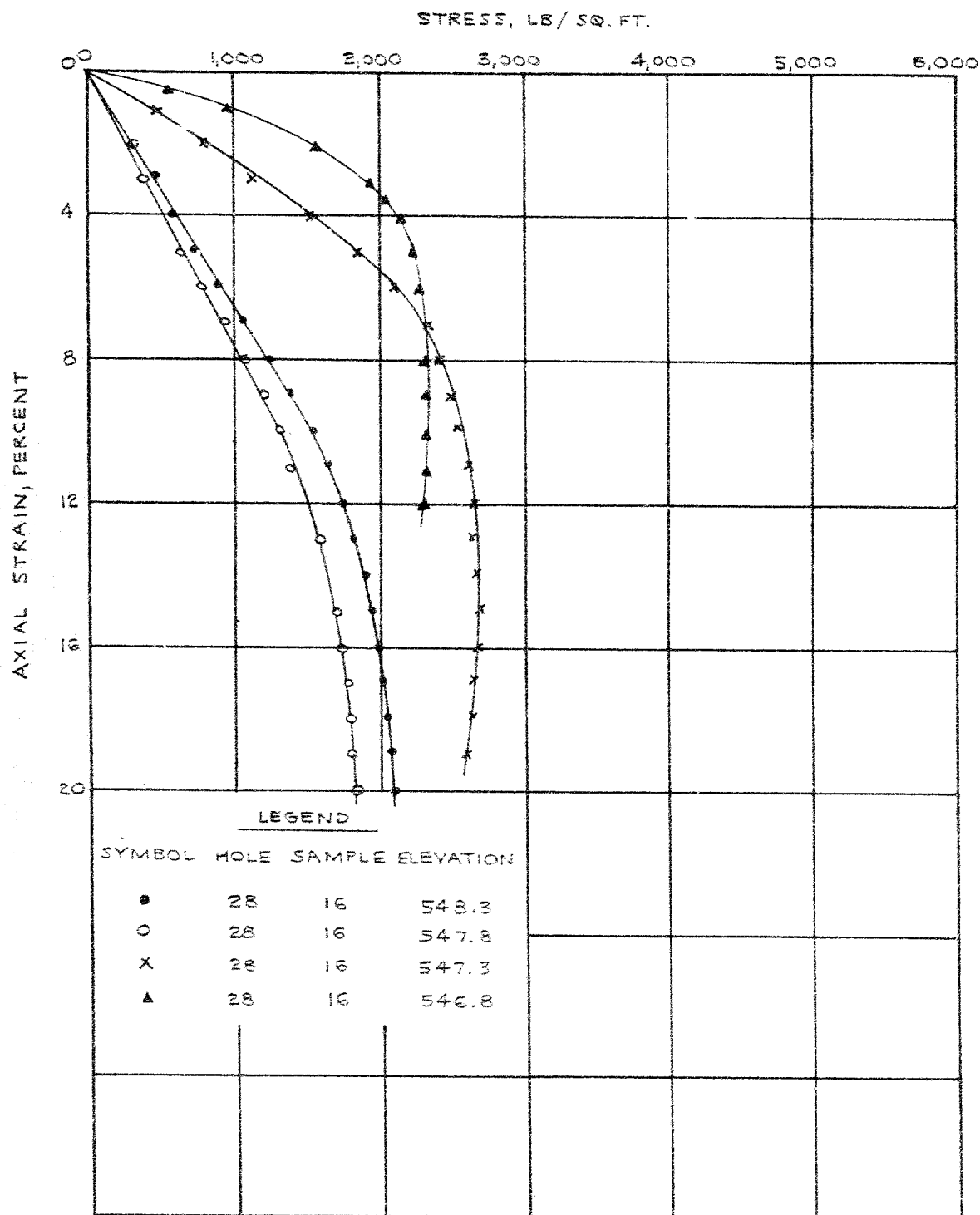
FIGURE 27



PROJECT NO. 63-77-1

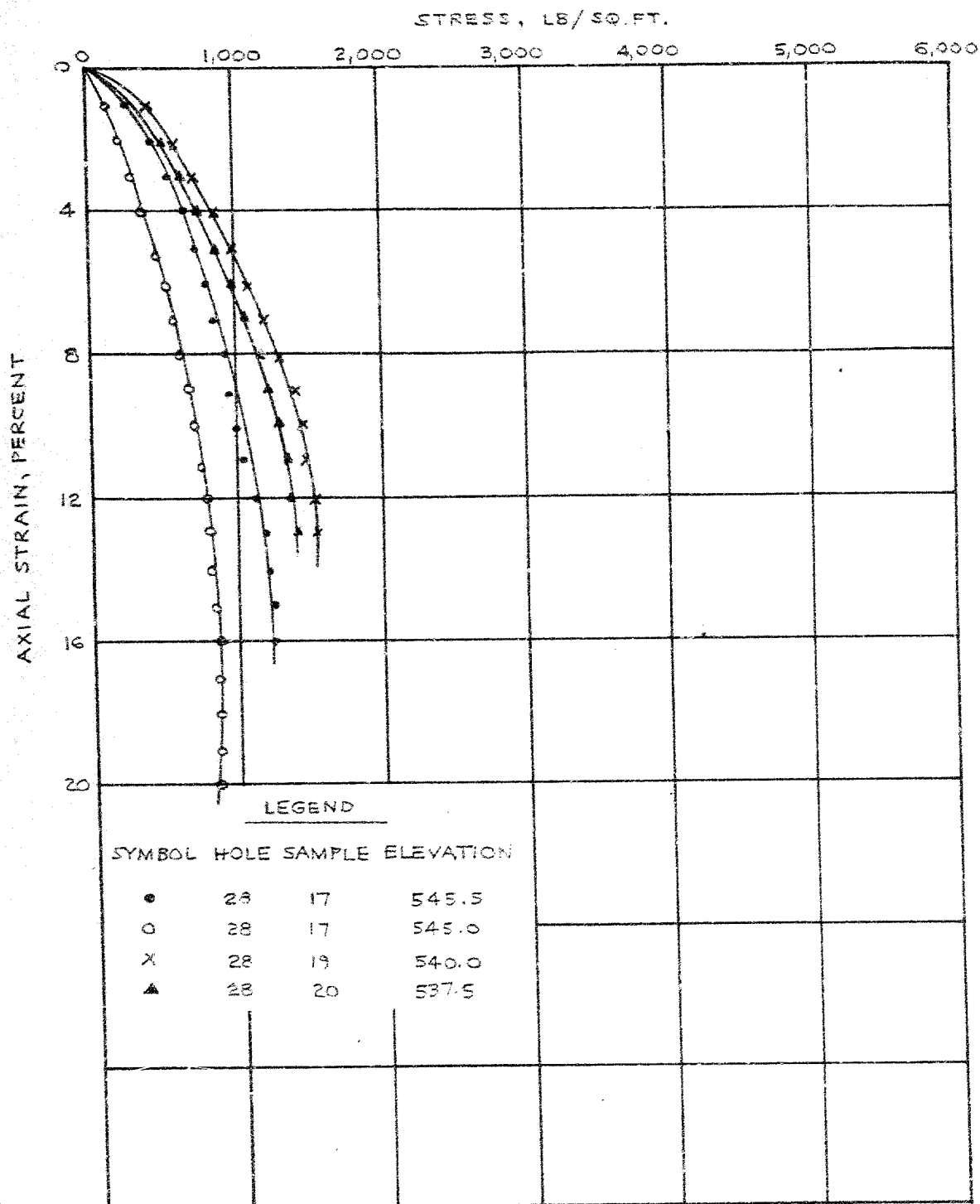
UNCONFINED COMPRESSION TESTS STRESS-STRAIN CURVES

FIGURE 28



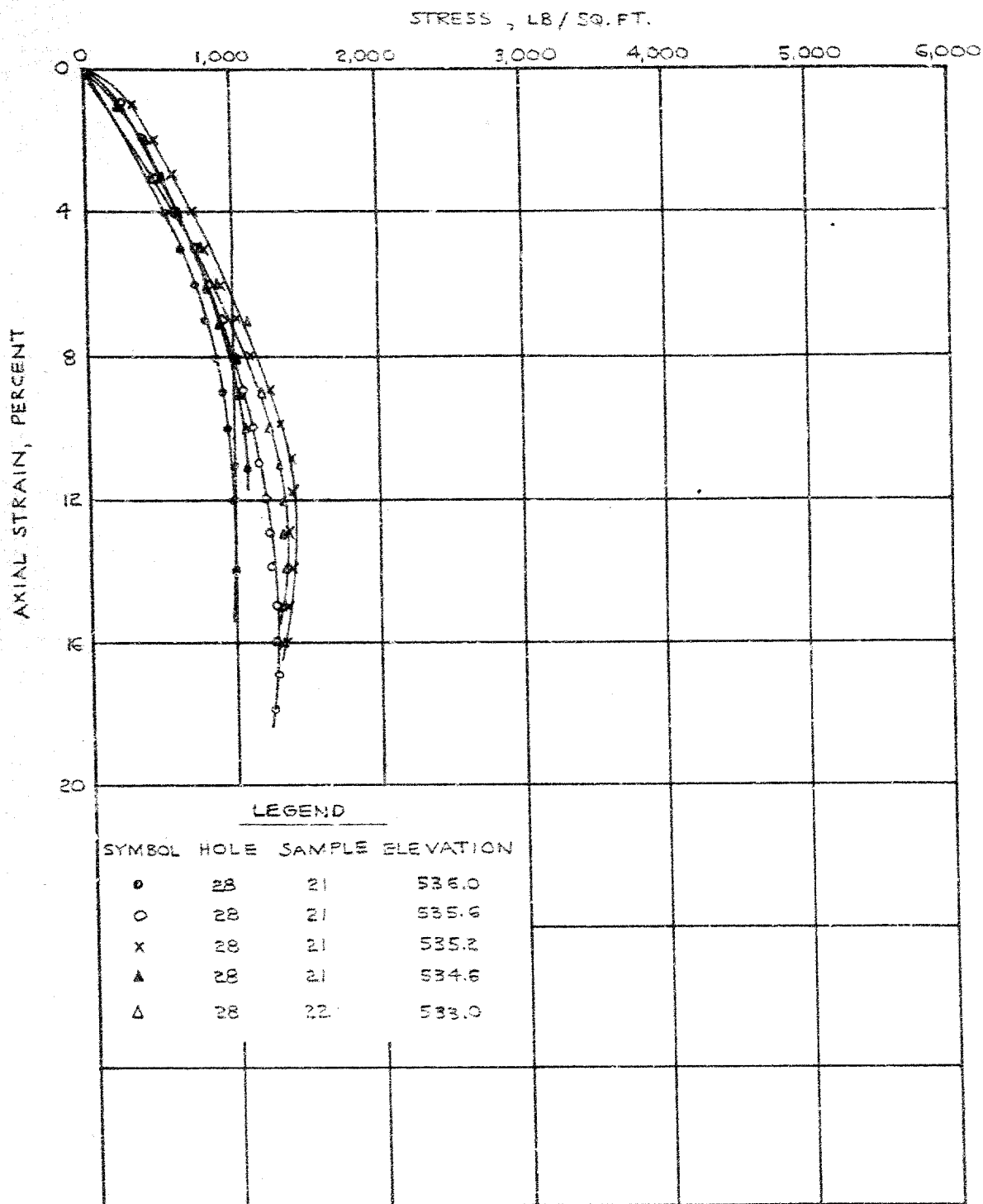
UNCONFINED COMPRESSION TESTS STRESS-STRAIN CURVES

FIGURE 29



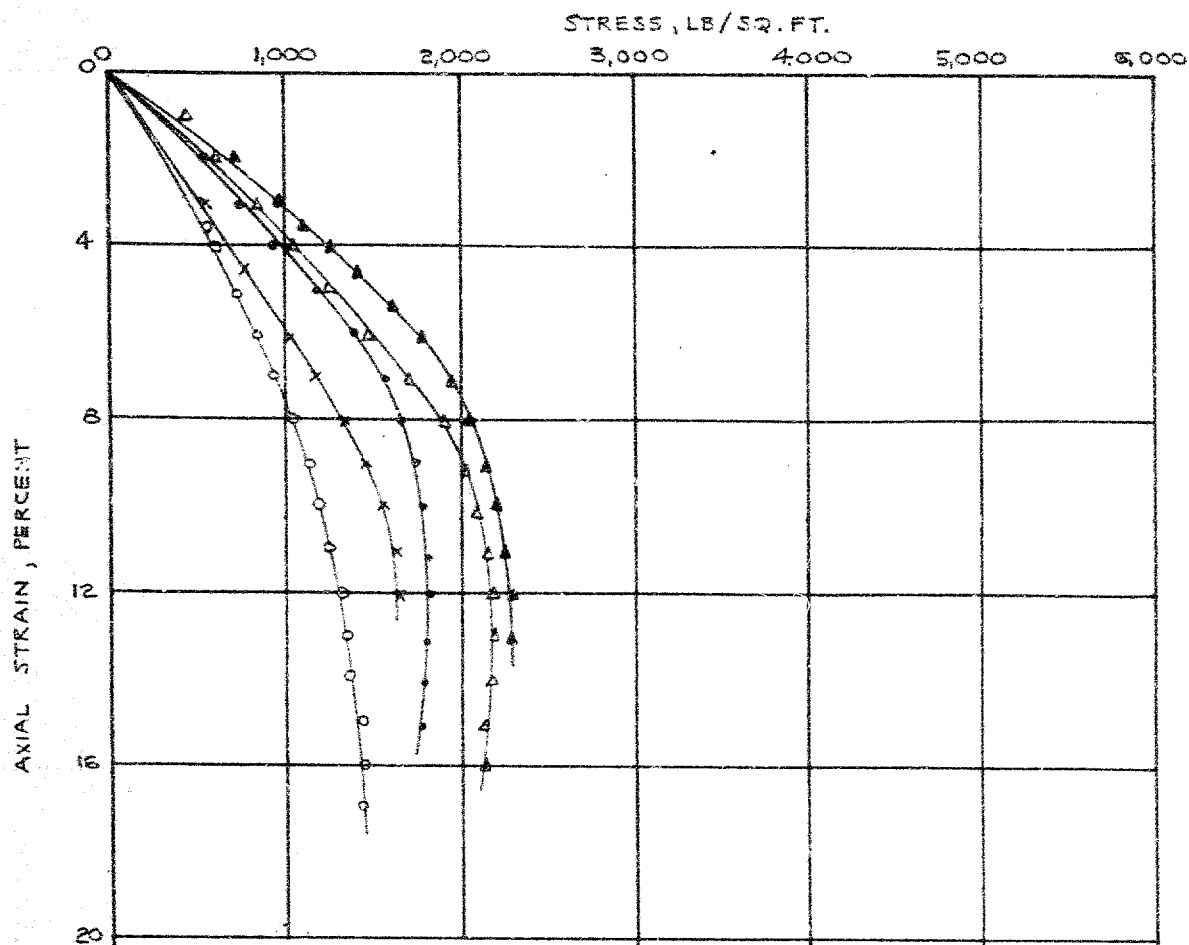
UNCONFINED COMPRESSION TESTS STRESS-STRAIN CURVES

FIGURE 30



UNCONFINED COMPRESSION TESTS STRESS-STRAIN CURVES

FIGURE 31



LEGEND

SYMBOL HOLE SAMPLE ELEVATION

•	28	24	528.0
○	28	25	526.7
×	28	25	526.1
△	28	25	525.7
▲	28	25	525.1

UNCONFINED COMPRESSION TESTS STRESS-STRAIN CURVES

FIGURE 32

