PAP-437

HYDRAULIC MODEL TESTS OF TWIN LAKES FILTER MATERIAL

BY

P. M. DEMERY

PAP-437

DFC-11 (12-61)
WPRS

INFORMATIONAL ROUTING

~~D-1530~~
~~King~~

Denver, Colorado
DATE: August 23, 1982

TO : Head, Embankment Dams Section

THROUGH: Chief, Hydraulics Branch, D-1530 D. King 8/25/82
Chief, Dams Branch, D-220

FROM : Head, Hydraulic Research Section, D-1532

SUBJECT : Hydraulic Model Tests of Twin Lakes Filter Material

The attached report "Twin Lakes Filter Study" by P. M. Demery completes the work agreed upon by engineers in the Embankment Dams Section and engineers in the Hydraulic Research Section on the above subject, (See memorandum dated November 4, 1981 to Chief Division of Research from Chief Design Engineer). Engineers in your section have reviewed the report.

The information obtained during the hydraulic study, and included in the report, can be used to assist in the design to stabilize the glacial till foundation material downstream from New Twin Lakes Dam. C. O. Duster, E. E. Esmiol, A. H. Kiene and D. B. Paul observed operation of the sectional model during testing. They made suggestions which were helpful in setting up and changing the test program to obtain the most useful data. The test apparatus has been preserved in place and can be used for similar tests for other earth dam problems.

E. J. Carlson

Attachment

Copy to: D-222 (Duster)
D-222 (Esmiol)
D-1530
D-1532

TWIN LAKES FILTER STUDY

by

P. M. Demery

INTRODUCTION

In 1978 construction began at Twin Lakes on an earthfill dam. This dam was built downstream of an existing structure to increase the storage capacity of the reservoir. The design concept considered outflow to be directed through outlet works during normal operation or intermittently spilled using a morning glory spillway. The initial filling of the reservoir began in the fall of 1980.

When the reservoir was filled to 65 percent of full pool, seepage was noticed between the stilling basins along the old streambed. As seepage flow increased, sand cones and boils were observed within the aforementioned area. Upon observation of the migrated sand, the impounded water was slowly released.

To maintain foundation stability, it is imperative to keep fine particle migration at a minimum. The proposed remedial treatment for soil migration at Twin Lakes consisted of dewatering the outlet works and spillway stilling basins, excavating 2.44 mm (8.0 ft) of material including 0.91 m (3.0 ft) of riprap, 0.46 m (1.5 ft) of bedding, and 1.07 m (3.5 ft) of natural material within the stilling basins and downstream channels, and replacing the excavated material with a staged filter. The proposed first stage consists of 0.5-m (1.5-ft) depth of concrete sand that meets USBR specifications. The second stage consists of 0.5-m (1.5-ft) depth of sand and gravel varying in size from 1.2 to 76 mm (0.05 to 3 in). A 0.6-m (2-ft) layer of bedding varying in size from 38.0 to 152 mm (1.5 to 6 in) will be placed above the second stage followed by 0.9-m (3-ft) layer of riprap on top. A 0.46-m (1.5-ft) filter blanket consisting of the same concrete sand will be placed over the old streambed and then surcharged with natural material.

The first stage of the filter will be the layer most critical in controlling fine particle movement. A sectional model was utilized in the Hydraulic Laboratory to test the efficiency of the concrete sand to act as a first-stage filter in controlling foundation material movement.

PURPOSE

The purpose of the study was to apply hydraulic pressure gradients to the foundation material while monitoring the soil specimen responses. Responses included fracturing, piping, or boiling that could be observed within the specimen and permeability values which were computed within the soil specimen.

TEST APPARATUS

The test apparatus (plastic box and water system) was previously constructed to evaluate filter designs (shown on fig. 1). The plastic box was 0.30 by 0.61 by 1.83 m (1 by 2 by 6 ft). Flow was provided to and from the plastic box by a bottom plate which was drilled with thirty-six 6.4-mm (0.25-in) diameter holes. A 150-mm (6-in) depth of base material with a 0.2 m^2 (2-ft^2) flow area was placed within the plastic box. Filter sand 450 mm (18 in) in depth was placed directly above the base material. Piezometer taps which were connected to water manometers were located on the face of the test box as shown on figure 2. Fine mesh screen was placed over the piezometer taps to prevent the movement of fine sand into the manometer lines.

The water system consisted of a storage tank, regulatory valves, piping, and a pump. Water was circulated between the storage tank and the plastic box. Water could be directed either upward or downward through the soil specimen within the plastic box, as desired.

TEST PROCEDURE

The filter testing program consisted of (1) placement of base and filter material, (2) initial filling of plastic box, (3) saturation in downward flow, and (4) filter testing.

Placement of Base Material

The base material consisted of glacial till from the Twin Lakes Dam foundation. The sample used was a composite mix taken from two locations along the spillway section. The gradation of the base material is shown on figure 3. The fraction of soil larger than 76 mm (3 in) was eliminated in this study. The large rocks would be more significant in reducing the model flow area. The reduction would not be representative of field conditions which are large in area content. The size analysis of the base material after large particle elimination is also shown on figure 3. The base material was placed in three increments. Each 50-mm (2-in) increment was compacted to achieve the desired dry density of 1844 kg/m^3 (115 lb/ft^3). Care was taken in placing the 38-mm (1.5-in) rocks within the sample interior rather than at the corners of the plastic box. This allowed for a more uniform velocity distribution across the soil sample rather than localized high velocities at the corners.

The filter material was a concrete sand that is available from the Sinclair Aggregate source located at Twin Lakes. The filter material used in the test apparatus was a composite mix from three representative samples provided from Sinclair. The gradation analysis for each sample and composite is shown on figures 4, 5, and 6.

Filling of Plastic Box

Chlorinated water entered the plastic box in an upward flow. In filling, care was taken so that the differential head between the manometer and wetting front did not exceed 150 mm (6 in). Once the wetting front rose to the surface of the entire soil specimen, upward flow was terminated and the eight piezometer taps were purged of air bubbles.

Saturation in Downard Flow Direction

In the saturation procedure, the valve system was adjusted so that waterflow was directed downward. It has been found in earlier laboratory tests that air bubbles are more readily dissolved under pressure. A downward flow allows the water to dissolve more air as it continually moves to a higher pressure. Operating in an upward flow direction could allow the water to release or hold less air as the water continually moves to a lower pressure. A downward flow also aids in preventing soil movement because the water is moving in a reverse direction through the soil specimen with respect to the normal filter alinement.

Air bubbles act in a way similar to small rocks which impede water movement. As air bubbles are dissolved, hydraulic conductivity of the soil increases. This increase was time monitored until the conductivity no longer changed. At this point the saturation procedure ended.

Filter Tests

When the saturation was completed the valves were adjusted for an upward flow. This direction was maintained for the duration of testing.

Discharge and pressure measurements were recorded as the pressure gradient across the base material was incrementally increased. Discharges were computed using a volumetric water sample collected during a time interval. Flow rates were used as a system stability indicator (the pressure gradients were not increased until the flow rates had stabilized).

Surcharge was placed on top of the soil specimen to allow for high-pressure gradient testing. Six concrete cylinders and a metal grate were used for the surcharge. Not only did the metal grate act as a supplemental load but it distributed the cylinder surcharge more uniformly over the entire flow area. This is shown on figure 7. The submerged mass of the total surcharge was 52 kg (115 lb). This submerged weight was equivalent to 0.37 m (1.12 ft) of additional filter sand upon the base material.

SATURATION RESULTS

A pressure gradient of 2.0 was applied across the base material with waterflow directed downward. The pressure gradient is defined by

$$i = \frac{dh}{L} \tag{1}$$

where dh is the measured head difference across the depth L.

Initially the hydraulic conductivities of the base and the filter material were 9.75×10^{-6} and 16.50×10^{-5} m/s (3.2×10^{-5} and 54.2×10^{-5} ft/s), respectively. The hydraulic conductivities of the soil specimen can be related to water viscosity by using the equation

$$\frac{K_s}{K_t} \cong \frac{v_t}{v_s} \tag{2}$$

where K_s and v_s are the permeability coefficient and the kinematic viscosity at a standardized temperature of 20 °C (68 °F) and K_t and v_t are the permeability coefficient and the kinematic viscosity at the measured temperature T. The value K_s is commonly referred to as the hydraulic conductivity. As shown on figure 8, the computed hydraulic conductivities continually increased as air bubbles were dissolved within the soil specimen. After approximately 150 hours of run time the conductivities stabilized at 2.74×10^{-5} m/s (9.0 by 10^{-5} ft/s) within the foundation material and at 49.80×10^{-5} m/s (150.0×10^{-5} ft/s) within the filter sand.

FILTER TESTING

Valves were adjusted for an upward waterflow. A pressure gradient of 0.5 was applied across the base material initially. After flow stabilization, the pressure gradients were increased by 0.5. Up to a pressure gradient of 2.5 applied to the base material, the hydraulic conductivity of the soil specimen remained constant with no apparent soil movement. However, at larger gradients, local fluidization occurred within the confines of the foundation material. It was noticed that the plastic box had become deformed from the vertical along the long north and south faces. A bulge developed at the same location of observed localized boiling activity. If the plastic box expanded with an increase in uplift pressures, soil fluidizations could be induced. Dial gages were mounted on the north and south sides to measure possible deflections of the plastic box. The pressure gradient was adjusted to 1.0 across the base material and the two gages recorded deflections of 3.05×10^{-2} mm (1.2×10^{-3} in). To best represent field conditions, the plastic box was restrained along the north and south faces using two aluminum channels with bar clamps. The channel clamps were tightened to reduce deflections to as near zero as possible.

With the plastic box restrained, the pressure gradient across the base material was again incrementally increased, and a stable contact between the soil and the plastic box was preserved. Tests were conducted on three separate dates as shown on figure 9. The test data are listed in tables B and C. The graph distinguishes between the responses within the bottom 76 mm (3 in) and within the top 76 mm of base material to the applied pressure gradients. With a constant flow area of 0.22 m^2 (2 ft^2), changes in line slopes indicate hydraulic conductivity changes.

Temperature control was difficult to maintain between the three tests; therefore, shifts in the line slopes could represent possible viscosity effects on the discharge. The nonhomogeneous condition of the base material introduced at the beginning of the test can be shown by the permeability shift between the bottom and top 76 mm (3 in) of soil.

The test conducted on April 5 shows a larger differential in permeability between the aforementioned base material depths. Furthermore, the permeability differences increased with the increasing gradient. This suggests either the base material was compressing or that some of the base material fines were migrating with the flow.

Observations of the base material during changes in pressure gradient for each test showed intermittent boiling effects at gradients as low as 3.0. However, the boiling was localized and not responsible for migrating fines across the filter interface. The boiling phenomenon appeared to be centered about a point of contact between a large rock within the base material and the plastic box. At a pressure gradient of 8.0 the boiling became steady but still occupied a small area. Small horizontal hairline cracks began to develop along the lower contact interface between the base material and the coarse sands and gravels.

As the pressure gradient was increased from 9.2 to 10.9, the hairline cracks lengthened and became wider. Eventually the cracks developed into a full fracture extending throughout the soil medium. The base material, filter sand, and surcharge had lifted due to the unbalance in forces between uplift and total surcharge. Testing limitations were the cause of the fracture rather than filter failure.

The tank was dismantled and soil samples were obtained within the filter and base materials as shown on figure 10. These samples were analyzed for particle size and compared to the original size analysis. Table A lists the particle size fractions for each sample location. A change in the fine particle concentration could indicate migration across the filter interface. Changes in fine particle concentration were minimal as shown on table A and figures 11 through 15. The composite gradation shown on figure 4 was used as the pretest sample for comparison on figures 11, 12, and 13. The apparent changes in sand concentrations were due in part to particle size variations between sample sacks and soil nonconformity caused by the initial placement of the material. Some slight changes in gradation can also be seen on figures 14 and 15. These changes reflect segregation upon placement of the base material which is of a large gradation.

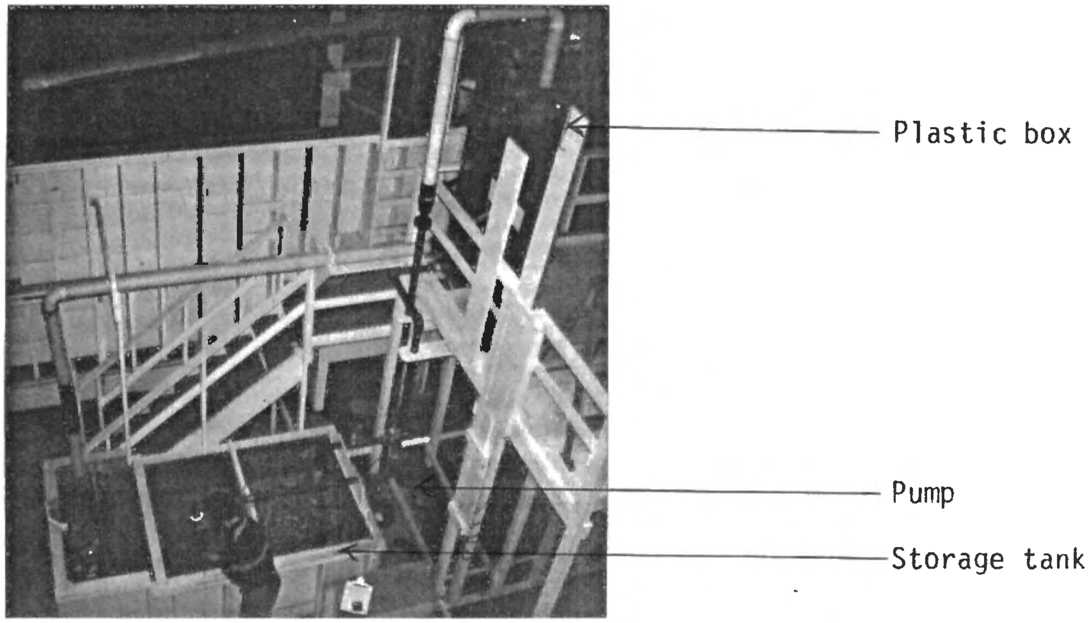


Fig. 1. - Test apparatus.

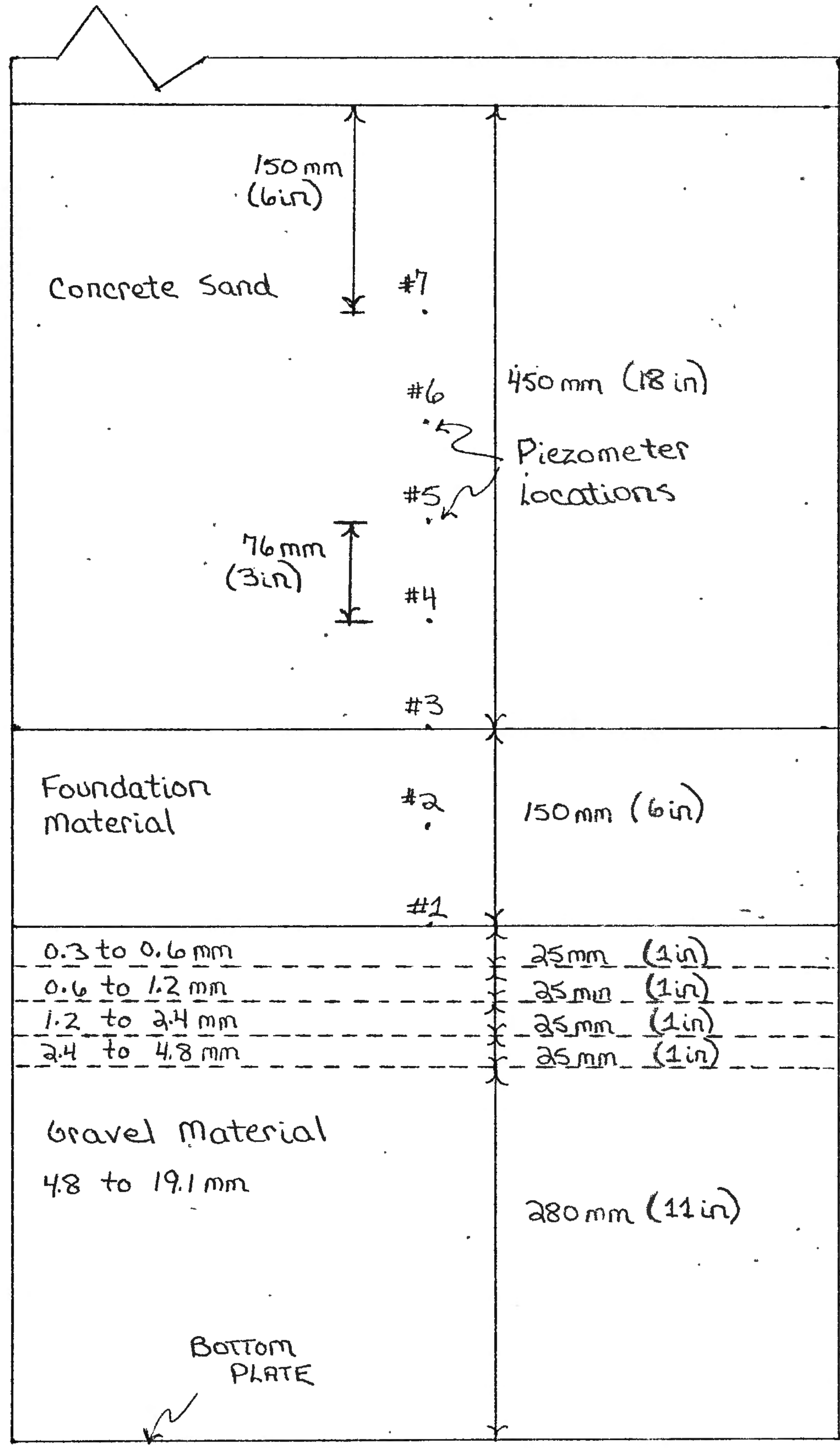


Figure 2 Filter Dimensions and Locations of Piezometer Taps

VEAD 11/23

7-1415 (8-70)
Water and Power

GRADATION TEST

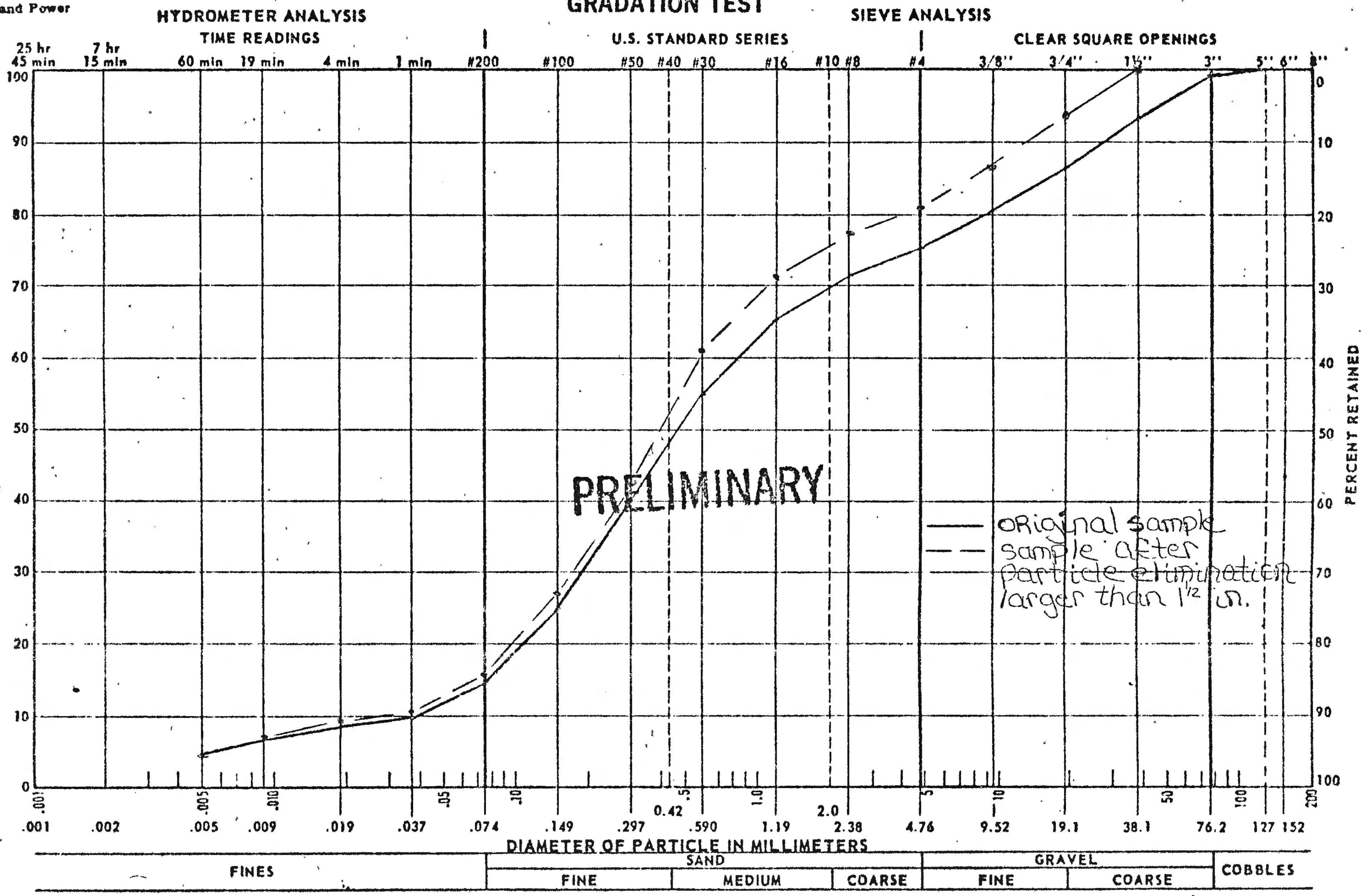


Fig. 3. - Foundation material size analysis.

CLASSIFICATION SYMBOL ______

Gravel 25 %
Sand 60 %
Fines 15 %

ATTERBERG LIMITS
Liquid Limit ______ %
Plasticity Index ______ %
Shrinkage Limit ______ %

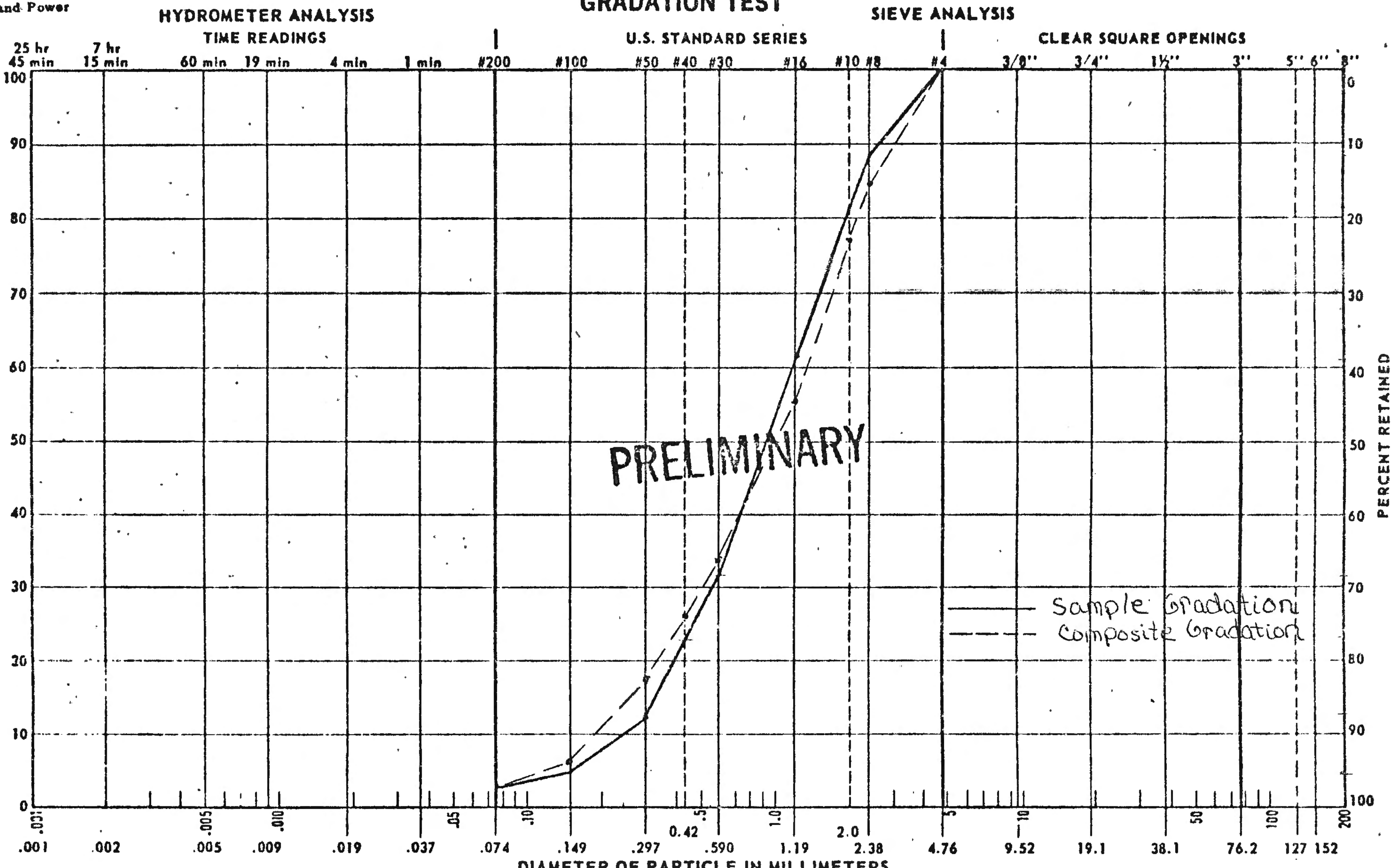
SPECIFIC GRAVITY
Minus No. 4 ______
Plus No. 4 ______
Bulk ______ Apparent ______

NOTES Composite sample of 53H-205 and 53H-206

SAMPLE NO. 53H-X208 HOLE NO. ______ ______ ft (______ m)

7-1415 (8-70)
Water and Power

GRADATION TEST



FINES	SAND			GRAVEL		COBBLES
	FINE	MEDIUM	COARSE	FINE	COARSE	

CLASSIFICATION SYMBOL SP

Gravel 0 %
Sand 97 %
Fines 3 %

ATTERBERG LIMITS
Liquid Limit ____ %
Plasticity Index ____ %
Shrinkage Limit ____ %

SPECIFIC GRAVITY
Minus No. 4 ____
Plus No. 4 ____
Bulk ____ Apparent ____

NOTES Concrete Sand
$C_u = 4.9$ $C_c = 1.07$

SAMPLE NO. 53H-207H HOLE NO. FROM SINCLAIR Aggregate Pit ft (____ m)

Fig. 4. -.Concrete sand size analysis.

VEAD 11/20/81

7-1415 (8-70)
Water and Power

GRADATION TEST

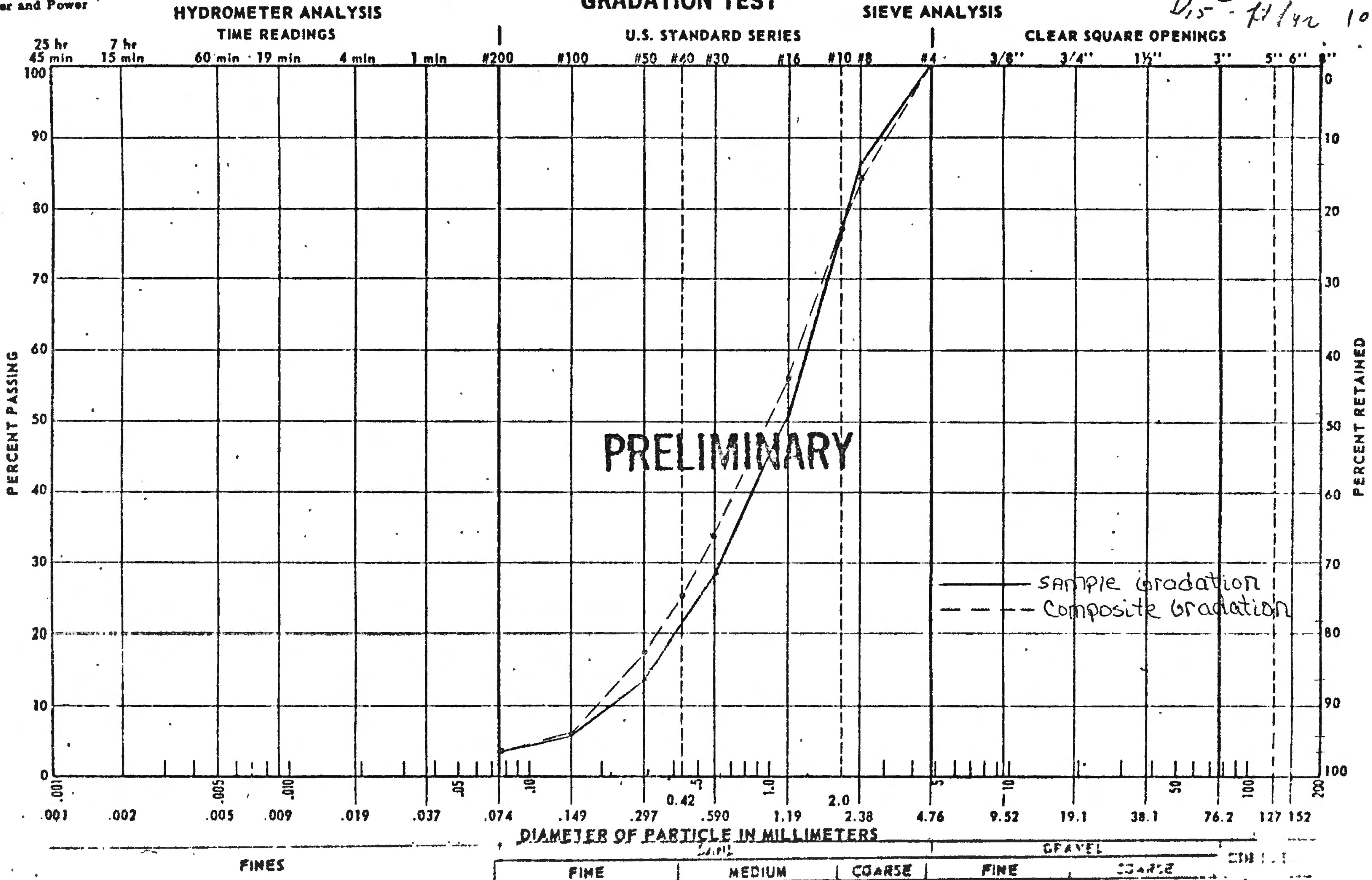


Fig. 5. - Concrete sand size analysis.

CLASSIFICATION SYMBOL SW

Gravel 0 %

Sand 97 %

Fines 3 %

ATTERBERG LIMITS

Liquid Limit ______ %

Plasticity Index ______ %

Shrinkage Limit ______ %

SPECIFIC GRAVITY

Minus No. 4 ______

Plus No. 4 ______

Bulk ______ Apparent ______

NOTES Concrete SAND

Cu = 6.4 Cc = 1.2

SAMPLE NO 53H-207I HOLE NO. From Sinclair Aggregate Pit ft (______ m)

7-1415 (8-70)
Water and Power

GRADATION TEST

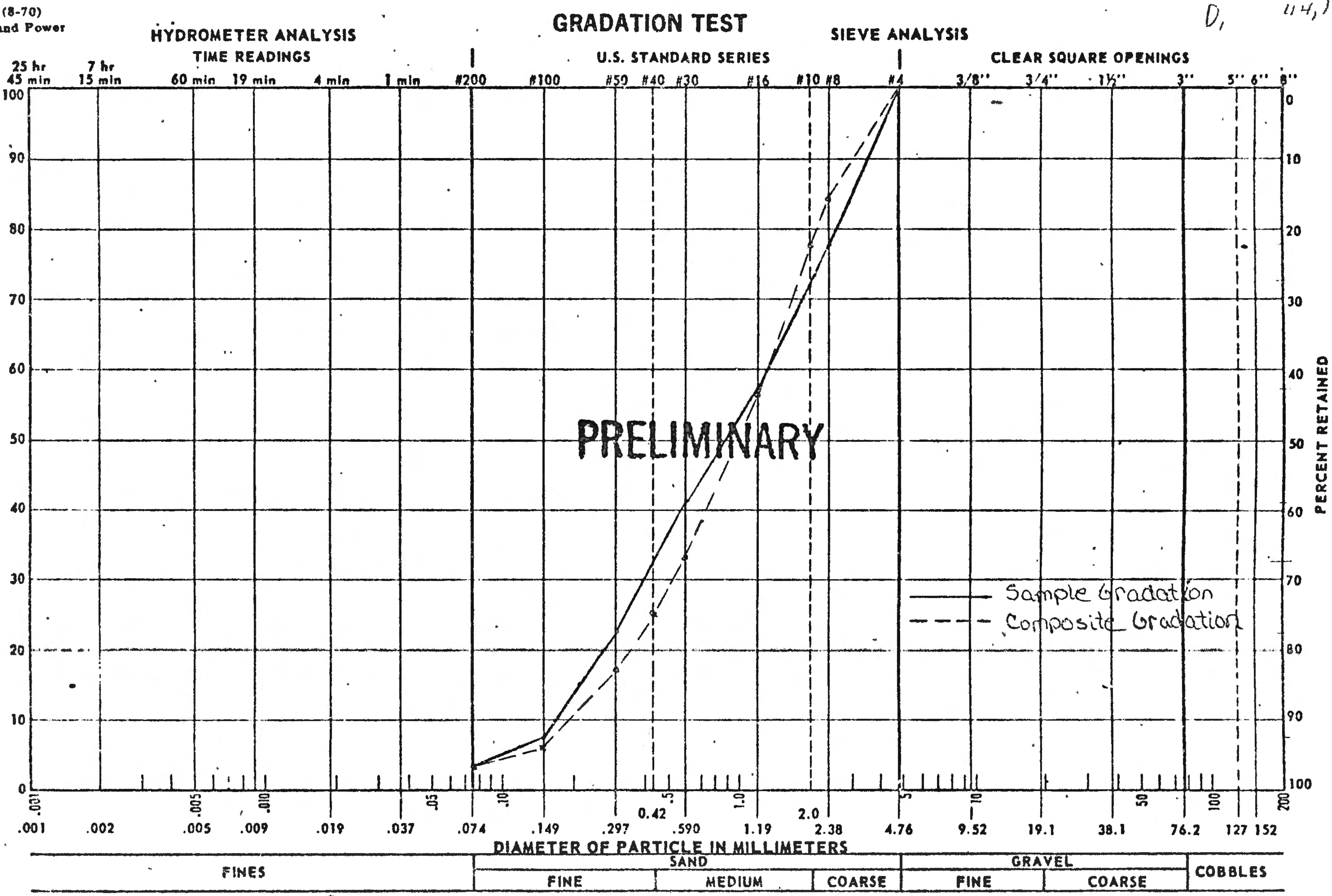


Fig. 6. - Concrete sand size analysis.

CLASSIFICATION SYMBOL SP

Gravel 0 %

Sand 97 %

Fines 3 %

ATTERBERG LIMITS

Liquid Limit ______%

Plasticity Index ______%

Shrinkage Limit ______%

SPECIFIC GRAVITY

Minus No. 4 ______

Plus No. 4 ______

Bulk ______ Apparent ______

NOTES Concrete Sand

$C_u = 7.6$ $C_c = .7$

SAMPLE NO. 53H-207G HOLE NO. FROM SINCLAIR Aggregate Pit ft (______m)

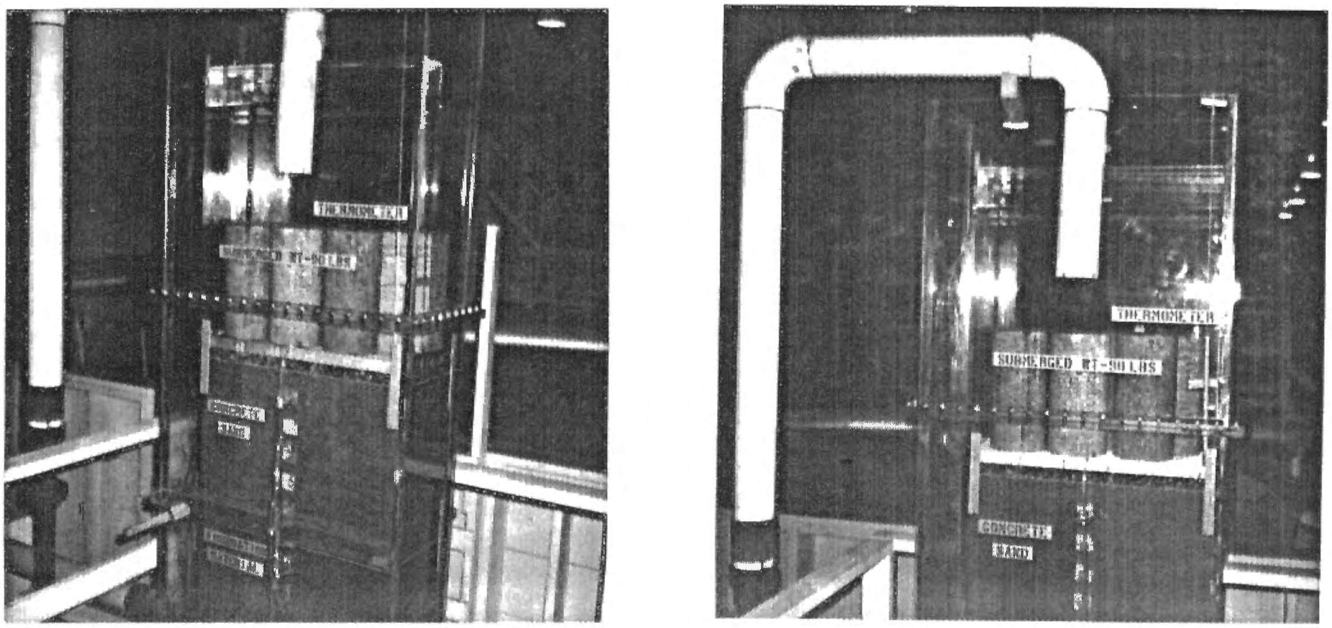
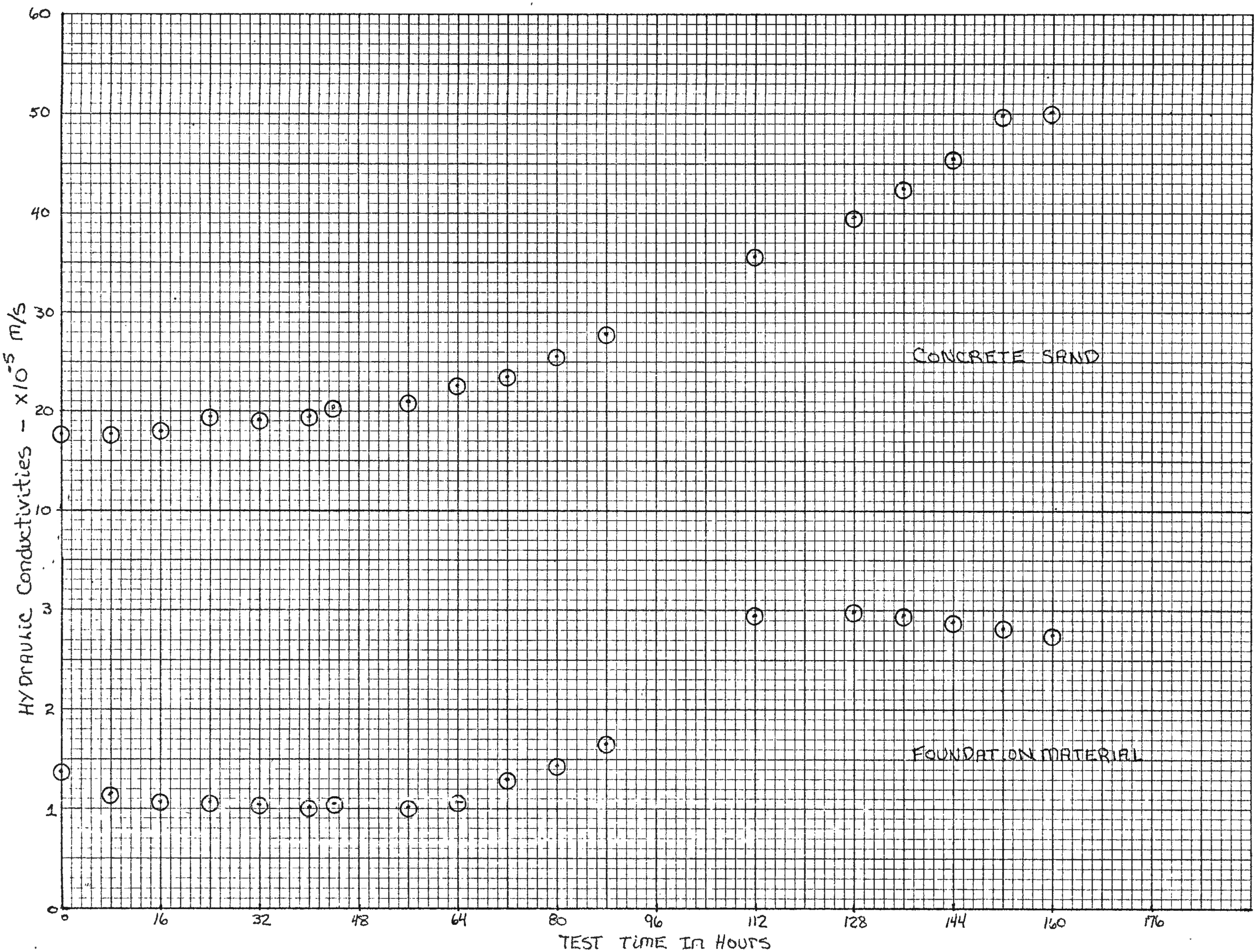


Fig. 7. - Surcharge loading upon soil specimen.

K•E 5 X 5 TO THE CENTIMETER 18 X 24 CM. KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1610



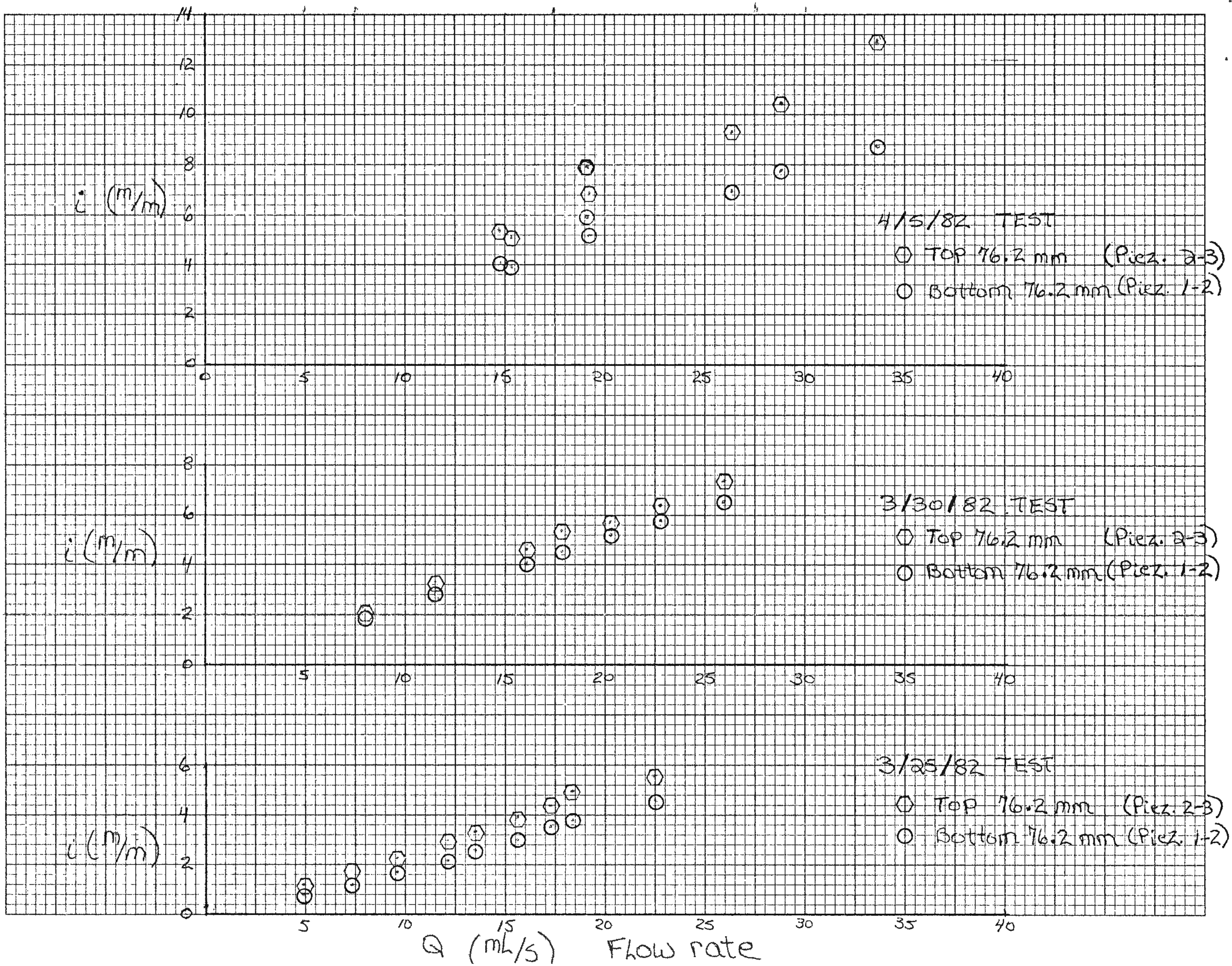


Fig. 9. - Discharge vs. pressure gradient within the foundation material.

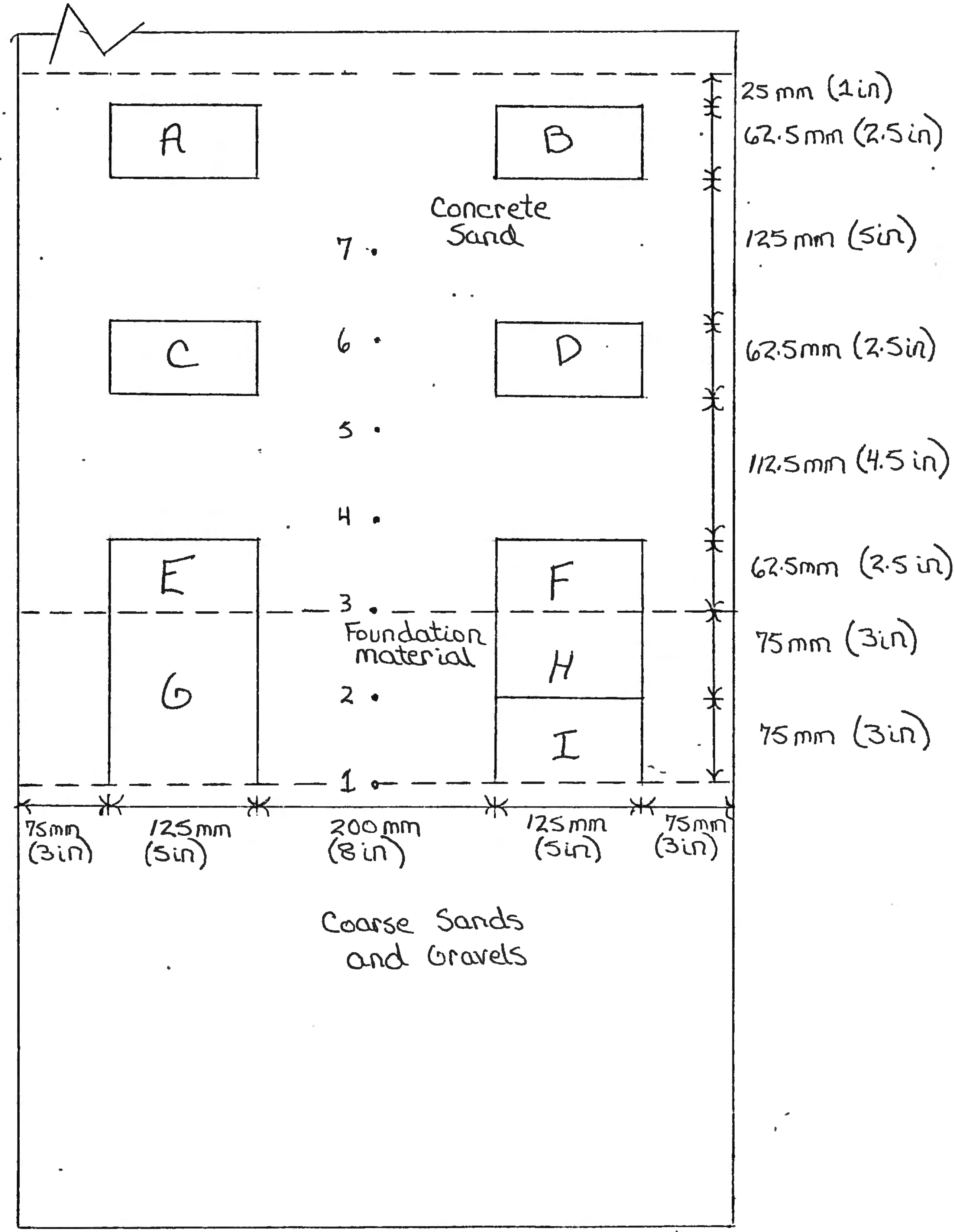
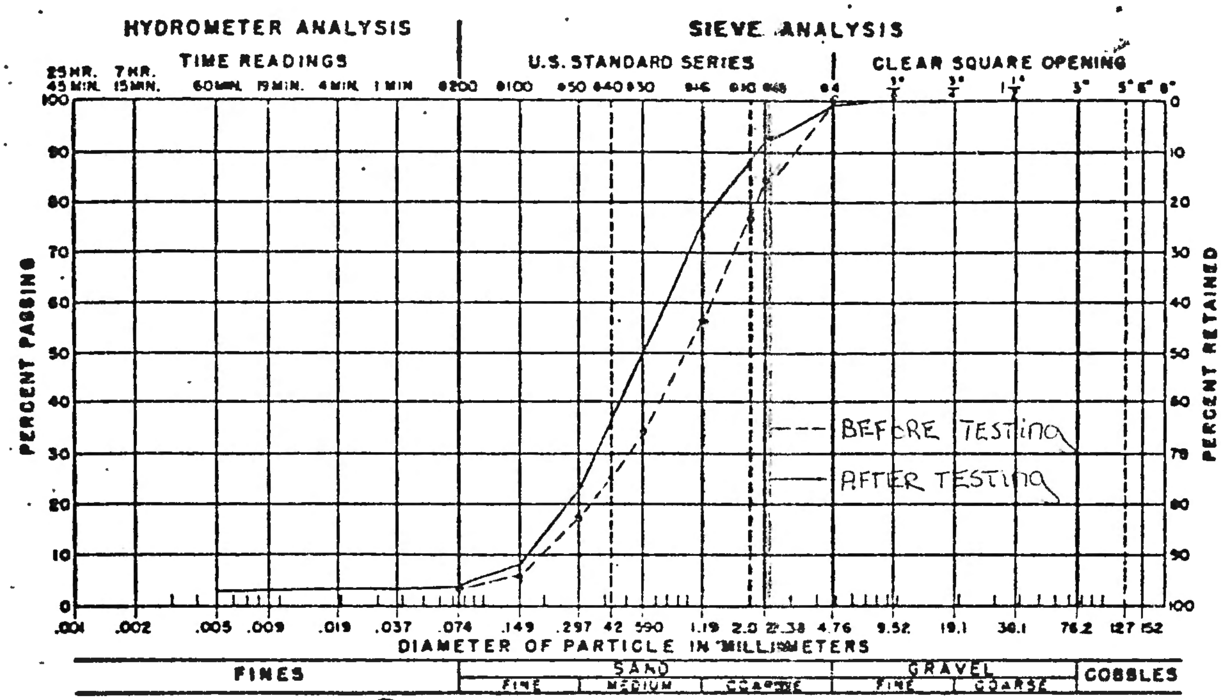


Figure 10 Sampling locations within the soil medium

7-1925 (6-71)
Bureau of Reclamation

IDENTIFICATION TEST SUMMARY

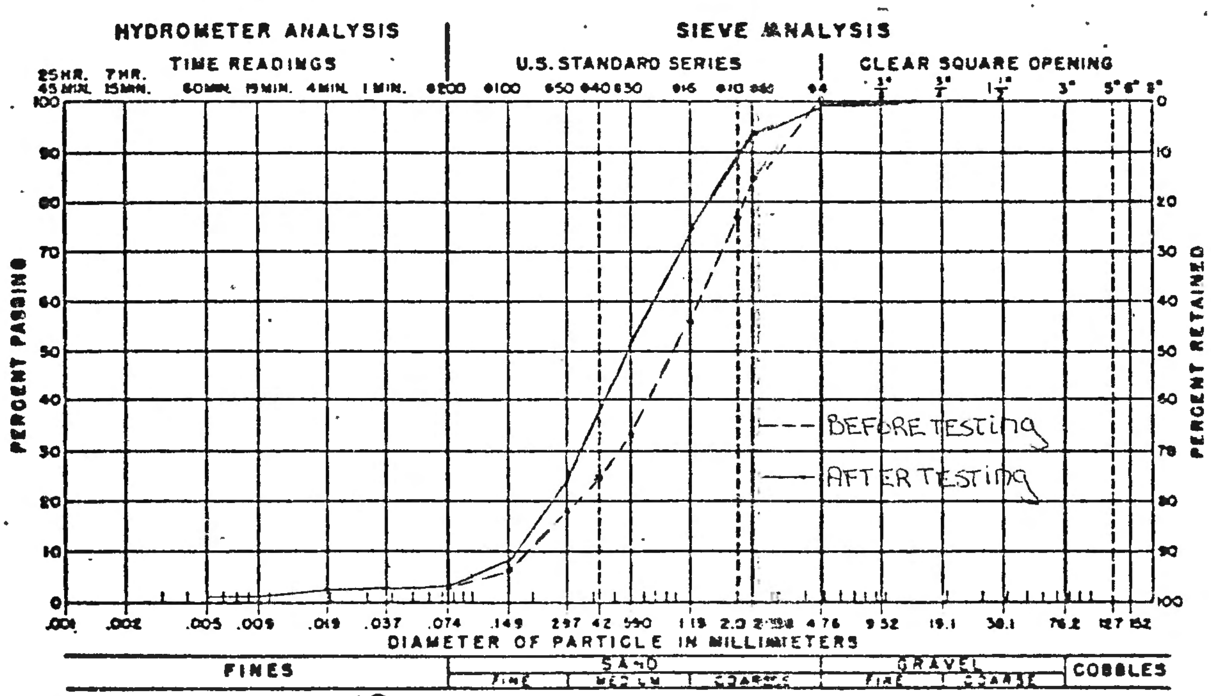


Classification Symbol SP Atterberg Limits Specific Gravity

Gravel	____ %	Liquid Limit	____ %	Minus No. 4	2.70
Sand	97 %	Plasticity Index	____ %	Plus No. 4	
Fines	3 %	Shrinkage Limit	____ %	Bulk ____	Apparent ____

Notes: Cu = 3.8 , Cc = 1.1
LOCATION A - See Fig 10

Sample No. 53H-207A Hole No. ________ Depth ____ ft (____ m)



Classification Symbol SP Atterberg Limits Specific Gravity

Gravel	____ %	Liquid Limit	____ %	Minus No. 4	2.70
Sand	96 %	Plasticity Index	____ %	Plus No. 4	
Fines	4 %	Shrinkage Limit	____ %	Bulk ____	Apparent ____

Notes: Cu = 4.4, Cc = .91
LOCATION B - See Fig 10

Sample No. 53H-207B Hole No. ________ Depth ____ ft (____ m)

Fig. 11. - Size analysis - Locations A and B.

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7-1925 (6-71)
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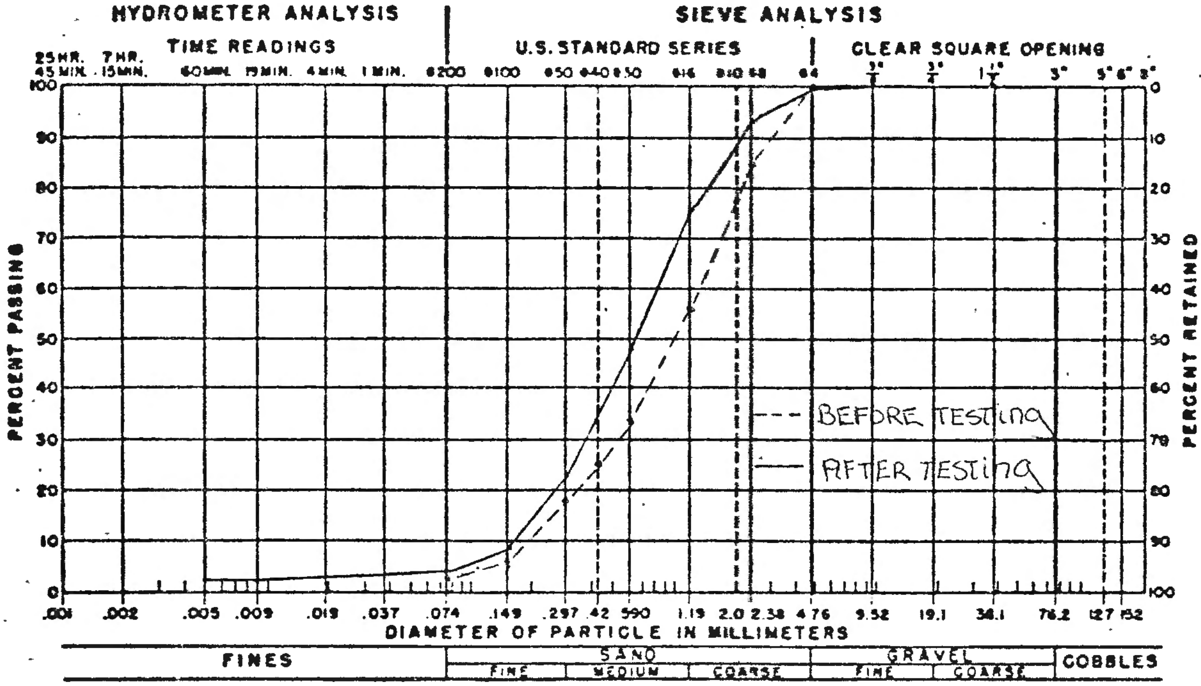
IDENTIFICATION TEST SUMMARY



Classification Symbol SP Atterberg Limits Specific Gravity

Gravel ____ % Liquid Limit ____ % Minus No. 4 2.70

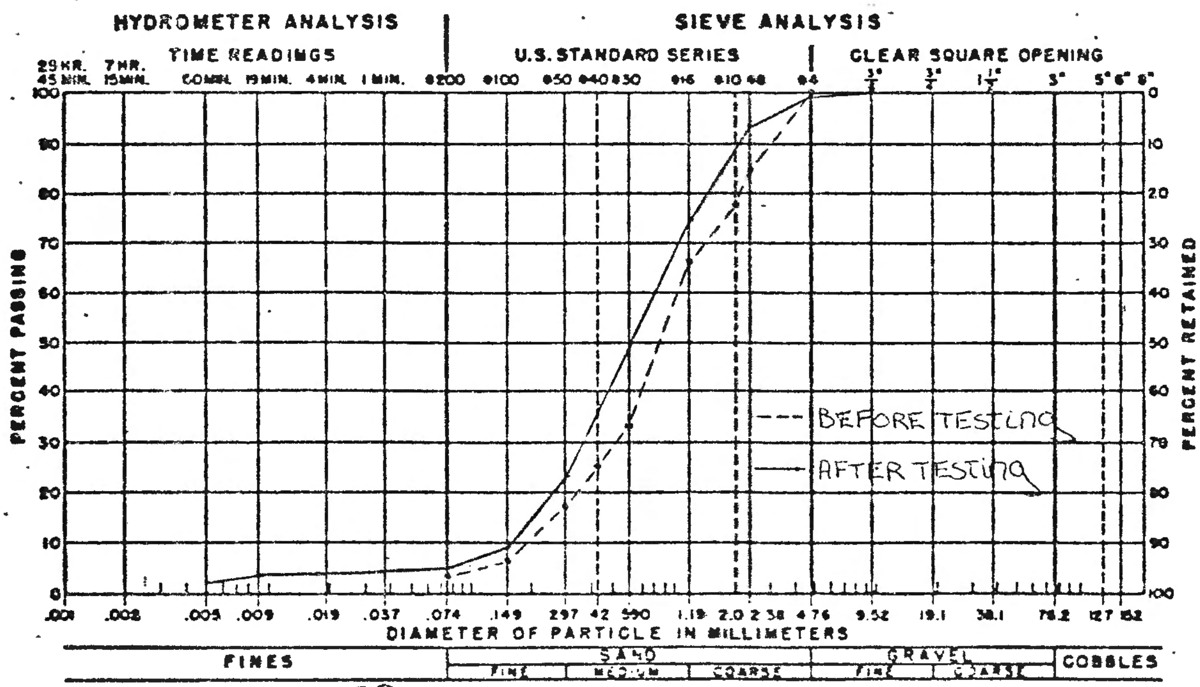
Sand 96 % Plasticity Index ____ % Plus No. 4

Fines 4 % Shrinkage Limit ____ % Bulk ____ Apparent ____

Notes: $C_u = 4.2$, $C_c = 1.2$

Location C - See Fig 10

Sample No. 53H-207C Hole No. ____ Depth ____ ft (____ m)



Classification Symbol SP Atterberg Limits Specific Gravity

Gravel ____ % Liquid Limit ____ % Minus No. 4 2.69

Sand 95 % Plasticity Index ____ % Plus No. 4

Fines 5 % Shrinkage Limit ____ % Bulk ____ Apparent ____

Notes: $C_u = 4.9$, $C_c = 1.0$

LOCATION D - See Fig 10

Sample No. 53H-207D Hole No. ____ Depth ____ ft (____ m)

Fig. 12. - Size analysis - Locations C and D.

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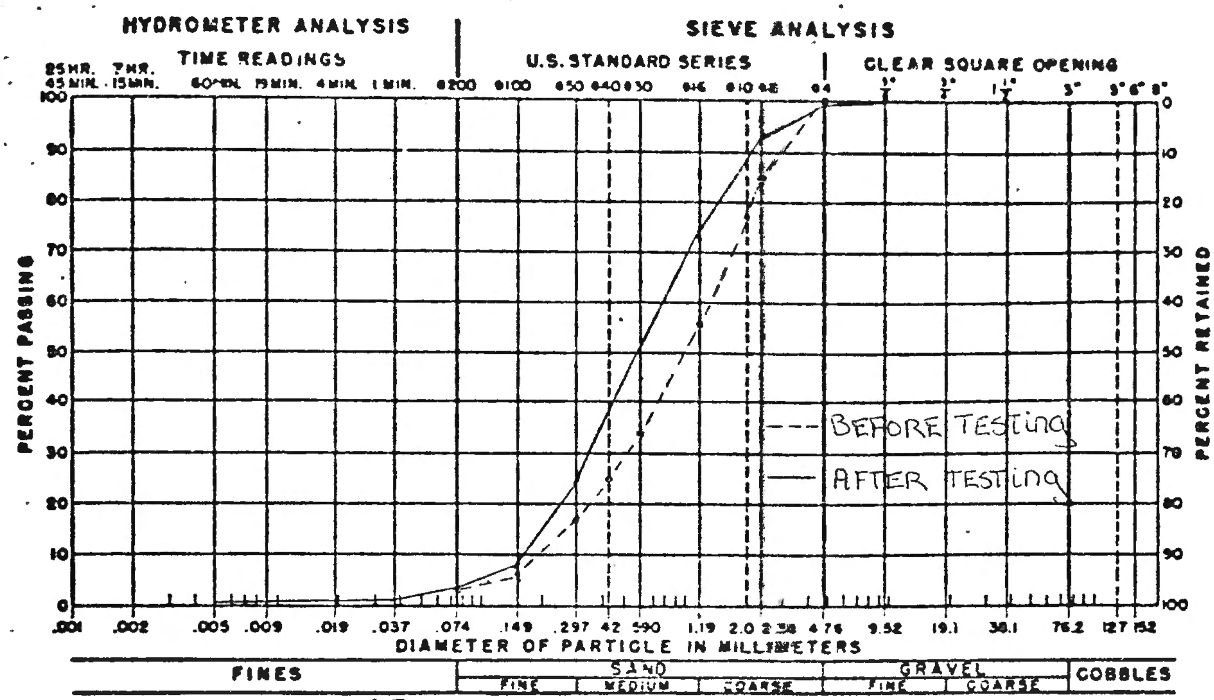
IDENTIFICATION TEST SUMMARY



Classification Symbol SP Atterberg Limits

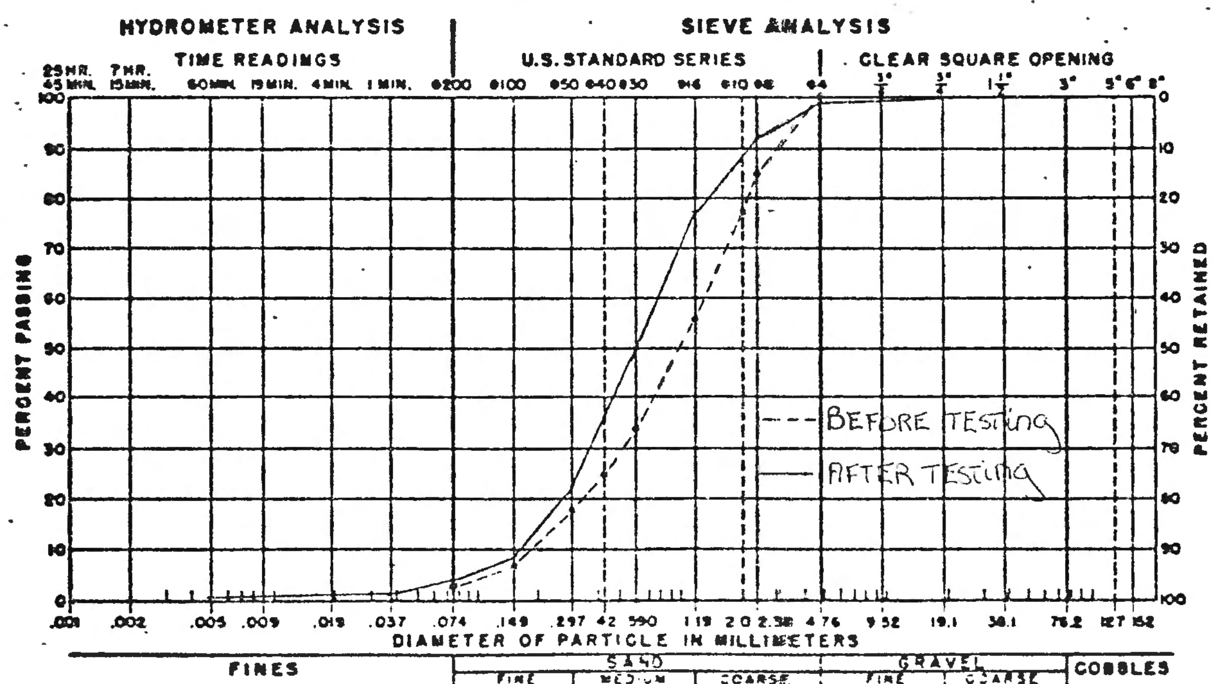
Gravel ____ %
Sand 96 %
Fines 4 %

Liquid Limit ____ %
Plasticity Index ____ %
Shrinkage Limit ____ %

Specific Gravity
Minus No. 4 2.70
Plus No. 4
Bulk ____ Apparent ____

Notes: C_u: 4.9, C_c = .87
Location E - See fig 10

Sample No. 53H-207E Hole No. ____ Depth ____ ft (____ m)



Classification Symbol SP Atterberg Limits

Gravel ____ %
Sand 96 %
Fines 4 %

Liquid Limit ____ %
Plasticity Index ____ %
Shrinkage Limit ____ %

Specific Gravity
Minus No. 4 2.70
Plus No. 4
Bulk ____ Apparent ____

Notes: C_u = 3.9, C_c = 1.1
Location F - See fig 10

Sample No. 53H-207F Hole No. ____ Depth ____ ft (____ m)

Fig. 13. - Size analysis - Locations E and F.

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7-1925 (6-71)
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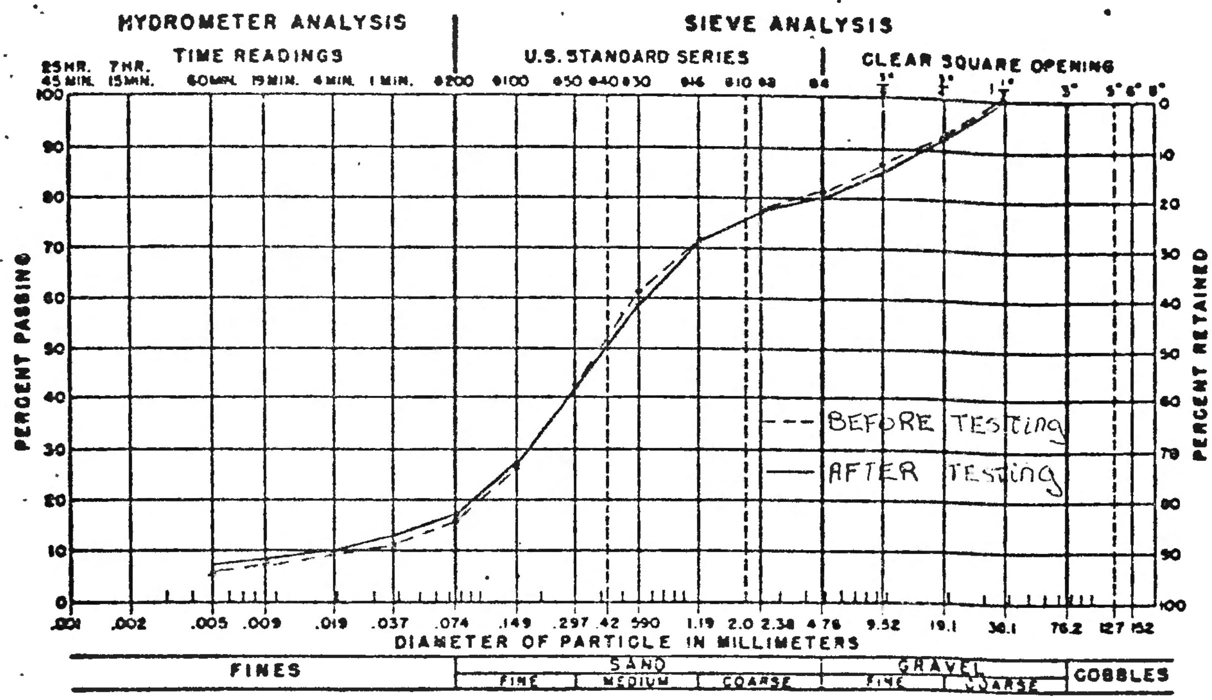
IDENTIFICATION TEST SUMMARY

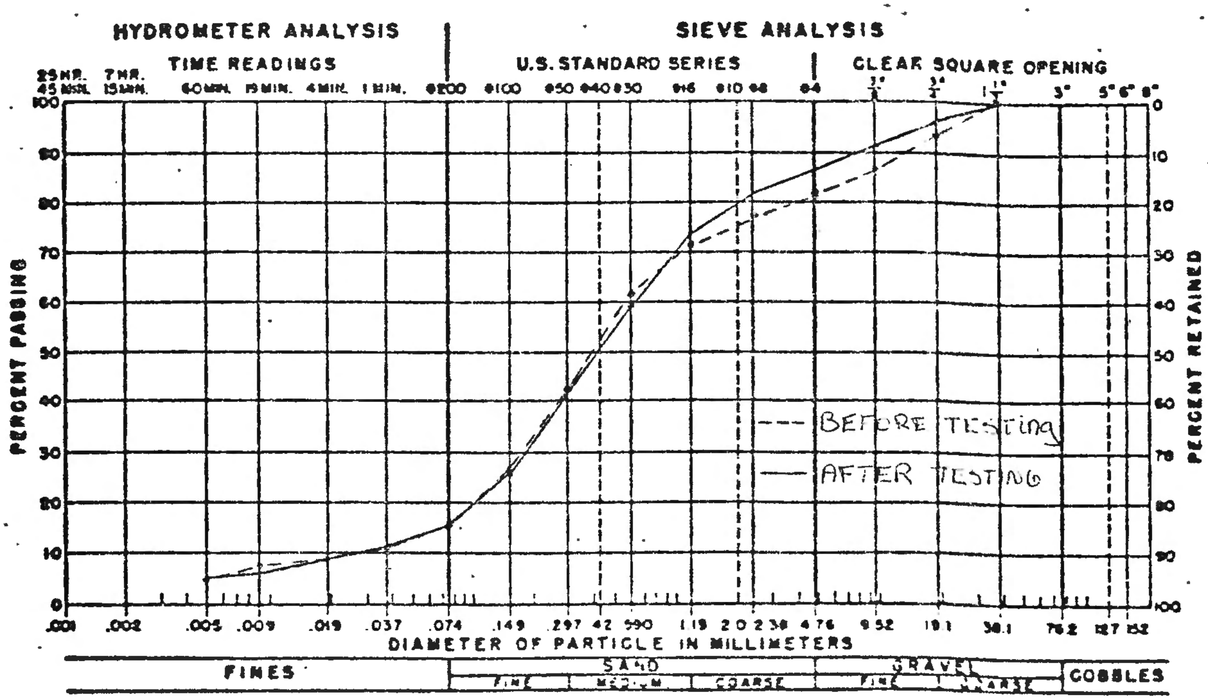


Classification Symbol ______ Atterberg Limits Specific Gravity

Gravel 20 %	Liquid Limit ____ %	Minus No. 4 2.66
Sand 63 %	Plasticity Index ____ %	Plus No. 4
Fines 17 %	Shrinkage Limit ____ %	Bulk ____ Apparent ____

Notes: ________________________________
Location G - See fig 10

Sample No. 53H-X208G Hole No. ____________ Depth ________ ft (________ m)



Classification Symbol ______ Atterberg Limits Specific Gravity

Gravel 14 %	Liquid Limit ____ %	Minus No. 4 2.68
Sand 70 %	Plasticity Index ____ %	Plus No. 4
Fines 16 %	Shrinkage Limit ____ %	Bulk ____ Apparent ____

Notes: ________________________________
Location H - See fig 10

Sample No. 53H-X208H Hole No. ____________ Depth ________ ft (________ m)

Fig. 14. - Size analysis - Locations G and H.

7-1925 (6-71)
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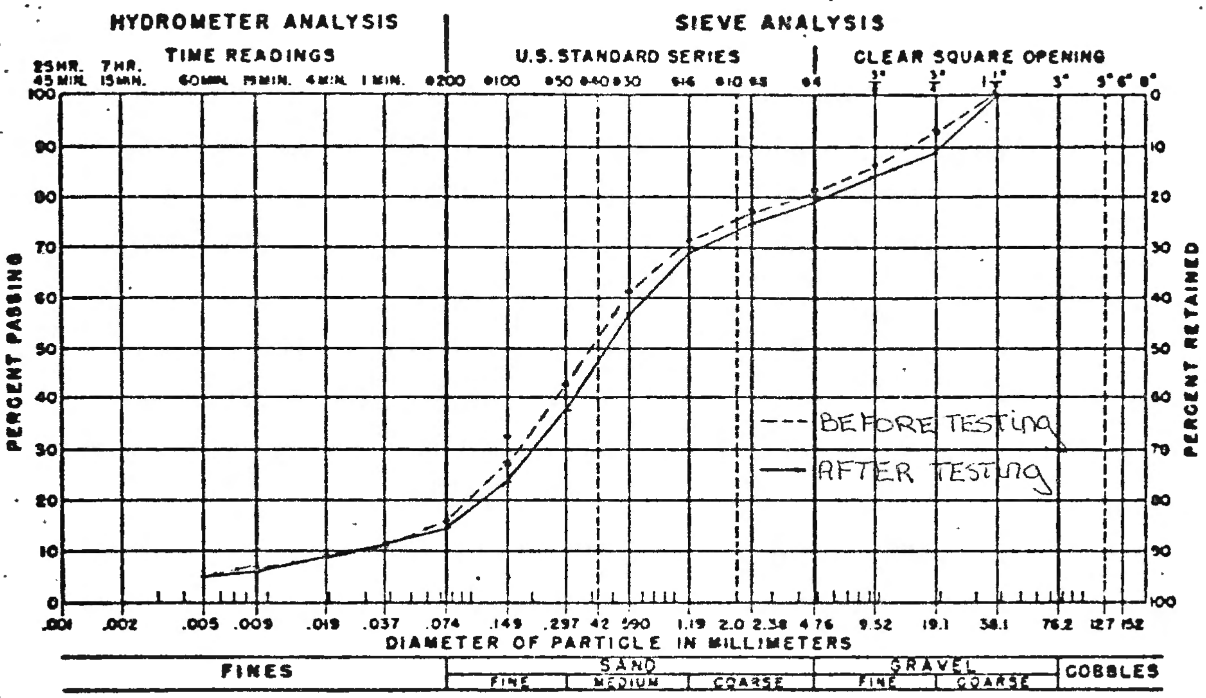
IDENTIFICATION TEST SUMMARY



Classification Symbol ______ Atterberg Limits Specific Gravity

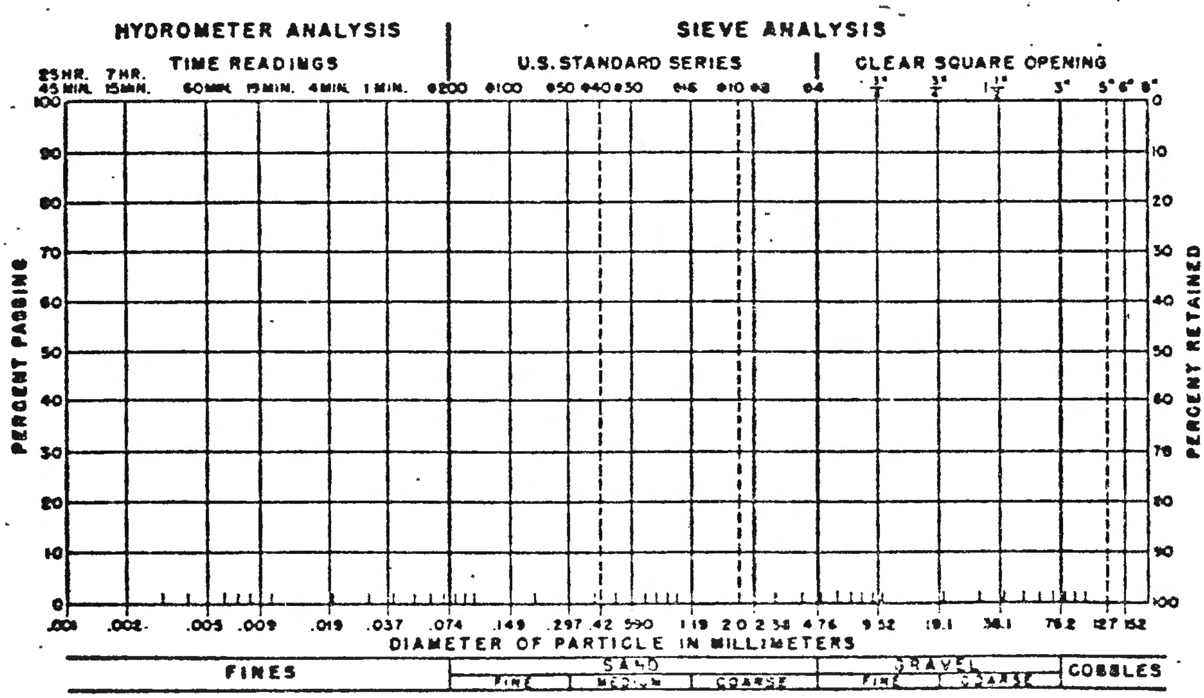
Gravel 21 % Liquid Limit ______ % Minus No. 4 2.67

Sand 65 % Plasticity Index ______ % Plus No. 4

Fines 14 % Shrinkage Limit ______ % Bulk ______ Apparent ______

Notes: Location I - See Fig 10

Sample No. 53H-X208I Hole No. ______ Depth ______ ft (______ m)



Classification Symbol ______ Atterberg Limits Specific Gravity

Gravel ______ % Liquid Limit ______ % Minus No. 4 ______

Sand ______ % Plasticity Index ______ % Plus No. 4

Fines ______ % Shrinkage Limit ______ % Bulk ______ Apparent ______

Notes: ______

Sample No. ______ Hole No. ______ Depth ______ ft (______ m)

Fig. 15. - Size analysis - Location I.

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7-1733 (8-71)
Bureau of Reclamation

Table A. - SUMMARY OF PHYSICAL PROPERTIES TEST RESULTS (Inplace Density)

PROJECT *FRYINGPAN-ARKANSAS* FEATURE *TWIN LAKES DAM* TABLE ____ SHEET ____ OF ____

IDENTIFICATION				PARTICLE-SIZE FRACTIONS IN PERCENT						CONSISTENCY LIMITS			SPECIFIC GRAVITY				INPLACE DENSITY			
				FINES										PLUS NO. 4				WATER CONTENT %		
SAMPLE NUMBER 53H	HOLE NUMBER	DEPTH - feet (m)	CLASSIFICATION SYMBOL	SMALLER THAN 0.005 mm	0.005 TO 0.074 mm	SAND NO. 200 (0.074 mm) TO NO. 4 (4.76 mm)	GRAVEL NO. 4 (4.76 mm) TO 3 IN. (76.2 mm)	COBBLES 3 IN. (76.2 mm) TO 5 IN. (127 mm)	OVERSIZE LARGER THAN 5 IN. (127 mm)	LIQUID LIMIT - %	PLASTICITY INDEX - %	SHRINKAGE LIMIT - %	MINUS NO. 4	BULK	APPARENT	ABSORPTION - %	DRY DENSITY - pcf (gm/cm³)	AVERAGE	TOP	BOTTOM
207A			SP	3	0	97							2.70							
207B			SP	1	3	96							2.70							
207C			SP	2	2	96							2.70							
207D			SP	2	3	95							2.69							
207E			SP	0	4	96							2.70							
207F			SP	1	3	96							2.70							
X208G				7	10	63	20						2.66							
X208H				5	11	70	14						2.68							
X208I				5	9	65	21						2.67							

[illegible] in parentheses are metric equivalents of numbers directly above.

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Table B. - Soil test data

Date and time	Piezometer values (ft) Taps No. 1	2	3	4	5	6	7	8	Water volume (mL)	Time (min)	Temperature Above soil	Below soil	Comments
-25-82													
0:30 a.m.	9.36	9.16	8.85	8.84	8.82	8.80	8.79	8.77	2320	8	67 °F	60.5 °F	Dial gages recorded deflections of 0.0001 in. Aluminum channels tightened until dial gages were again zeroed.
0:50 a.m.	9.55	9.25	8.81	8.79	8.765	8.74	8.725	8.68	1720	4	67 °F	60.5 °F	Channels again tightened as dial gages recorded deflections of 0.001 in. Small amount of bubbling occurred on the north side of box at point of contact between large rock and plastic box.
1:10 a.m.	9.77	9.34	8.765	8.74	8.705	8.675	8.655	8.605	2270	4	67 °F	60.5 °F	Bubbling stopped.
2:40 p.m.	10.02	9.48	8.74	8.70	8.66	8.625	8.595	8.535	2863	4	69 °F	-	-
:30 p.m.	10.405	9.62	8.63	8.59	8.54	8.49	8.46	8.385	3800	4	69 °F	-	-
:45 p.m.	10.59	9.71	8.60	8.56	8.505	8.45	8.415	8.325	3185	3	70 °F	62 °F	-
:00 p.m.	10.68	9.74	8.58	8.53	8.47	8.425	8.38	8.285	3405	3	70 °F	62 °F	North side dial gage recorded a deflection of 0.00003 in.
:15 p.m.	10.865	9.825	8.555	8.50	8.435	8.38	8.335	8.24	3730	3	70 °F	62 °F	-
:30 p.m.	11.08	9.92	8.52	8.465	8.395	8.335	8.285	8.18	4125	3	71 °F	-	Dial gages showed deflections of 0.0001 in. Channels were again tightened.

Table B. - Soil test data (continued)

ate and time	Piezometer values (ft) Taps No. 1	2	3	4	5	6	7	8	Water volume (mL)	Time (min)	Temperature Above soil	Below soil	Comments
-30-82													
a.m.	9.39	8.92	8.375	8.355	8.325	8.30	8.28	8.24	2465	5	70 °F	-	-
) a.m.	9.83	9.115	8.29	8.26	8.215	8.18	8.15	8.10	2840	4	70 °F	-	-
l a.m.	10.355	9.34	8.17	8.12	8.07	8.03	7.98	7.905	2985	3	70 °F	63 °F	A small pipe in length and width developed in base material along south side of box. Dial gages showed deflec tions of 0.00005 in.
:15 p.m.	10.37	9.35	8.19	8.14	8.09	8.05	8.01	7.92	3000	3	70 °F	63 °F	Pipe appeared to be inactive.
:45 p.m.	10.36	9.335	8.195	8.15	8.095	8.055	8.02	7.925	3020	3	70 °F	63 °F	-
:45 p.m.	10.315	9.30	8.18	8.125	8.075	8.03	7.99	7.90	2972	3	71 °F	64 °F	-
15 p.m.	10.485	9.35	7.995	7.84	7.99	7.93	7.91	7.81	3390	3	72 °F	-	-
35 p.m.	10.77	9.47	8.04	7.985	7.93	7.81	7.82	7.71	3845	3	72 °F	-	-
55 p.m.	11.05	9.605	8.0	7.93	7.87	7.81	7.755	7.64	3610	2.5	72 °F	-	-
05 p.m.	11.40	9.77	7.93	7.87	7.79	7.72	7.66	7.54	3290	2	72 °F	-	-
5-82													
:30 a.m.	8.31	7.34	6.065	6.025	5.98	5.93	5.90	5.82	3370	3.5	71 °F	-	-
p.m.	8.445	7.42	6.07	6.025	5.98	5.935	5.90	5.82	3280	3.5	71 °F	-	-
15 p.m.	8.95	7.65	5.915	5.865	5.80	5.735	5.69	5.59	2435	2	72 °F	64 °F	Boiling along with a pipe developed along the north side of the box within the base material.

Table C. - Foundation material data

Date and time	Computed discharge (x 10^{-5} ml/s)	Standardized discharge (x 10^{-5} ml/s at 20 °C)	Pressure gradients			Hydraulic conductivities		
			Bottom 76.2 mm	Top 76.2 mm	Average 152.4 mm	Bottom 76.2 mm	Top 76.2 mm	Average 152.4 mm
3-25-82								
10:30 a.m.	4.83	4.90	0.80	1.24	1.02	3.30	2.13	2.59
10:50	7.17	7.27	1.20	1.76	1.48	3.26	2.22	2.64
11:10	9.46	9.59	1.72	2.30	2.01	3.00	2.24	2.57
12:40 p.m.	11.93	12.10	2.16	2.96	2.56	3.01	2.20	2.54
1:10	13.69	13.51	2.62	3.36	2.99	2.78	2.17	2.44
1:30	15.83	15.63	3.14	3.96	3.55	2.68	2.12	2.37
1:45	17.69	17.23	3.52	4.44	3.98	2.64	2.09	2.33
2:00	18.92	18.43	3.76	5.08	4.62	2.64	2.14	2.36
2:30	22.92	22.53	4.64	5.60	5.12	2.61	2.14	2.35
3-30-82								
8:00 a.m.	8.19	7.95	1.88	2.18	2.03	2.27	1.96	2.11
10:00	11.83	11.47	2.86	3.30	3.08	2.16	1.87	2.01
11:00	16.58	16.10	4.06	4.68	4.37	2.13	1.85	1.98
12:15 p.m.	16.67	16.18	4.08	4.64	4.36	2.13	1.87	2.00
12:45	16.78	16.29	4.10	4.56	4.33	2.14	1.92	2.02
1:45	16.64	16.16	4.06	4.48	4.27	2.14	1.94	2.04
2:15	18.83	17.85	4.54	5.42	4.98	2.12	1.77	1.93
2:35	21.36	20.27	5.20	5.72	5.46	2.10	1.91	2.02
2:55	24.07	22.83	5.78	6.42	6.1	2.12	1.96	2.01
3:05	27.42	26.02	6.52	7.36	6.94	2.15	1.90	2.02
4-5-82								
11:30 a.m.	16.05	15.43	3.88	5.10	4.49	2.14	1.63	1.85
1:00 p.m.	15.62	14.81	4.10	5.40	4.75	2.00	1.52	1.73
1:15	20.29	19.26	5.20	6.94	6.07	1.99	1.49	1.71
1:30	23.52	19.07	5.96	7.92	6.94	1.72	1.51	1.73
1:45	27.86	27.44	7.08	9.28	8.18	1.70	1.30	1.47
2:00	30.33	28.79	7.76	10.48	9.12	1.00	1.48	1.70
2:15	35.48	33.64	8.76	13.04	10.90	2.07	1.39	1.66

Table B. - Soil test data (continued)

ate and time	Piezometer values (ft) Taps No. 1	2	3	4	5	6	7	8	Water volume (mL)	Time (min)	Temperature Above soil	Below soil	Comments
-5-82													
:30 p.m.	9.30	7.81	5.83	5.78	5.715	5.65	5.59	5.485	2823	2	71 °F	64 °F	-
:45 p.m.	9.86	8.09	5.77	5.70	5.62	5.53	5.435	5.35	3343	2	70 °F	64.5 °F	-
p.m.	10.25	8.31	5.69	5.62	5.53	5.44	5.37	5.225	3640	2	70 °F	-	Hairline cracks developed along the lower contact interface. Boiling appeared to be more pronounced.
:15 p.m.	10.98	8.79	5.53	5.44	5.35	-	-	-	3193	1.5	70 °F	-	Hairline cracks became a full fracture extending through the entire specimen. The crack was 10 mm in width, so that a light could be seen through the crack. At this time the test was terminated.

l ft = 0.3048 m
°F = 1.8 (°C) + 32