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bject: Correlation of field penetration and vane shear test for saturated cohesive soils

INTRODUCTION

is progress report presents the results of a research study in which an tempt was made to correlate standard penetration resistance of saturated hesive soils with in-place shear strength. It was believed that there ght be a direct relationship, and the first objective of this study was determine whether or not this relationship existed. If the relation- ip did exist, then the correlation could be used to make penetration sistance data more usable on a quantitative basis than it has been in e past.

e field penetration test with split tube sampler has been used for a mber of years for estimating the denseness or firmness of soils. The -place vane shear test has also been used in recent years to determine e in-place shear resistance of saturated cohesive soils for the design foundations and natural soil slopes. A large number of penetration sistance holes and vane test holes have been drilled in the same areas a few Reclamation projects. These adjacent, or nearly adjacent, drill le tests provided information for study. Such information was available m soil investigations of Willard Dam near Ogden, Utah; Stanaker Dam ar Vernal, Utah; and Crown Hill Cemetery in Denver, where a special search project on subsurface exploration was conducted.

DISCUSSION OF FIELD EQUIPMENT USED

vane shear test apparatus and the standard split tube sampler are the pieces of equipment used to gather the field data correlated in this port. The vane shear apparatus is described in Designation E-20 1/ and penetration resistance test equipment in Designation E-21 2/ of the th Manual, 1960 Edition.

Numbers refer to references at end of the report.

Vane Test Apparatus

The vane shear test apparatus includes a 4-blade vane, shown in Figure 1, which is inserted into undisturbed soil, and the torque required to shear a cylindrical surface is measured. The test is made in three parts: (1) instrument friction determination, (2) undisturbed soil strength, and (3) remolded soil strength after the cylindrical surface has been fully sheared by a 90° turn. The friction measurement is made by a special coupling which enables the vane rod, for which a friction coefficient is needed, to move through 80° of rotation before lugs make contact and force is applied to the vane. Torque is measured by the strain of a sturdy ring which has a small section cut from it. The instrument is supported by an 8-inch-diameter casing embedded 1 foot into the ground surface. The casing is anchored by side fins. The stem consists of standard drill rods and can be installed with standard drilling equipment.

Standard Penetration Test

The field penetration test equipment shown in Figure 2 includes a split tube sampler, drill rod, a 140-pound drop weight, a jar coupling, and a drill rig or tripod with pulleys to raise the weight. The test is performed by drilling a hole to the desired depth, lowering the split tube sampler, which is attached to the drill rod, to the bottom of the hole and driving the tube into the soil by dropping the 140-pound weight 30 inches against the jar coupling. The sampler is first driven 6 inches into the soil, and then the blows required to drive the tube 1 foot into the soil are counted and recorded to indicate the denseness or firmness of the material tested. The sampler, which is a split tube with a hardened steel tip, is removed from the hole and opened to obtain a disturbed sample of the material tested. The sample may be used for classification purposes and for gradation, Atterberg limits, and moisture tests. The penetration test is repeated at intervals of depth as required.

The penetration test is generally used for: (1) preliminary investigations of a structure site, (2) complete investigations for small structure sites, and (3) extending detailed test data over large structure sites. The tests are also used for estimating the length of piles needed in a particular soil to carry required loads.

PLAN OF STUDY

Essentially the correlation process consisted of selecting a value of penetration resistance and obtaining a corresponding value of in-place shear strength. The correlation study was carried out in the following three phases: (1) selection of data which could be correlated, (2) grouping of the correlation points according to degree of reliability, and (3) presentation of results in graph form. The assumption made in selecting a correlation point is that the penetration resistance test and the vane test were performed in the same material. Penetration resistance and vane test shear strength values were plotted adjacent to logs of the drill holes to determine where penetration resistance and vane tests were made in the same stratum. These plots are shown in Figures 8 to 32 in the Appendix.

Sometimes an irregularity in the test caused the correlation point to be unreliable. The vane test holes and the penetration resistance holes were often so far apart that correlation between the two became doubtful. It seemed that a more objective analysis of the data could be made if the correlation points were grouped according to their degree of reliability, so each point was evaluated as high, medium, or low reliability. Table 1 in the Appendix lists all of the data obtained from the logs of the test holes, and Table 2 gives the grouping and lists the bases for the grouping.

Several graphs of shear strength versus penetration resistance were plotted in an effort to bring out new variables and emphasize the trends. Some graphs show all of the correlation points, and others show only clays and clay mixtures. Some graphs exclude points considered to have low reliability and include materials of all types.

DISCUSSION OF RESULTS

Most of the correlation points were obtained from Willard Dam and Crown Hill Cemetery. The Crown Hill Cemetery data were more easily correlated than the Willard Dam data, probably because Crown Hill tests were made specifically for research and extra precautions were taken.

As stated above, some correlation points were grouped as having low reliability because of irregularities in the vane test, or great difficulty in correlating strata between holes. However, all points, regardless of degree of reliability, were included in the tabulation of correlation points to insure that no useful data were overlooked.

Figure 3 is a plot of all the correlation points. The presence of several unreliable points makes a trend difficult to distinguish, but most of the points seem to lie in a belt which trends upward to the right as shown by the dashed curves. A few very fine sands and some silts were included in this study, and it is interesting to note that almost all of these materials lie within the trend shown. It may be that these sands and silts seem to conform only because relatively few tests were made in these materials, since vane tests are not generally considered applicable for cohesionless granular soils.

Figure 4 is similar to Figure 3, but excludes the points considered to have low reliability. A definite trend is more obvious on this graph. There are seven points above the belt which seem to constitute another trend. The only thing these points appear to have in common is their depth range. Almost all of them were obtained at a depth greater than 20 feet. Previous penetration resistance studies 3/ have indicated that the additional weight applied by increasing the rod length may have an effect, in the case of soft materials, which aids penetration and causes the number of blows per foot to decrease if the penetration resistance is low. The additional weight effect would cause the points in question to move to the left. At the same time, the greater overburden pressure in the deeper holes would increase the shearing strength obtained by the vane test and cause the points to move upward. Combining these two effects would cause the points to move toward the upper left corner of the graph, thus explaining their apparent deviation from the trend. No explanation is offered for the points below the belt, except that two of the points were chosen from an area where correlation of strata between holes was quite difficult.

Figure 5 was drawn to investigate the effect of depth. Figure 5(a) is a plot of points obtained from 0- to 20-foot depths and excludes low reliability points. Figures 33 and 34 in the Appendix show the same points plotted in two 10-foot increments. The small number of deviations from the trend indicates that tests made at depths less than 20 feet are relatively consistent. Points in Figure 5(b) were obtained from depths greater than 20 feet and indicate a higher trend on the graph, although the random locations of points indicate that, as depth increases, consistent results become more difficult to obtain.

Figure 6 shows a comparision of the correlation belts obtained by plotting the correlation points in various ways. Each correlation belt is described in the explanation. It is significant that all of these belts, except one, have approximately the same lower limit. The upper limits of the belts seem to move up with increasing depth, which is in accordance with the previously discussed added weight effect of increased rod length for soils of low penetration resistance. The correlation belt which includes all points is slightly wider than most of the other belts. The slight widening effect is probably due to the inclusion of low reliability points. The curves for 20-to 125-foot depths have moved up and widened slightly. The rest of the belts, however, cover approximately the same area. This figure also contains a curve which represents data published by Terzaghi and Peck.4/ It is based on one-half the unconfined compression strength plotted against penetration resistance.

Figure 7 is a graph of penetration resistance versus one-half the unconfined compressive strength of several clay soils tested in the course of project investigations.5/ It is interesting to note that these points tend to follow a line which is slightly higher than Terzaghi and Peck's correlation curve 4/ and also appears to start from the origin. The portion of this penetration resistance versus shear strength curve above about 15 psi and 10 blows per foot penetration resistance is in a similar range of values as that of the vane test correlation curves, presented in this report. This may be explained by the fact that these stiffer clays are better able to retain their structure during sampling and, therefore, the unconfined compression test more closely represents in-place shear strength.

The correlations shown by vane tests in this report (Figure 6) lie significantly above that shown by unconfined compression tests in Figure 7, for the range of shear strength from 0 to 15 psi and penetration resistance from 0 to 10 blows per foot. This may be explained by considering the following facts:

a. The vane test is performed in place with overburden pressures acting on the specimen and, therefore, it may be considered a measure of the in-place strength.

b. Similarly the penetration resistance test is made in place with overburden pressures acting on the specimen.

c. The unconfined compression test is performed on samples from which the overburden pressures have been released and, therefore, lower shearing strengths are obtained.

However, in soft soils the penetration resistance test is critically affected by the length of drill rod, which causes a reduction in the penetration resistance values.

CONCLUSIONS

1. The results of this preliminary study indicate that a definite relationship between penetration resistance and in-place shear strength does exist, although there is yet much to learn about the relationship. At this point, it appears that shear strength of saturated cohesive soils is closely proportional to penetration resistance in the range of 1 to 13 blows per foot.

2. The correlation belts (Figure 6) seem to move upward slightly with increasing depth, although a comparison of points obtained at different depth ranges indicates that as depth increases, consistent results become more difficult to obtain. Since most of the field tests were made in relatively soft materials, it is likely that the shift upward is partly due to the increased weight of drill rods.

3. Since all of the correlation points for 0- to 20-foot depths plot in approximately the same area, it seems that for this depth increment, the effect of depth is negligible. The exclusion of the low reliability points serves to eliminate many of the serious deviations from the trend, but it does not narrow or shift the position of the correlation belt appreciably.

4. Terzaghi and Peck 4/ published the following table showing the approximate relationship between unconfined compressive strength and penetration resistance in blows per foot.

PENETRATION-STRENGTH RELATION FOR CLAYS

Consistency	Very soft	Soft	Medium	Stiff	Very stiff	Hard
Number of blows	2	2-4	4- 8	8-15	15-30	30
Unconfined compressive strength (psi)	3.5	3.5-7	7-14	14-28	28-56	56

For the sake of comparison, it was assumed that the shear strengths of the above materials were obtained by taking one-half of the unconfined compressive strength. If the data are plotted on the basis of this assumption, a nearly straight line is obtained between 2 and 13 blows per foot as shown in Figure 6. It is interesting to note that Terzaghi and Peck's curve is very nearly parallel to the curves presented in this report and is located about 5 psi lower on the graph than our average values and 2 psi lower than our minimum values. The curves obtained with the vane test apparatus include the effects of overburden pressures, and, therefore, should be located higher on the graph than curves representing unconfined shear strength which is obtained on unloaded laboratory specimens. It is also possible that Terzaghi and Peck were logically conservative in their estimates. The data studied herein generally confirm their values, particularly for use in preliminary work where conservatism is desirable. It should be pointed out, however, that for very soft soils where little or no penetration resistance is observed, the shear strength, as measured by the vane test, may be in the order of 5 psi. Penetration with a few or no blows in soft soils may be caused by the weight of the test apparatus.

5. The effect of rod weight and length upon penetration resistance is not fully understood, and it has not been definitely proven in this study that penetration resistance is a function of shear strength alone, although this study shows interesting and useful trends. Some of the answers to the above questions can probably be obtained in future studies by further subdividing correlations into depth increments. With this information as a beginning, further observations can be added to the correlations and programs can be specifically planned to evaluate some of the items still in question.

Table 1

TABULATION OF CORRELATION POINTS

Correlation Point No.	DH No.	Approximate depth (ft)	Soil classification	Penetration resistance in blows per foot	Shear strength in psi	Location
1	217	22	SM	7	12.0	Willard
2	218	25-30	ML-CL	7	13.5	Willard
3	218	45-49	OH	1	4.8	Willard
4	203	5-8	CL	1	3.9	Willard
5	203	8-12	SM	11	16.2	Willard
6	203	19-23	SM	8	14.2	Willard
7	203	23-30	SP	16	19.5	Willard
8	202	4-16	ML	2	5.5	Willard
9	202	60-63	CL	6	18.8	Willard
10	239	6-11	CL	9	11.3	Willard
11	239	11-16	CL	6	10.2	Willard
12	239	16-21	CL-ML	2	8.3	Willard
13	208	5-10	CL-ML	1	5.8	Willard
14	201	7	ML	3.5	8.1	Willard
15	201	47-53	ML	4	5.3	Willard
16	207	8-11	ML	5.2	7.5	Willard
17	212	25-30	MH	4	8.7	Willard
18	213	40-43	CL	2	5.9	Willard
19	213	43-46	CL	3	13.8	Willard
20	215	29-32	CL	1	3.9	Willard
21	204	10-13	ML	3	6.9	Willard
22	204	14-17	SM	4	7.5	Willard
23	205	8-13	CL	2	6.0	Willard
24	216	4-10	CL-CH	3	12.6	Willard
25	216	10-14	ML	5	7.8	Willard
26	216	23-29	CL-ML	5	13.8	Willard
27	216	30-36	CL	1	4.6	Willard
28	206	4-6	SM	2	5.2	Willard
29	206	24	CL	1	6.1	Willard
30	206	30	ML-CL	2	8.2	Willard
31	206	38	CL	1.7	6.9	Willard
32	206	48	CL	4.2	8.6	Willard
33	239	3-6	CL-ML	5	10.7	Willard
34	202	115-120	CH-OH	2	11.2	Willard
35	219	10	CL	2	11.3	Willard
36	218	10-16	ML	1	7.1	Willard
37	211	5-8	ML	2	7.2	Willard
38	212	40-46	CL	1	5.0	Willard
39	VT-3	12-35	CL-SM	7	13.3	Stanaker

Table 1--Continued

Correlation Point No.	DM No.	Approximate depth (ft)	Soil classification	Penetration resistance in blows per foot	Shear strength in psi	Location
40	C-28	10	CL	6.7	11.9	Crown Hill
41	C-28	12	CL	4.5	8.5	Crown Hill
42	C-28	15	CL-SC	4.6	8.7	Crown Hill
43	C-28	17	CL	7.5	13.3	Crown Hill
44	C-28	20	CL	9.5	11.6	Crown Hill
45	C-28	22	CL	7.5	11.8	Crown Hill
46	C-48	4	CL-CH	5.7	8.9	Crown Hill
47	C-48	7	CL	11.3	10.2	Crown Hill
48	C-48	9	CL	5.7	9.4	Crown Hill
49	C-48	12	CL	5.7	9.1	Crown Hill
50	C-48	14	CL	4.2	10.2	Crown Hill
51	C-48	17	CL	7.8	11.4	Crown Hill
52	C-48	19	CL	12.6	16.0	Crown Hill
53	C-48	22	CL-SC	10.7	19.9	Crown Hill
54	C-47	5	CL-CH	7.2	8.5	Crown Hill
55	C-47	7	CL	10.7	14.8	Crown Hill
56	C-47	10	CL	5.6	10.9	Crown Hill
57	C-47	12	CL	3.2	5.7	Crown Hill
58	C-47	15	CL	4.4	6.6	Crown Hill
59	C-47	19	CL	12.8	22.6	Crown Hill
60	C-47	22	CL	10.2	16.6	Crown Hill
61	C-38	5	CL-CH	7.2	8.0	Crown Hill
62	C-38	7	CL	10.4	12.1	Crown Hill
63	C-38	10	CL	5.5	3.4	Crown Hill
64	C-38	12	CL	4.4	2.9	Crown Hill
65	C-38	15	CL	4.5	6.4	Crown Hill
66	C-38	20	CL	12.4	23.8	Crown Hill
67	C-38	22	CL	8.5	5.3	Crown Hill
68	C-30	5	CL-CH	7.2	8.0	Crown Hill
69	C-30	7	CL	10.4	10.6	Crown Hill
70	C-30	10	CL	6.7	10.8	Crown Hill
71	C-30	12	CL	4.6	7.9	Crown Hill
72	C-30	15	CL	4.5	9.7	Crown Hill
73	C-30	17	CL	7.5	12.1	Crown Hill
74	C-30	20	CL	12	16.9	Crown Hill
75	C-30	22	CL	9.6	19.0	Crown Hill
76	C-29	5	CH	7.2	6.5	Crown Hill
77	C-29	7	CL	10.5	4.9	Crown Hill
78	C-29	10	CL	5.6	7.8	Crown Hill
79	C-29	12	CL	2.8	7.3	Crown Hill
80	C-29	15	CL	4.2	7.0	Crown Hill
81	C-29	17	CL	7.5	11.5	Crown Hill
82	C-29	20	CL	10.6	14.3	Crown Hill
83	C-29	22	CL	7	16.0	Crown Hill

Table 2

GROUPING OF CORRELATION POINTS ACCORDING TO DEGREE OF RELIABILITY*

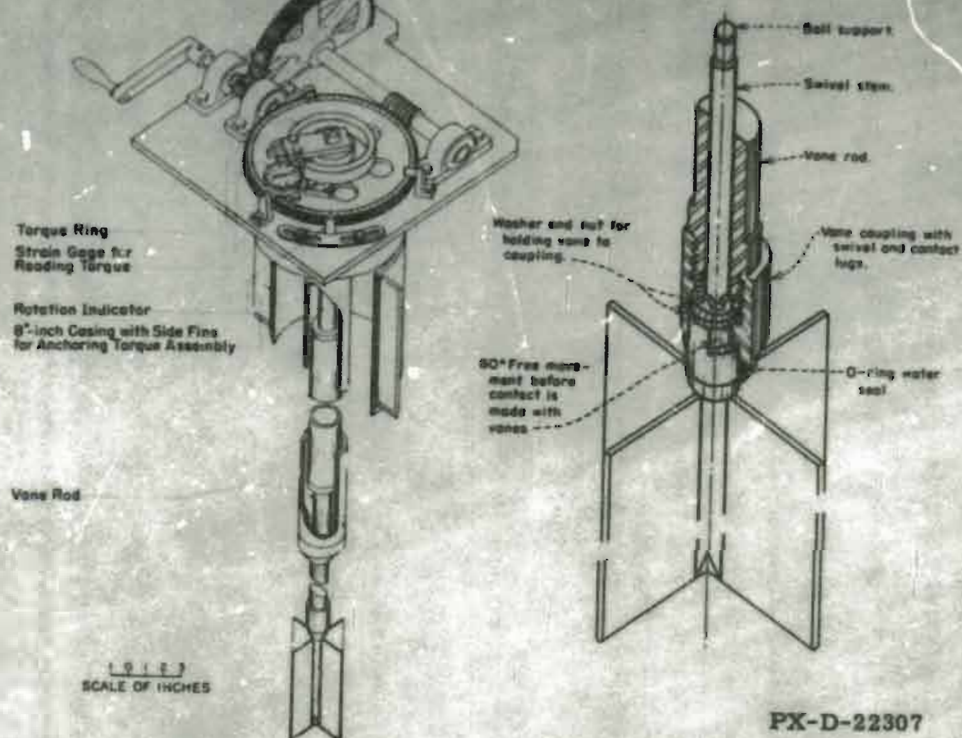
Correlation Point No.	Grouping	Correlation Point No.	Grouping	Correlation Point No.	Grouping
1	H	29	H	57	H
2	M	30	H	58	H
3	H	31	M	59	L
4	H	32	M	60	H
5	H	33	L	61	L
6	L	34	M	62	M
7	L	35	M	63	M
8	M	36	M	64	M
9	L	37	L	65	M
10	H	38	L	66	L
11	H	39	M	67	M
12	H	40	M	68	L
13	H	41	M	69	L
14	L	42	M	70	M
15	H	43	M	71	M
16	M	44	M	72	M
17	L	45	M	73	M
18	L	46	L	74	M
19	L	47	L	75	M
20	H	48	H	76	L
21	H	49	H	77	M
22	M	50	H	78	M
23	M	51	H	79	M
24	M	52	H	80	L
25	L	53	H	81	M
26	M	54	L	82	M
27	M	55	H	83	M
28	L	56	H		

H = High degree of reliability
M = Medium degree of reliability
L = Low degree of reliability

*Groupings are the opinion of W. N. Houston

REASONS FOR GROUPING SOME CORRELATION POINTS AS LOW OR MEDIUM RELIABILITY

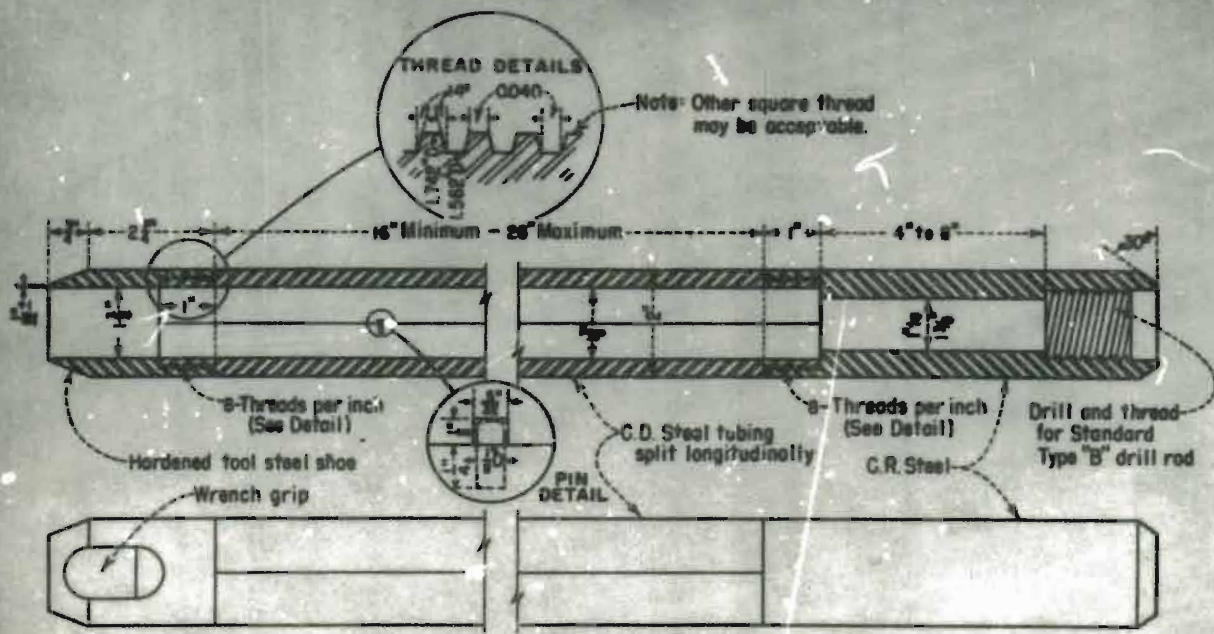
1. Limit of vane test apparatus reached before failure.
2. Slippage in vane test apparatus during test.
3. Pronounced irregularity in vane readings.
4. Necessity to interpolate for friction values in vane tests.
5. Interference by rocks.
6. Tests performed above or near the water table.
7. High probability that shear strength and penetration resistance were not measured in the same strata.



PX-D-22307

The Bureau of Reclamation Vane Test Apparatus.

Fig. 1



STANDARD SPLIT TUBE SAMPLER

101-D-169

Field Penetration Test Equipment
Used by The Bureau of Reclamation

Fig. 2

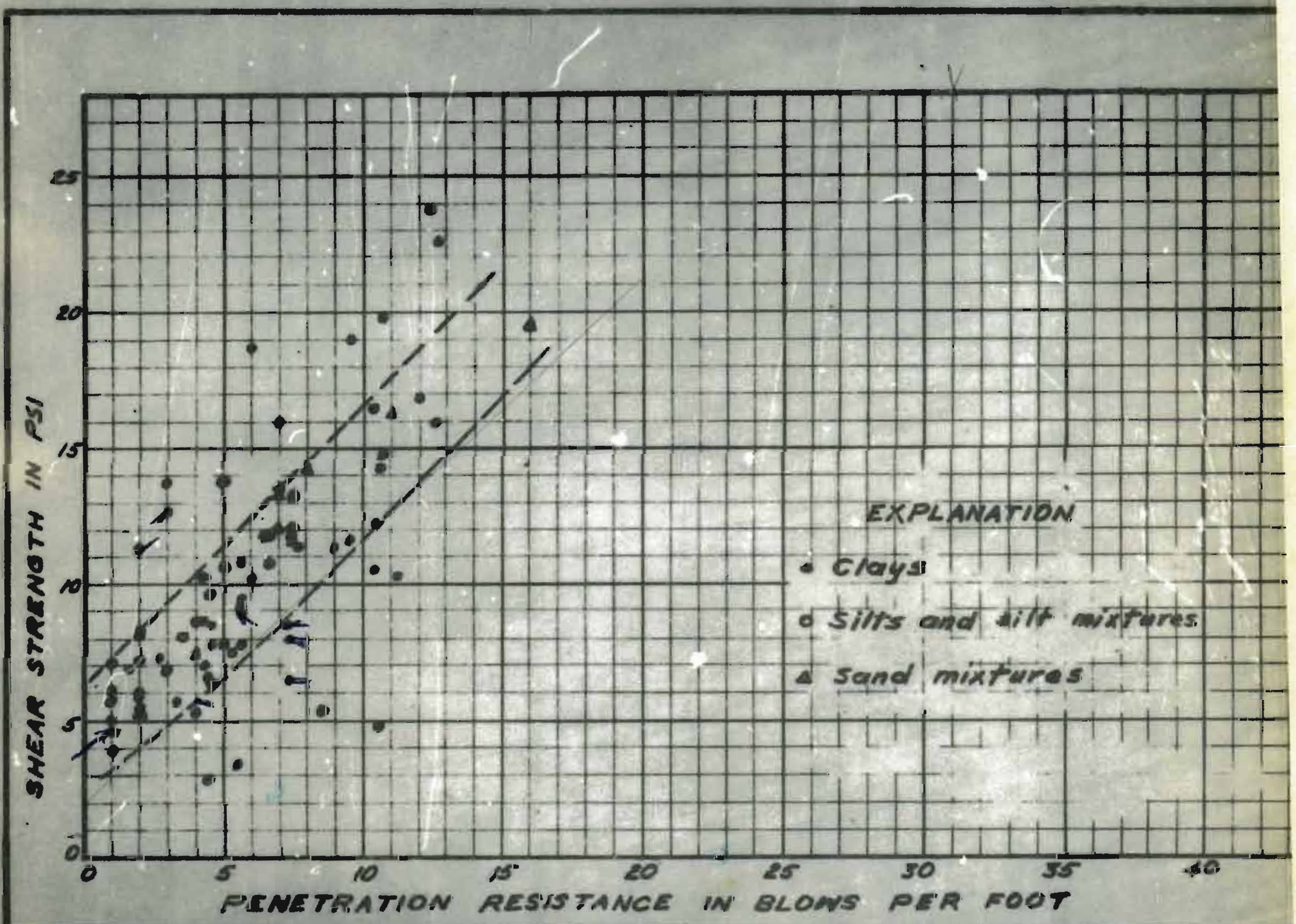
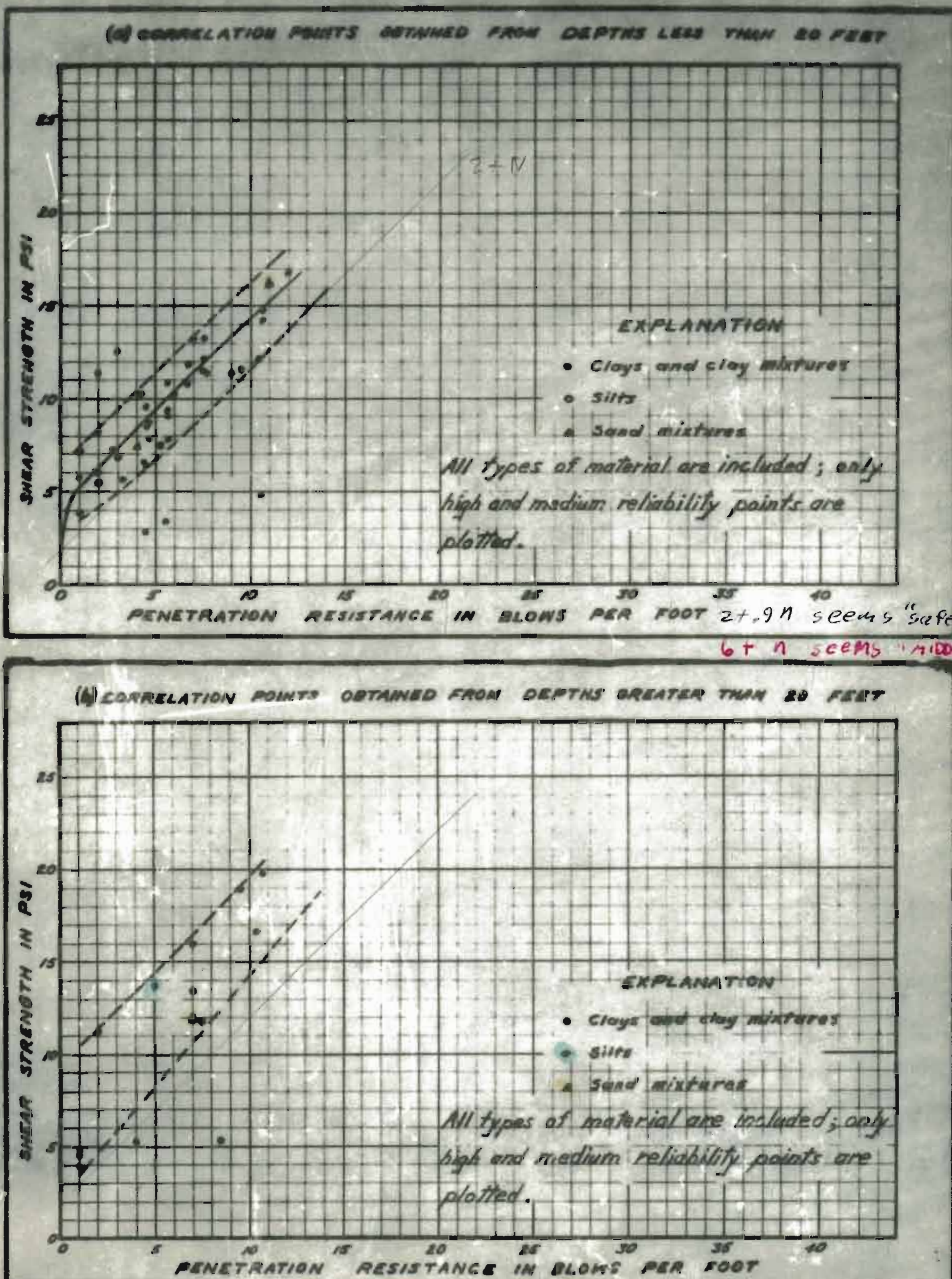


Fig. 3 PLOT OF SHEAR STRENGTH VS. PENETRATION RESISTANCE INCLUDING All POINTS OF OBSERVATION



EFFECTS OF DEPTH OF TESTING ON CORRELATIONS

Fig. 5

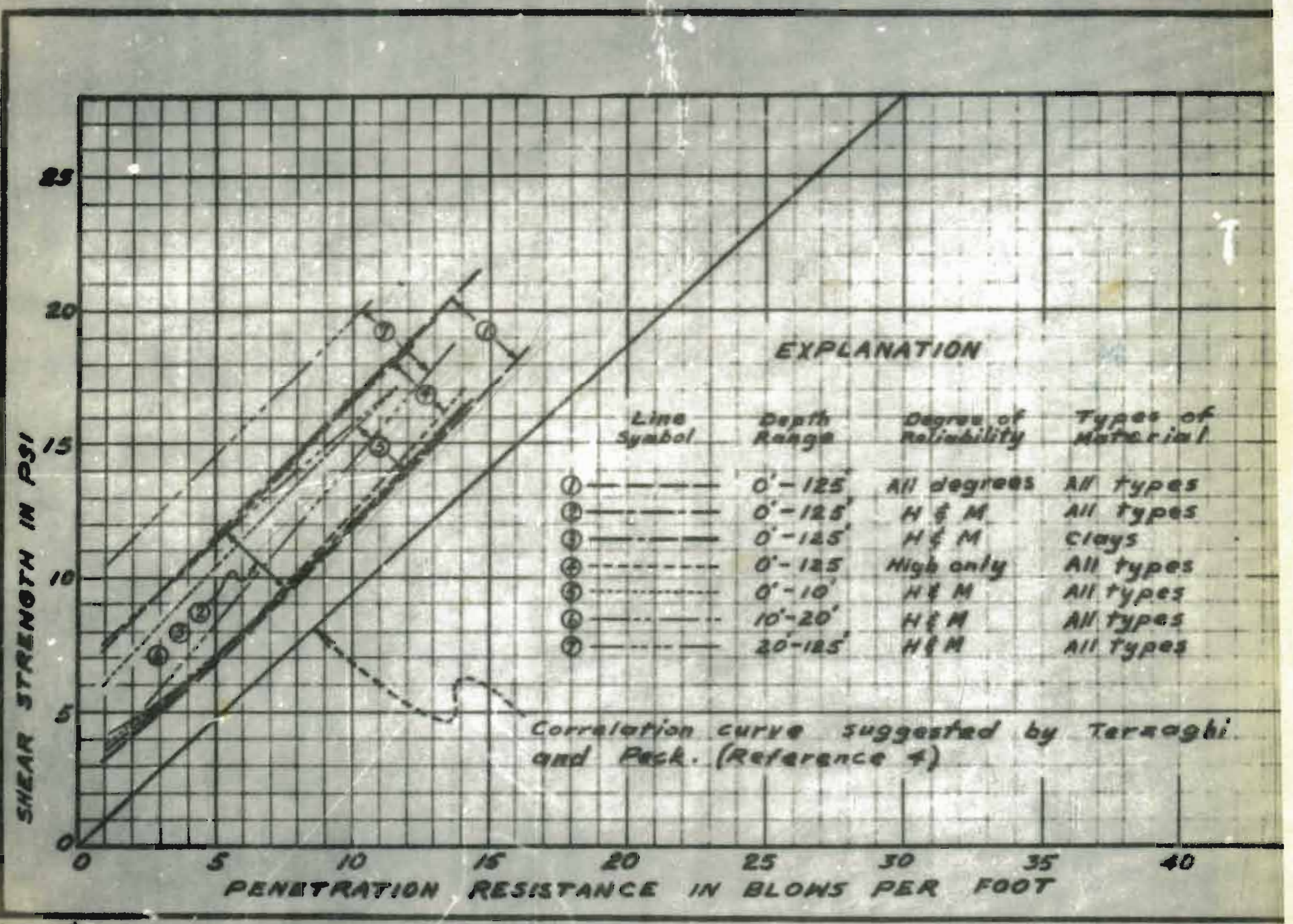


Fig. 6 – COMPARISON OF CORRELATION BELTS OBTAINED BY VARIOUS MEAN

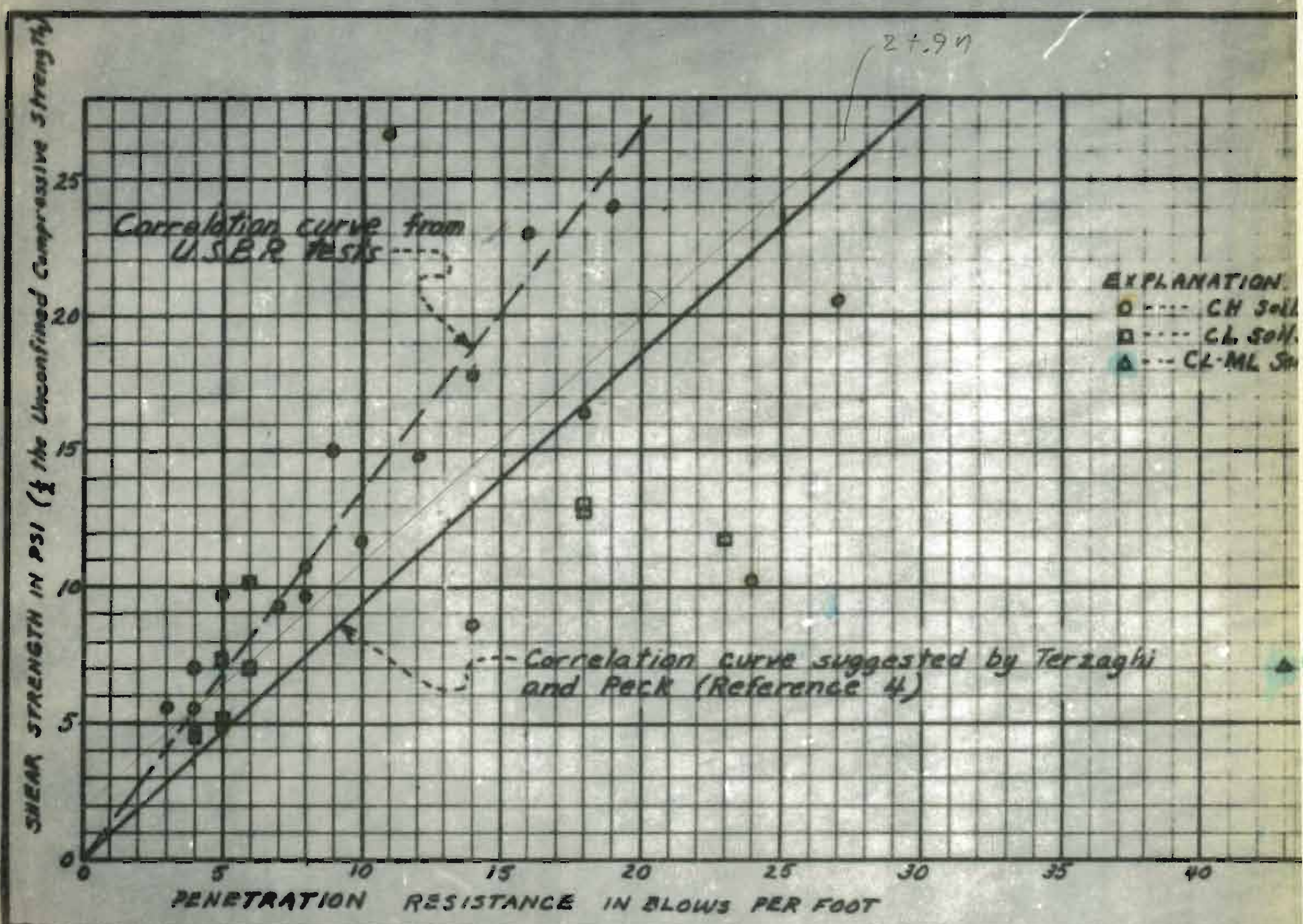


Fig. 7 Correlations Using Unconfined Compression Tests

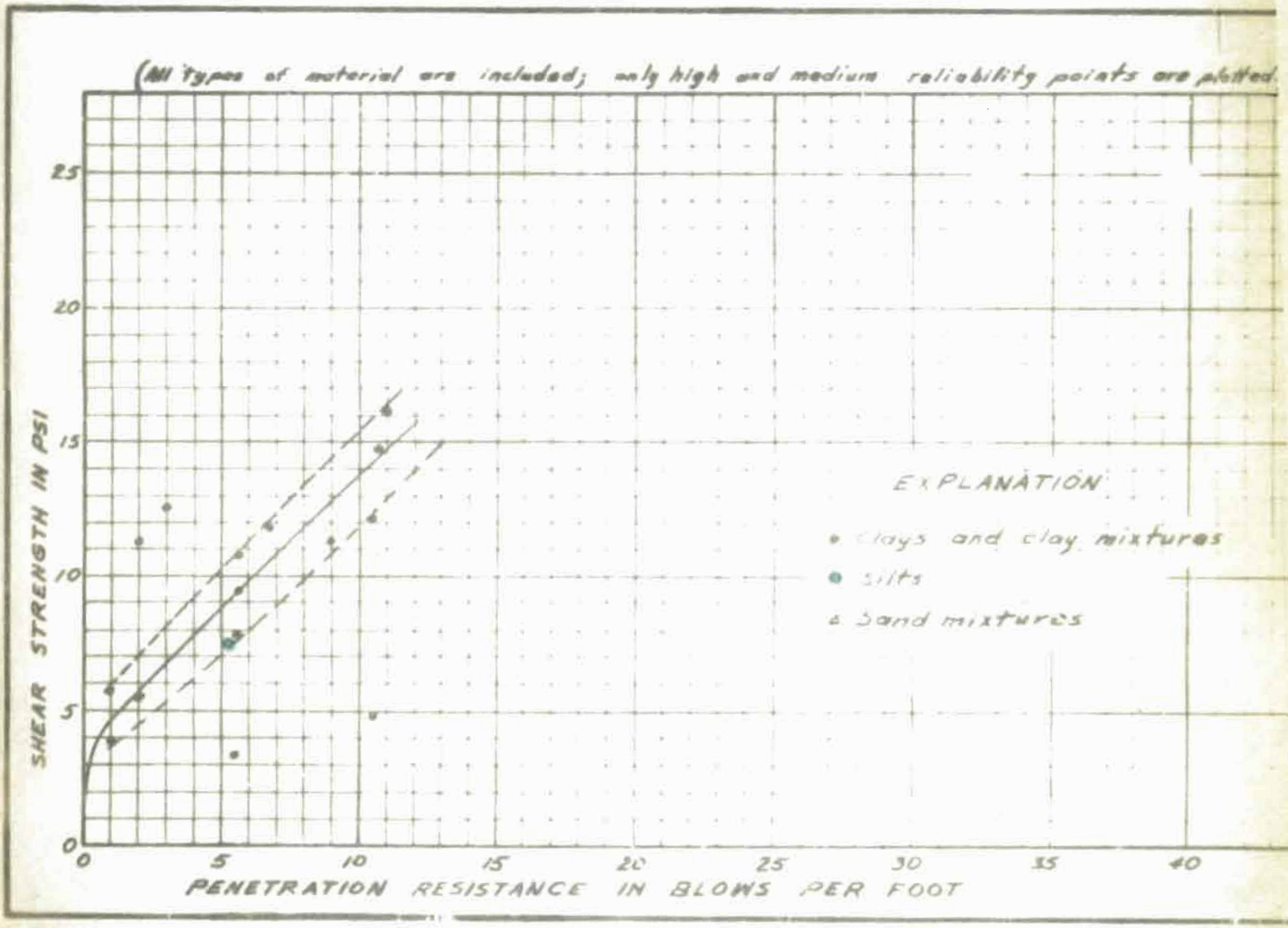
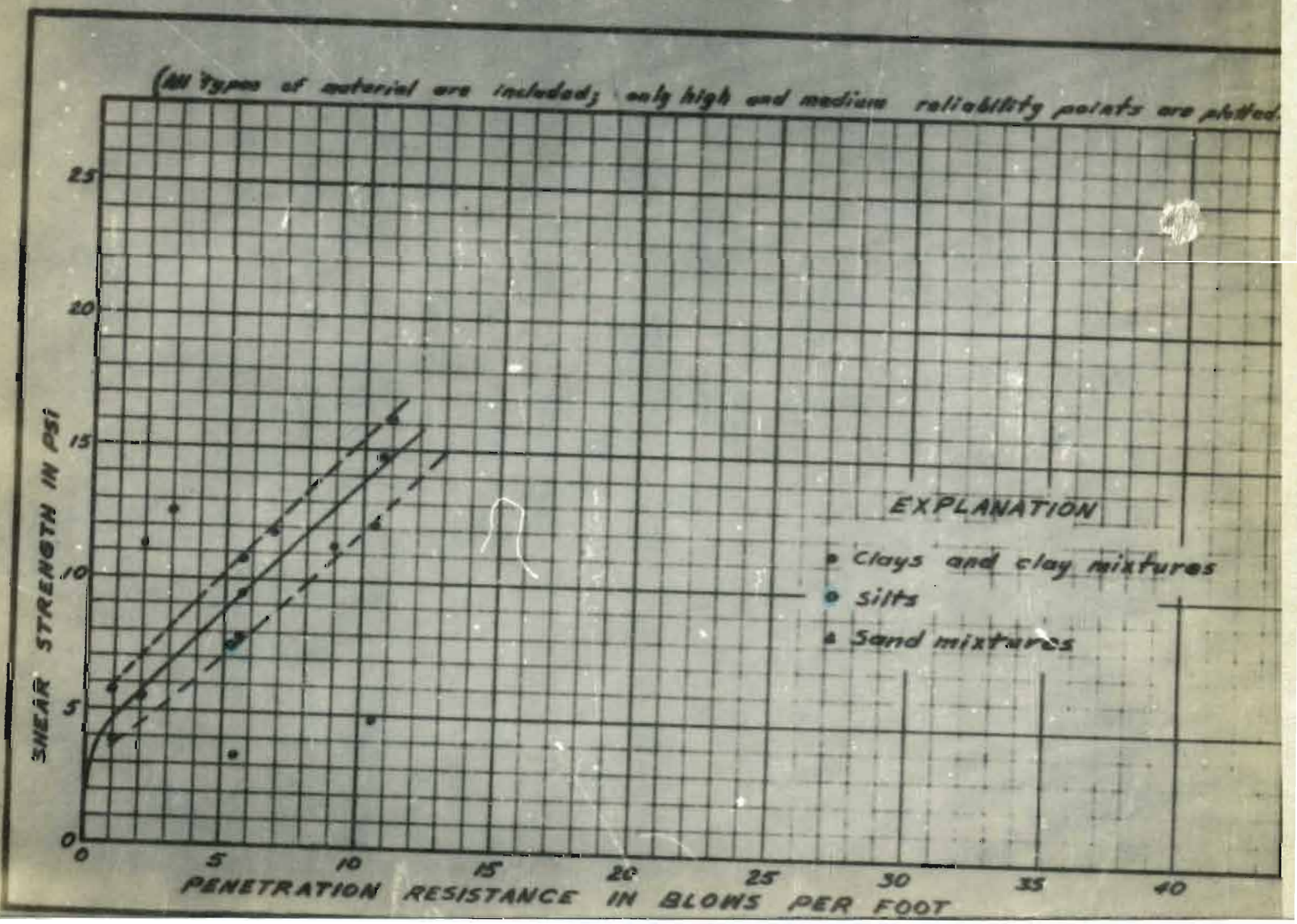


Fig.33 CORRELATION POINTS OBTAINED FROM DEPTHS 0—10 FEET


(All types of material are included; only high and medium reliability points are plotted.
SHEAR STRENGTH IN PSI
0
5
10
15
20
25
PENETRATION RESISTANCE IN BLOWS PER FOOT
0
5
10
15
20
25
30
35
40
EXPLANATION
Clays and clay mixtures
Silts
Sand mixtures

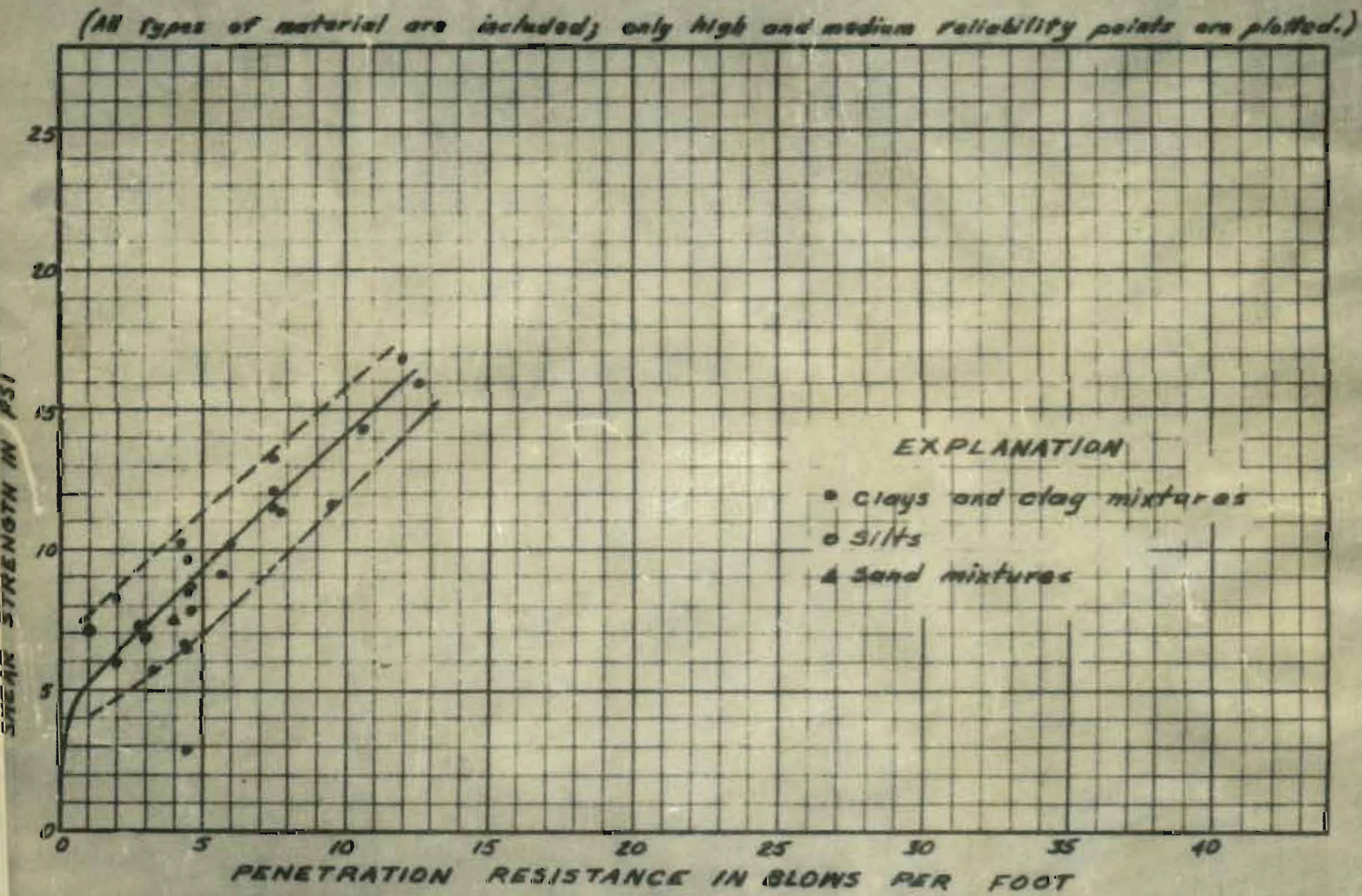


Fig. 34 CORRELATION POINTS OBTAINED FROM DEPTHS 10–20 FEET