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RESEARCH ON DETERMINING THE DENSITY OF SANDS BY SPOON PENETRATION TESTING

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RESEARCH ON DETERMINING THE DENSITY OF SANDS BY SPOON PENETRATION TESTING[1]

by H. J. Gibbs and W. G. Holtz[2]

ABSTRACT

The split spoon sampler has been used for a number of years as a sounding and sampling device for estimating the denseness or firmness of soils in place. The Bureau of Reclamation has used this device for estimating foundation conditions at transmission tower or small structure sites or for extending more detailed field and laboratory data obtained at larger structure sites. As the empirical rules available for interpreting the data did not provide an evaluation for the length and weight of drill rod, and effects of moisture and overburden pressure, a closely controlled research study was initiated to evaluate these factors.

The portion of the research program related to fine and coarse sands has been completed and the results of numerous closely controlled tests are presented and evaluated. It is believed that this evaluation leads to better understanding of some of the anomalies which are often apparent in the field test data and provides a means for a better interpretation of the data obtained by this common field test.

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[1] A paper prepared for presentation at the Fourth International Conference on Soil Mechanics and Foundation Engineering, London, England, August 1957.

[2] Head, Special Investigation and Research Section, Earth Laboratory Branch and Chief, Earth Laboratory Branch, Division of Engineering Laboratories, Office of Assistant Commissioner and Chief Engineer, Bureau of Reclamation, Denver, Colorado.

INTRODUCTION

The penetration resistance test is a sounding method of subsurface exploration with a general purpose of evaluating the soil characteristics of firmness and denseness. Although many types of sounding tests have this same basic purpose, the Bureau of Reclamation has selected one type on which to gather a background data for empirical application to foundation investigations. This particular test is essentially the same as that published by Terzaghi and Peck.3* An important advantage of this test, besides obtaining penetration resistance, is that a sample is retained for inspection.

The test provides an indirect method of evaluating, to a certain extent, soil mechanics properties of subsurface soils. It has generally been established that it has fairly reliable application to granular, cohesionless soils and has less application to cohesive soils which are appreciably influenced by moisture content and clay mineral characteristics. The previously established correlations with soil mechanics properties are considered general and further confidence was needed in using them for different test conditions. Since the equipment consists of a rod containing a penetration-end device driven by blows of standard hammer dropped a standard distance, it was believed that such variables as depth and consequently overburden pressure, length of rod, and weight of rod would influence the values to the greatest degree.

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*References are given at the end of paper.

To determine the effect of these influences, a research testing program was conducted using equipment in which the soil was placed at controlled conditions of density and moisture, stressed by varying overburden pressures, and tested with rods of varying length, size, and weight. Combinations of these variables were made to represent actual field testing at varying depths.

EQUIPMENT

The standard test consists of measuring, in terms of blows per foot, the resistance of the soil to the penetration of a standard spoon driven by the free-fall of a 140-pound weight dropped 30 inches. The dimensions of the spoon are given in Figure 1a. It is split longitudinally and can be opened to inspect the soil penetrated.

To control the variable conditions of this research study, a heavy steel tank, 3 feet in diameter by 4 feet high, was constructed and fitted with load plates and loading springs for representing overburden pressure as shown in Figure 1b. The load was applied to the top plate by a compression machine and, by tightening the bolts on the load retaining rods spaced at intervals around the tank, the compressed springs held the load on the soil during the penetration tests.

The test soils were placed in the tank at controlled density and moisture content with the first series at air-dry moisture content (about 0.5 percent), the next series at medium moisture content (about 5 percent), and the last series at saturated moisture content. The soils were compacted by a vibrator working up and down the center axis of the tank, as shown in Figure 2, and for more vigorous vibration the vibrator was also attached to the sides of the tank. Differences in denseness were obtained by varying the time and effort of vibration.

The penetration tests were made in six uniformly spaced holes around the tank as shown in Figure 1b. The density of the soil tested was measured by averaging three direct density determinations immediately after completing the penetration tests.

The weight and flexibility of the driving rod were varied by using three sizes, N-rod, B-rod, and A-rod. The length of rod was varied by operating the hammer at a balcony level and on the roof of the laboratory building and directly above the tank. The rod was enclosed in a standard drill hole casing pipe to simulate field conditions. Three lengths were studied (1) 0 feet (driving head and spoon only), (2) 32 feet, and (3) 65 feet.

DISCUSSION OF TESTS

Standard Properties Tests

The gradation curves of the coarse and fine sands studied are shown in Figure 3. These sands were cohesionless except for the fact that the fine sand contained 14 percent minus No. 200 material. Tests for the coarse sand indicated a minimum density of 93 pcf and a maximum density of 124 pcf, and for the fine sand a minimum density of 74 pcf and a maximum density of 120 pcf. The basic equation for determining the degree of relative density is

$$R.D.\% = \frac{e_{max}-e}{e_{max}-e_{m}} \times 100 = \frac{\gamma_d - \gamma_{min}}{\gamma_{max}-\gamma_{min}} \times \frac{\gamma_{max}}{\gamma_d} \times 100$$

e = void ratio for variable densities
e_{min} = void ratio at maximum density
e_{max} = void ratio at minimum density
γ_d = variable densities
γ_{max} = maximum density
γ_{min} = minimum density

The maximum density was determined by vibrating the saturated material to constant density or by using extreme compaction by hammer blows, whichever gave higher values, in a container of known volume. The minimum density was found by lightly pouring the dry material into the container of known volume.

Because of side friction on the soil resulting from the limited size and the confinement of the test tank, the applied pressure on the top of the soil was not distributed in the full amount to lower depths in the tank. The pressure at the level of the penetration test (6 to 18 inches below the surface) was evaluated by four pressure cells installed in the soil at the 6- and 18-inch levels. The intergranular pressure values used throughout the study were the average of the four cell measurements for each pressure application on each of the two sands.

<u>Effect of Overburden Pressure</u>

The overburden pressures were found to have the most pronounced and consistent effects on the penetration resistance values. These results for the coarse and fine sands are shown in Figures 4 and 5, respectively. The points on the graphs are the results in blows per foot of penetration obtained in the sands placed at relative density values shown and with intergranular pressures indicated by the various symbols. The results do not include the effects of rod weight or length as all values in these figures were obtained with the penetration spoon and jar-coupling only. Figure 4 includes a series of tests at air-dry moisture content, shown by hollow points, and at intermediate moisture, shown by solid points. The values (air dry and moist) so closely resemble each other that only a single interpretation was considered warranted. The final interpretation of the graphs was the drawing of curves for variable overburden pressures of 0, 10, 20, and 40 psi which gave the correlations obtained between penetration resistance, relative density, and overburden pressure.

Figure 6 shows how the curves for the coarse and fine sands were averaged to obtain a series of curves which are considered applicable to air-dry and moist cohesionless sands. This figure shows rather close correlations for the two sands.

Results of Tests on Saturated Sand

Tests were made on each sand to simulate saturation and high water table conditions by maintaining the water level in the test tank above the surface. Data similar in type to that shown in Figures 4 and 5 were obtained for each of the sands. The final curves are shown in Figure 7, with dashed curves for the coarse sand and dashed-dot curves for the fine sand. The results indicated some reduction in penetration resistance for the coarse sand and appreciable reduction for the fine sand. It seems reasonable that high moisture contents would reduce the frictional resistance to penetration of the spoon because of lubrication and delayed drainage around the spoon during the short time of the dynamic blows of the hammer. Also, it is reasonable that the delayed drainage effect is more pronounced in the fine sand than in the coarse sand. The delayed drainage thereby restrained the action of effective grain-to-grain pressures in resisting penetration. On the other hand, it is recognized from previous literature[4] that excessive blows per foot may be obtained in very fine sand below the water table in a natural stratum due to the restriction of water movements making space for the penetration device. It is doubtful that these laboratory tests truely represented a natural water table condition since the tank was of limited size and the water surface was relatively close to the test location in all cases. Therefore, until better evaluations of saturated conditions are obtained, it would be advisable to use the higher resistance curves for air-dry and moist cohesionless sands, shown by heavy solid lines in Figure 7, as these would be on the conservative side when predicting density.

Effect of Rod Weight, Size, and Length

When penetration data using rods of varying length, 0, 32, and 65 feet, were compared, the greater length of rod showed reduced blows per foot in the sands at relative densities of medium and loose, and increased blows in dense and very dense sands. Therefore, there were two views of interpretation taken: (1) The loose sands which normally had low penetration resistance showed still less blows per foot because the added weight of the rod was assisting penetration of the spoon, and (2) the denser sands which normally had high penetration resistance showed increased blows per foot because of flexure and whipping of the rod during hard driving. From these views it seems logical that a relatively stiff rod would be preferable to reduce the flexure effect but, on the other hand, it would not be advisable to have an excessively heavy rod which would show lower penetration resistance for loose soils that are of major concern.

The effect of weight was investigated separately by using the rod as weight and driving the spoon on a jar coupling at the lower end of the rod. These tests emphasized the reduced blows per foot for medium and loose sand but showed less reduction for dense sand. Therefore, the length of rod effect apparently partially compensated for the weight effect. Of the three rod sizes tried, the B-rod had the least resultant effect and this effect appeared to be within the accuracy of the test itself. Although reduced blows per foot were found for medium and loose sand when weight and length were considered, it was considered advisable not to use these values to arrive at the correlation curves. Instead, the higher resistance correlation curves, shown by heavy lines in Figure 7, were considered best so that excessively high densities would not be predicted.

Results of a Field Test to Evaluate the Correlation Curves

Because the correlation of penetration resistance versus relative density published by Terzaghi and Peck[5] have been widely used in this country, a dashed curve giving their correlation has been plotted, in Figure 7, for comparison to the correlation from this research. Although their publication shows their correlation only in general descriptive terms of very loose to very dense, values of relative density were applied on the basis of divisions in common use by the Bureau. It may be noted that this correlation follows closely to the correlation found in this study for higher overburden pressures of 40 psi.

The interpretation of this study may be visualized by analyzing the relative density of a cohesionless sand having a penetration resistance of 20 blows per foot. The Terzaghi and Peck curve would show it to have a medium density of 52 percent relative density without regard to overburden pressure. The findings of this study indicate a relative density of 55 percent for 40 psi pressure, 65 percent for 20 psi pressure, and a very dense sand if tested near the surface with practically no pressure. Thus, it may be said that the Terzaghi-Peck correlations are on the conservative side for shallow footing work for which they were intended.

Figure 8 shows the results of a field trial made in a deposit of fine sand similar to that used in the study and located in the vicinity of Cherry Creek Dam near Denver, Colorado. A great number of density observations were obtained from undisturbed sampling by the Denison and fixed piston samplers and by test pit excavation. These are shown by hollow circle points. The heavy dash-dot line shows their approximate average trend. The values of penetration resistance at 2-1/2-foot intervals of depth were averaged from several holes and are listed in the circles on the extreme left of the figure. The curve on the right is an approximate computation of the overburden pressures. From Figure 7 and the relative density scale at the top of Figure 8, the relative densities predicted from penetration resistance values are shown by three curves. The curve shown by solid dot points was obtained from the heavy lines in Figure 7 and indicates densities closest to the measured densities. The curve shown by solid triangular points is from the Terzaghi and Peck correlation and indicates lower than measured densities for all points. The third curve using the findings for saturated fine sand in Figure 7 shows excessively high values. Although the penetration tests did not indicate a general increase in resistance below the water table, the excessive densities shown by the saturated sand correlation curve would indicate the advisability of using the more conservative unsaturated curves (heavy lines) given in Figure 7.

CONCLUSIONS

1. Penetration resistance increases with an increase in either relative density or overburden pressure. Since the principal object of the penetration test in cohesionless sands is to evaluate density, the effect of overburden pressure at the depth of the test must be taken into account.

2. An increase in rod length appears to have relatively small effect when compared to the effect of overburden pressure. It is considered to be within the accuracy of the test itself and is found to be partially counteracted by the effect of rod weight due to increasing length. This finding is limited to depths less than 65 feet which were covered by this study.

3. The apparent effect of rod weight alone is to reduce the penetration blows per foot as weight increases. This is particularly true at low densities when resistance is low. This effect is small in comparison to overburden effect and it would be on the safe side to use the correlation values for the case of no-weight effect.

4. The effect of saturation in these tests in a relatively small laboratory tank compared to field conditions was to show lower penetration resistance. However, it is considered doubtful that the laboratory model truely represents water table conditions in a natural deposit. Therefore, it is considered advisable to use the correlations for the air-dry and moist sands so as not to falsely predict high densities.

5. Finally, the correlations for air-dry and moist cohesionless sands (shown by the heavy curves in Figure 7) are most recommended for predicting densities from penetration resistance values and giving consideration to the important effect of overburden pressure. The results of these curves showed reliable correlation in a trial test in a natural field deposit.

ACKNOWLEDGMENTS

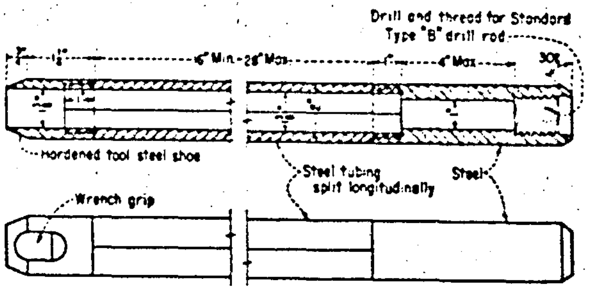
Acknowledgment is given to Messrs. J. Merriman and E. R. Williams for their assistance in performing these tests.

REFERENCES

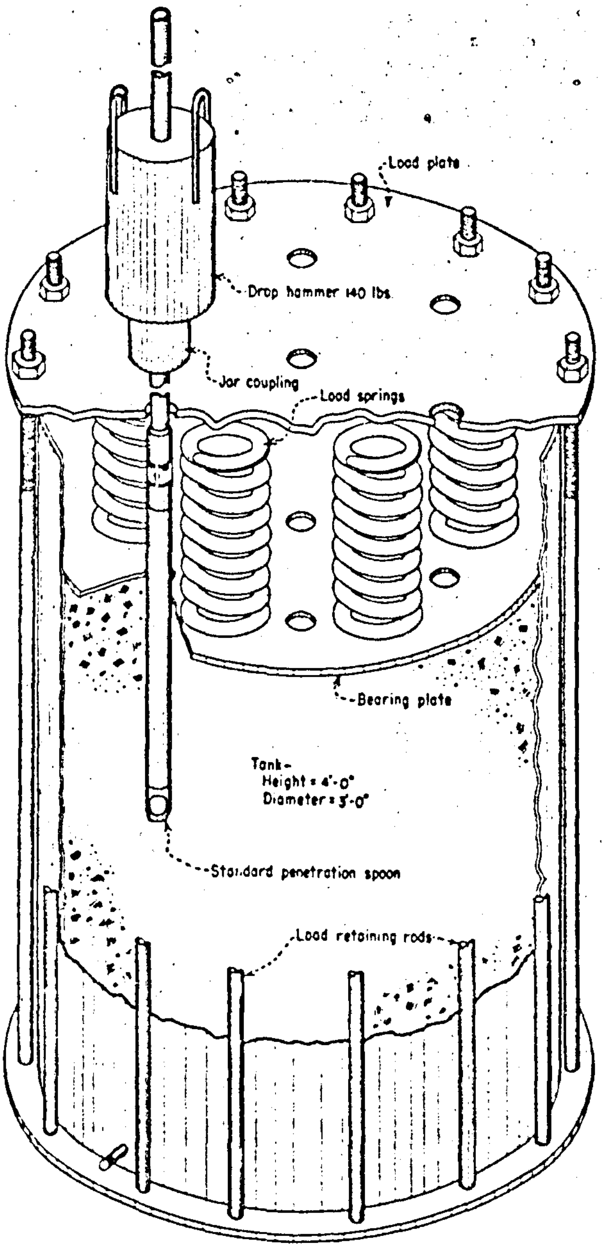
[3] Terzaghi and Peck, Soil Mechanics in Engineering Practice, John Wiley & Sons, N. Y., 1948, pp 265.

[4] Terzaghi and Peck, op. cit., pp 425 and 426.

[5] Terzaghi and Peck, op. cit., pp 294.



(a) DETAILS OF STANDARD PENETRATION SPOON



(b) TEST TANK FOR LABORATORY TESTS

FIGURE 1 - TESTING EQUIPMENT

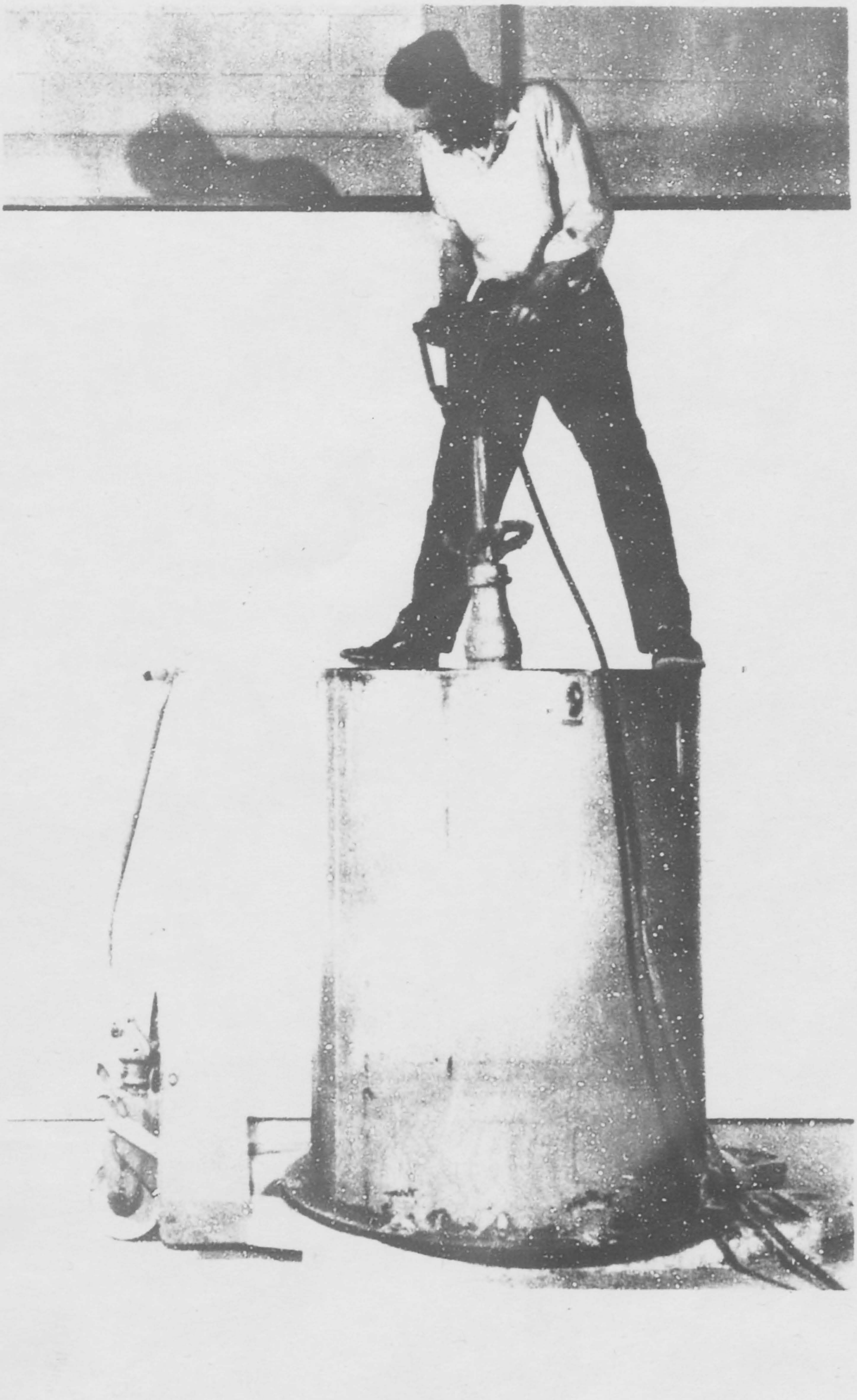


Figure 2 COMPACTING SAND BY VIBRATION

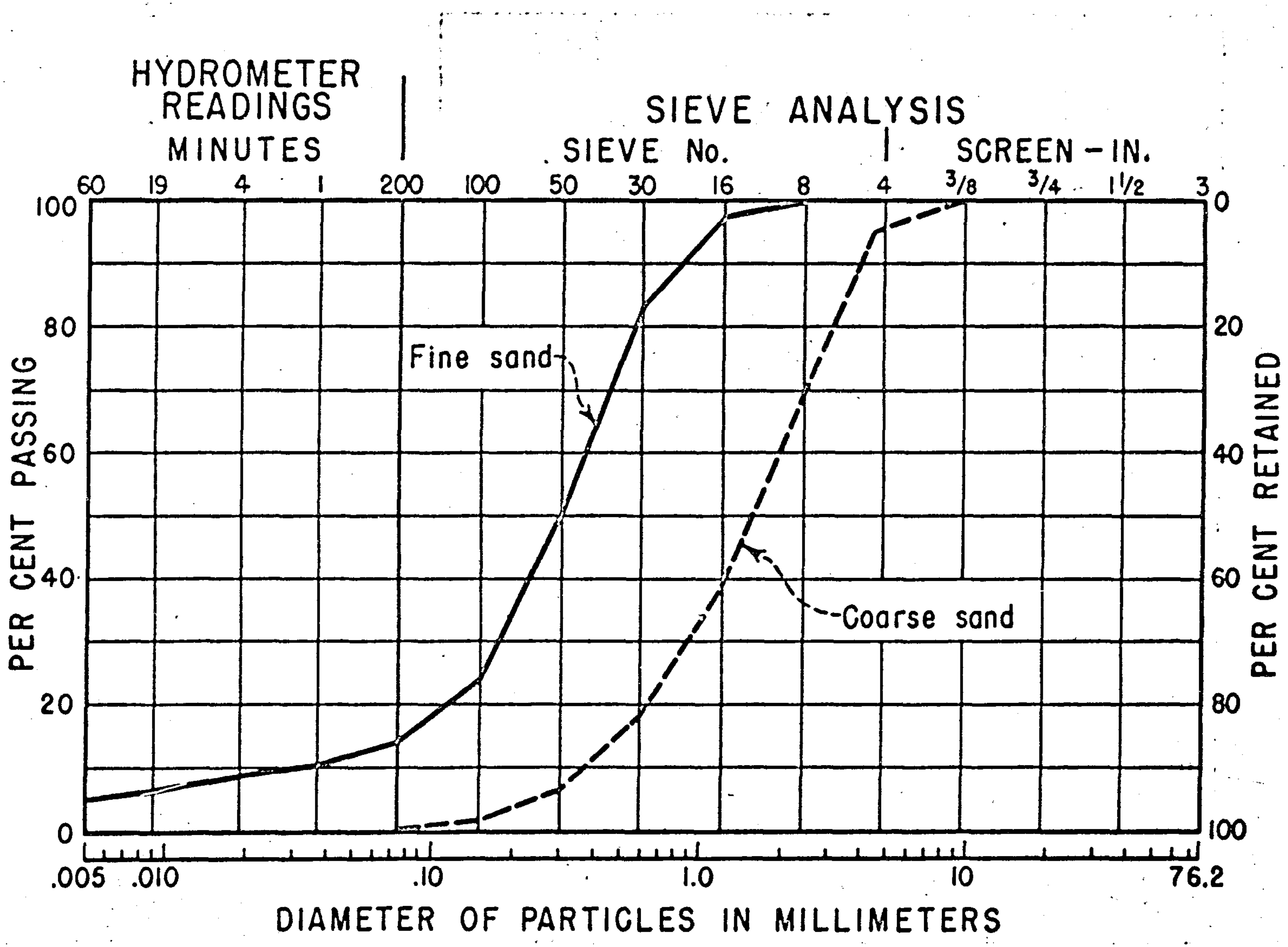


FIGURE 3 — GRADATION TESTS OF THE SANDS USED IN THE PENETRATION STUDIES

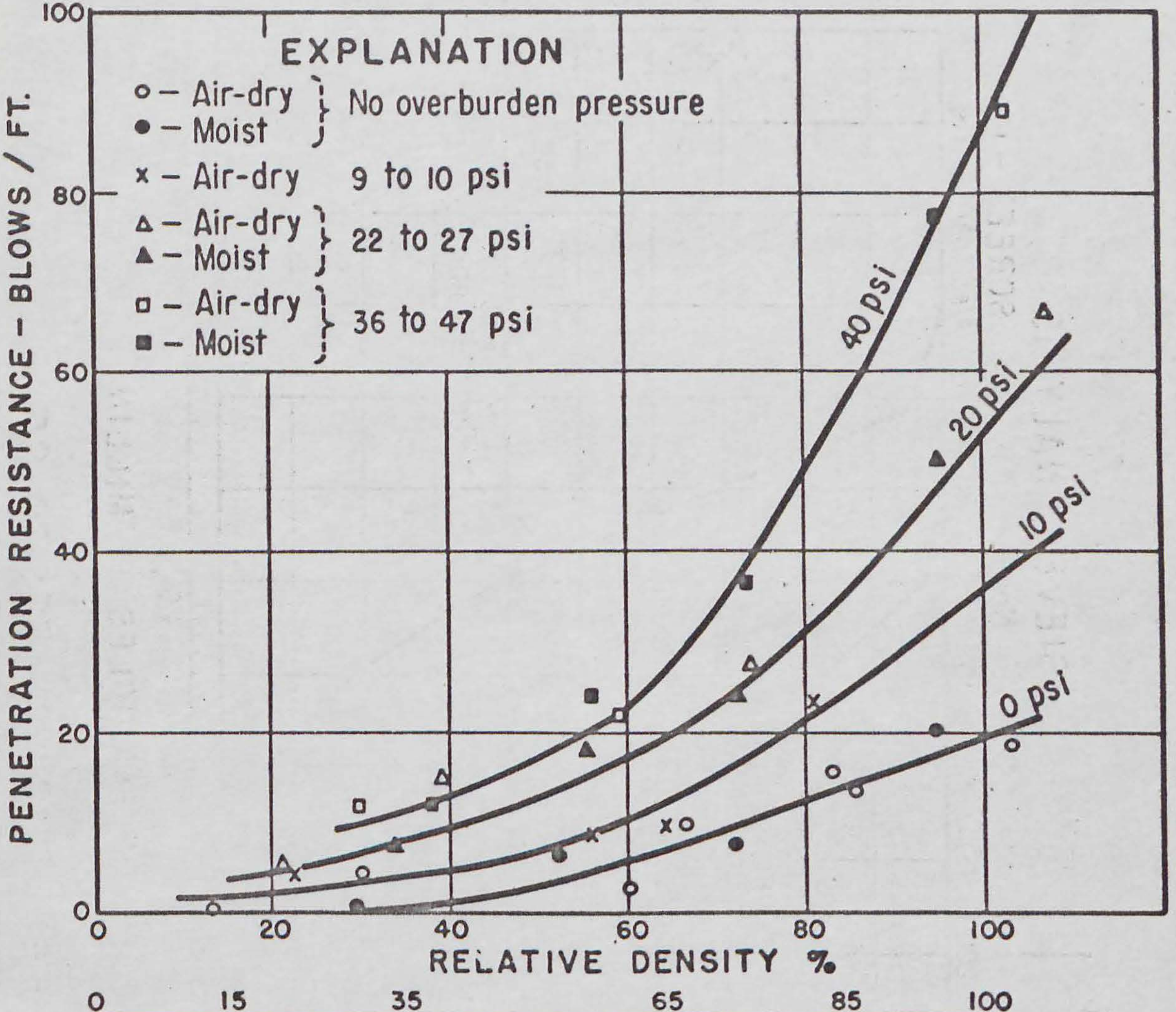


FIGURE 4 - EFFECT OF OVERBURDEN PRESSURE FOR COARSE SAND, AIR-DRY AND MOIST

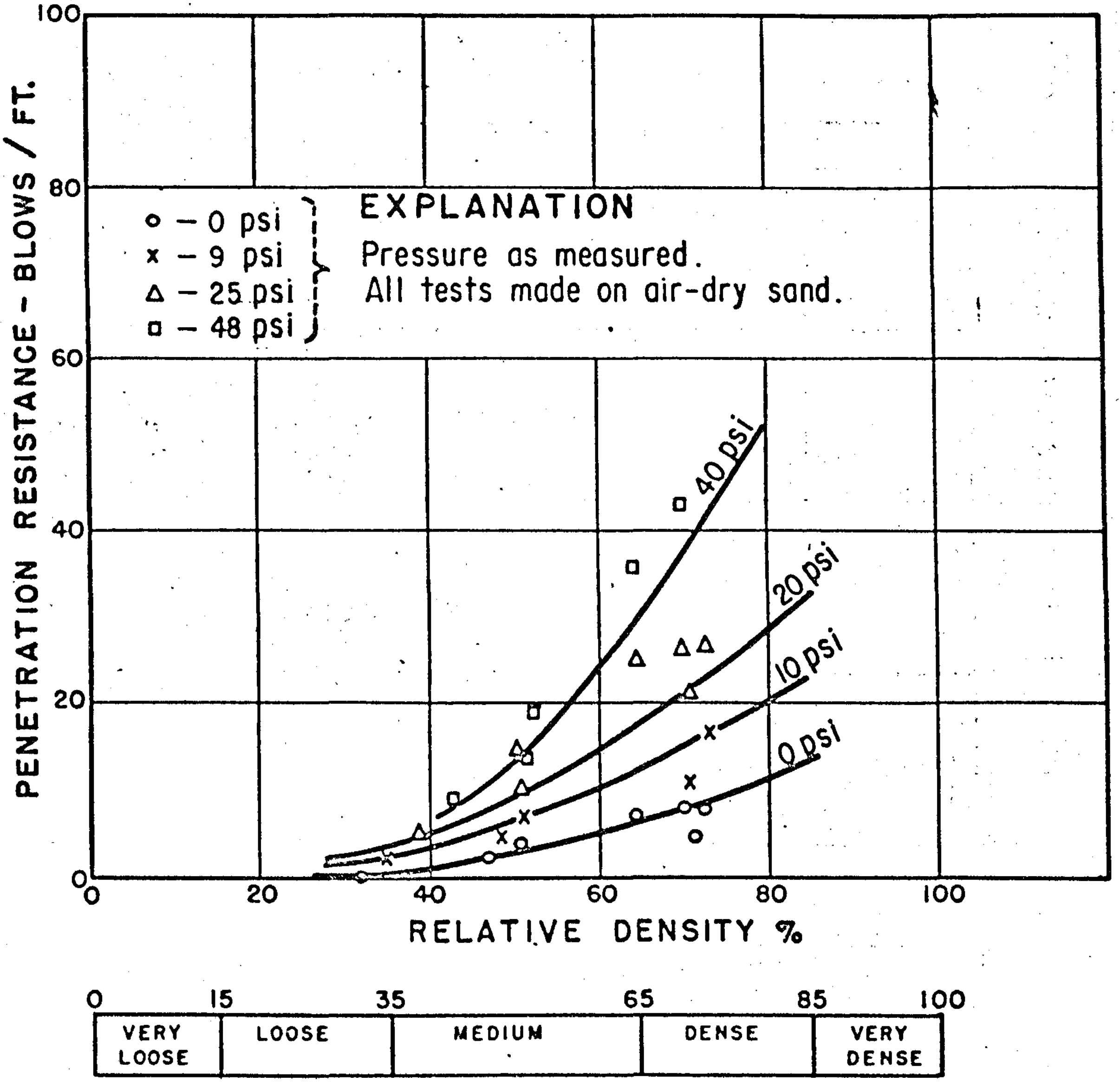


FIGURE 5 – EFFECT OF OVERBURDEN PRESSURE FOR FINE SAND, AIR-DRY

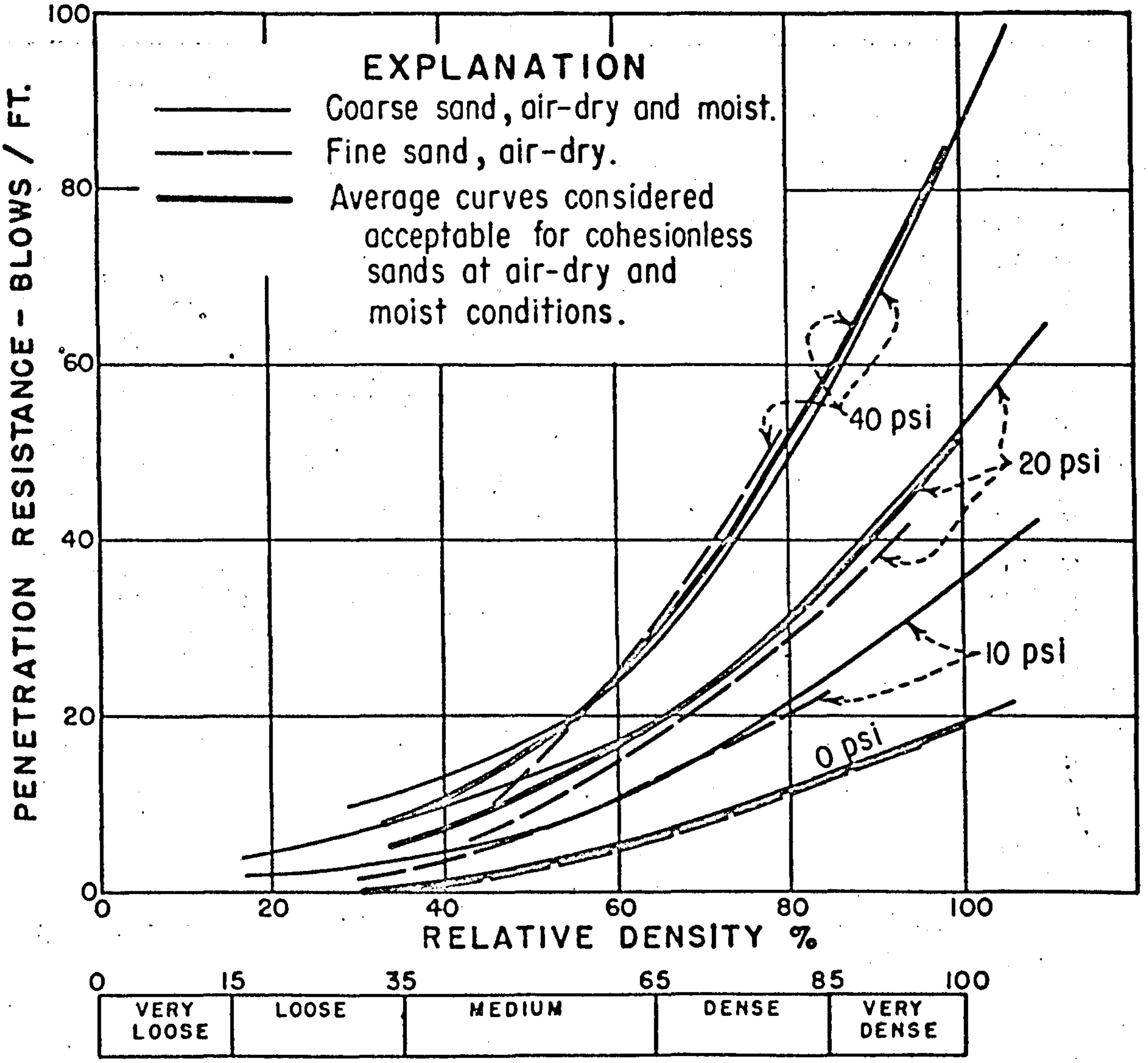


FIGURE 6-COMPARISON OF THE FINE AND COARSE SANDS AND A DETERMINATION OF AVERAGE CURVES

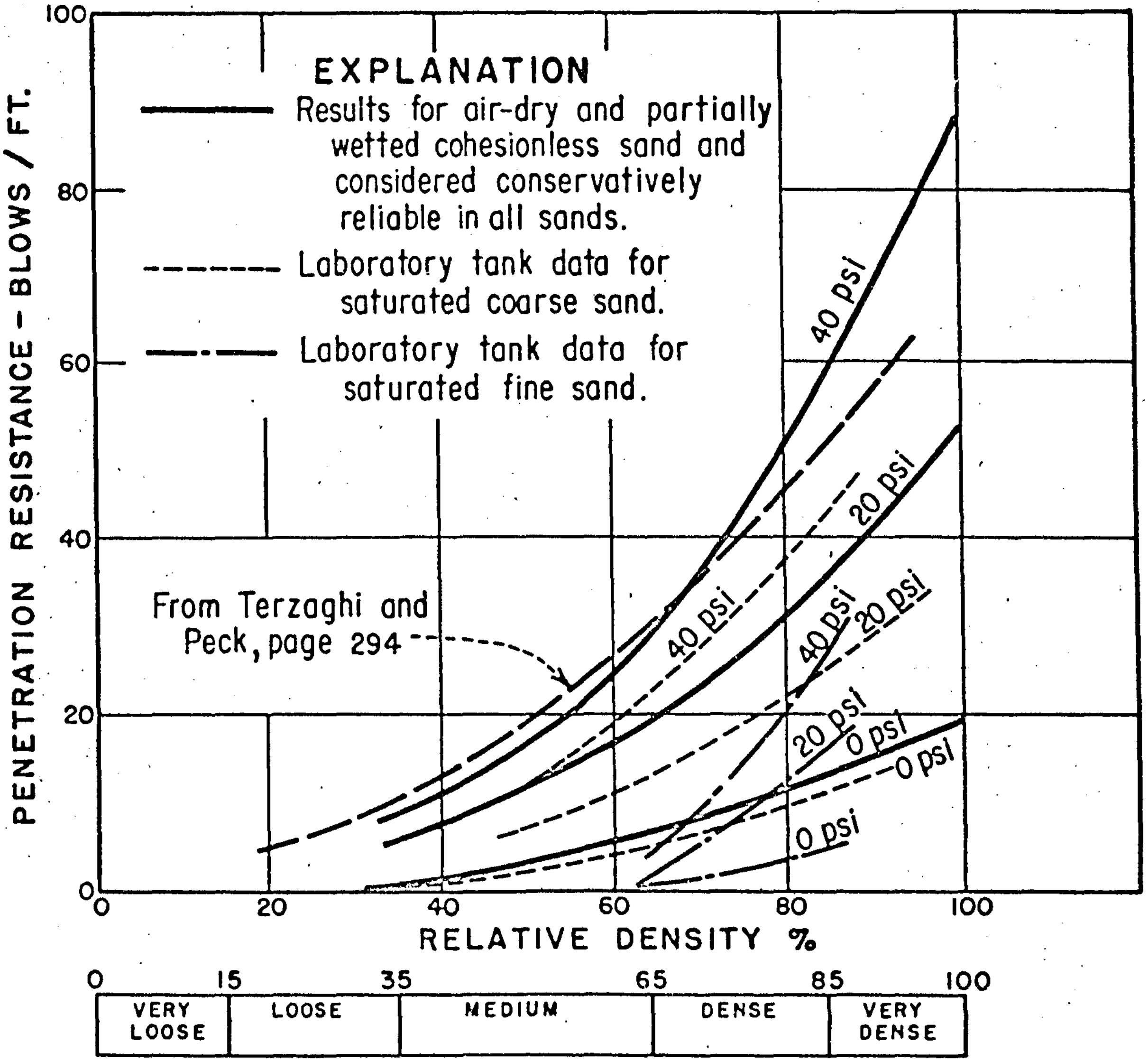


FIGURE 7 – GENERAL RELATIONSHIP BETWEEN PENETRATION RESISTANCE AND RELATIVE DENSITY FOR COHESIONLESS SAND

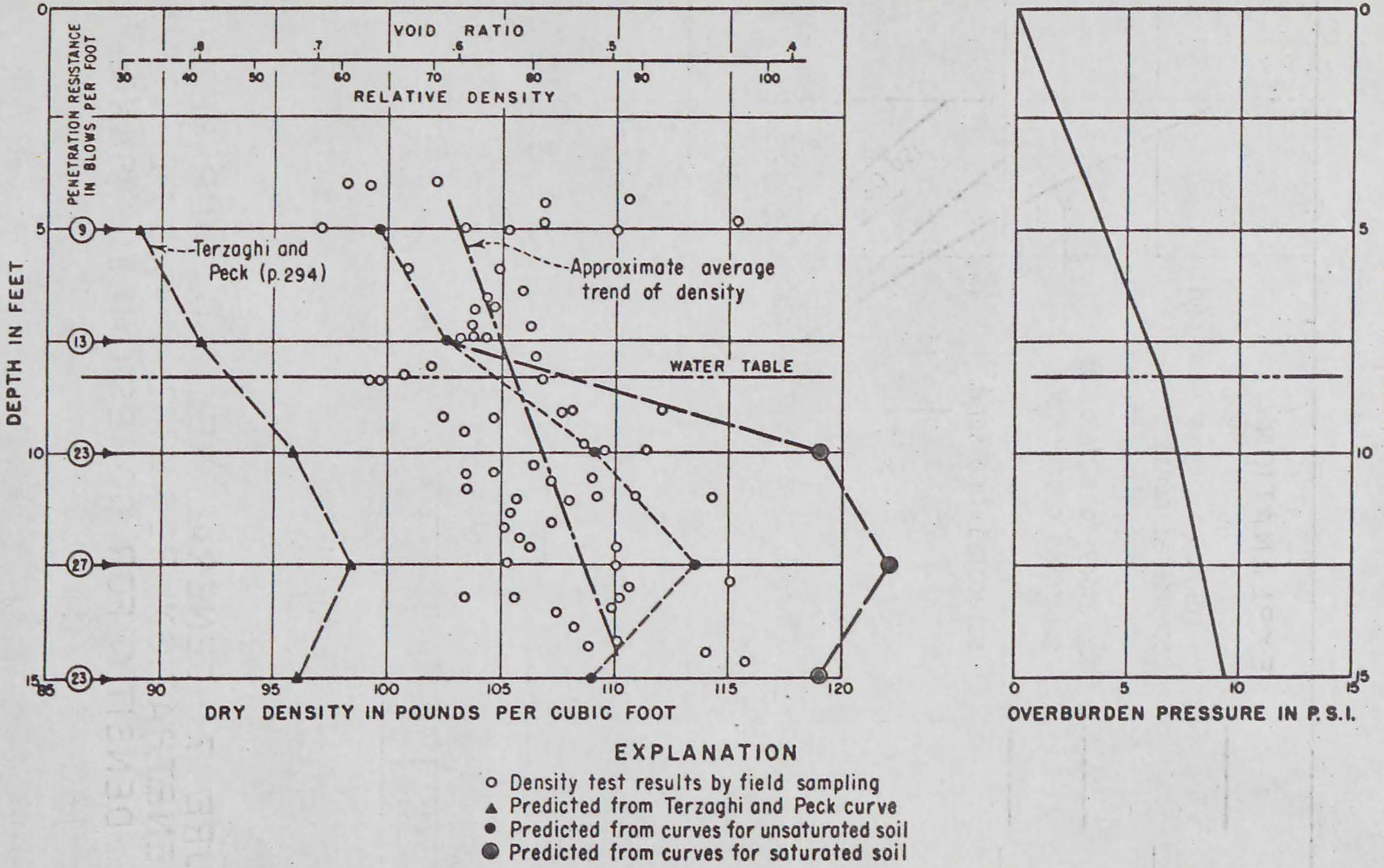


FIGURE 8- FIELD TESTS TO EVALUATE CORRELATION CURVES OBTAINED FROM THE RESEARCH STUDY

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