Experiences With Penetrometers, With Particular Reference to the Standard Penetration Test

Expériences avec des pénétromètres portant en particulier sur l'essai de pénétration normalisé

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Summary

The standard penetration test is widely used for determining allowable bearing pressures of cohesionless soils. There has grown a tendency to place undue reliance on the results of this test, although TERZAGHI and PECK do not regard it as giving anything more than an approximate guide. The common practice in the U.K. is to carry out the standard penetration test in holes sunk by shelling, although the test was originally designed for use in small diameter wash borings. In this Paper the results of standard penetration tests in sands and gravels are compared with data obtained from dynamic and static cone penetrometer probings and some plate bearing tests. It is shown that unavoidable disturbance of the soil in shelling, particularly in the denser soils, may affect the results obtained with the standard penetration test, emphasising the necessity for great care in the boring procedure if reliable data on relative density is to be obtained.

Attention is drawn to other in-situ tests, e.g. dynamic and static cone penetrometer probings, which do not require to be carried out in boreholes. It is shown that a different procedure should be adopted for determining the bearing capacity of submerged sand from dynamic penetration probings than that given by TERZAGHI and PECK (1948) for the standard penetration test.

The results of some tests on fly-ash, indicate that the relationship between dynamic cone resistance and bearing capacity of a soil is not a unique relationship for all soils, but will depend on the type of soil.

Sommaire

L'essai standard de pénétration est largement utilisé pour déterminer la charge autorisée des sols sans cohésion. Une tendance s'est même développée qui vise à placer une confiance excessive dans les résultats de cet essai, quoique TERZAGHI et PECK ne le regardent que comme un guide approximatif. La pratique, habituelle en Grande-Bretagne est de réaliser l'essai de pénétration normalisé dans des trous forés par tubage bien que l'essai fut à l'origine prévu pour des sondages par injections à faible diamètre. Dans ce rapport les résultats des essais de pénétration normalisés dans les sables et graviers sont comparés avec les données fournies par des sondages statiques et dynamiques par pénétromètre à cône et par quelques essais de charge sur plaque. Il est démontré qu'un remaniement inévitable du sol au cours du forage par tubage, particulièrement dans les sols denses, peut affecter les résultats obtenus avec l'essai de pénétration normalisé mettant en lumière la nécessité de précautions spéciales au cours de la procédure de forage pour le cas où doivent être obtenues des données sûres de densité relative.

L'attention est portée sur d'autres essais in situ, e.g. forages statiques ou dynamiques par pénétromètre à cône, lesquels n'exigent pas d'être effectués dans des trous de forage. On montre qu'il faut adopter, pour déterminer la capacité portante de sables submergés au moyen de forages par pénétration dynamique un processus différent de celui indiqué par TERZAGHI et PECK (1948) pour l'essai de pénétration normalisé.

Les résultats de quelques essais sur cendres volantes indiquent que la relation entre la résistance dynamique au cône et la capacité portante d'un sol n'est pas la même pour tous les sols, mais dépendra du type de sol essayé.

1. Introduction

During the course of some site investigations the opportunity was taken to compare the results obtained with a number of different types of in-situ penetration tests. The types of tests made at each site depended upon the site circumstances and they are summarised in Table 1 together with the details of the test procedure. The investigations were carried out primarily in non-cohesive soils — sands and gravels. The results of some tests on a slightly cohesive granular material — fly-ash — are included for comparison. Typical grading curves of the materials in which penetration tests were made are given in Fig. 1.

2. Method of Boring

The general practice in the U.K. for boring through sands and gravels is to remove the soil by means of a "shell". In the cases included in this Paper the boreholes were lined with casing, the cutting shoe of the casing being kept at or slightly below the bottom of the hole as the boring proceeded. To reduce to a minimum any disturbance resulting from the shelling action during these investigations, the shell used for the boring was smaller than that normally required for the particular size casing, e.g. a 6 in. dia. shell was used inside 8 in. dia. casing. In addition, the travel of the shell during the boring operation was kept as small as practicable.

3. Dynamic Penetration Tests

(a) *Comparison between standard (cone) penetration test and dynamic penetrometer*—At Site 1 a series of dynamic penetrometer probings were carried out at each of 15 piers for a proposed bridge. These probings were used as a cheap and rapid method of exploring the variation in relative consistency of the sand and gravel deposits and to enable the more expensive borings to be located at critical conditions. It was intended to correlate the probings with standard or standard (cone) penetration tests [1] made in the boreholes. A typical set of results at one of the pier locations is given in Fig. 2. The results of the standard (cone) penetration tests did not reflect the actual variation in relative density of the sand and gravel, which varied from very dense at the top of the deposit to medium dense at the bottom.

Site 2 was a case where a large number of standard borings had been sunk and some plate bearing tests carried out in

[1] Information obtained from tests in sands at a number of sites has shown that over a large range of penetration resistances the average values obtained with the standard and standard (cone) penetration tests were of the same order.

Table 1
Summary of types of tests made at each site
Résumé des types d'essais à chaque chantier

Site	Dia. of Borehole	Types of Tests Made[1] A	B	C	D	E	Type of Soil	Remarks
1	8 in.		×	×		×	Sand and gravel	Soil too coarse for Test D
2	10 in.		×	×		×	Gravel	Soil too coarse for Test D
	6-8 in.	×	×		×[2]		Fine to medium sand	
3	8 in.	×	×		×		Silty sand with gravel overlying sand with some gravel	
4	—			×	×	×	Fly-ash (silty sand grading)	

[1] Details of test procedure :
- A. Standard penetration test : 2 in. dia. split-spoon sampler ; 140 lb. hammer with 30 in. drop (Terzaghi and Peck, 1948).
- B. Standard (cone) penetration test ; as (A) but with a 60° cone in place of the cutting shoe (Palmer and Stuart, 1957).
- C. Continuous dynamic cone penetrometer : 2·5 in. dia. 60° cone ; BX drill rods, 1·9 in. o.d. ; 350 lb. hammer with 24 in. drop.
- D. Static cone penetrometer : Dutch deep-sounding machine ; 1·4 in. dia., 60° cone.
- E. Plate loading tests.

[2] When the load on the apparatus reached its limiting value, a 6 in. dia. borehole was sunk to enable the test to continue at greater depth.

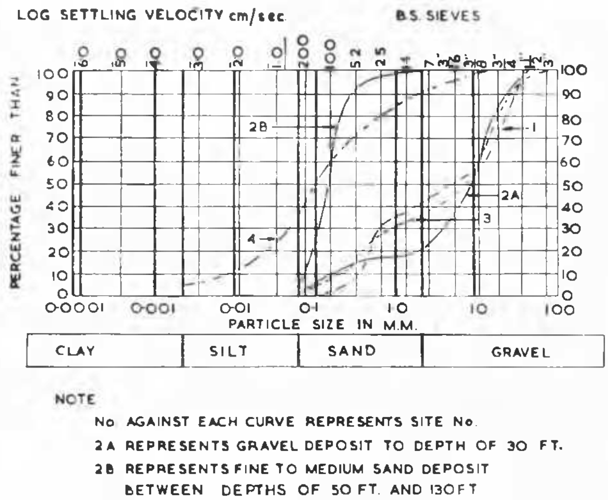


Fig. 1 Typical grading curves.
Types de courbes granulométriques.

a deep test pit excavated in the upper gravel deposit. The opportunity was taken to make five dynamic penetrometer probings in the vicinity of the test pit for comparison with the other tests. The variation of penetration resistance with depth was similar in all the probings and the average curve is plotted in Fig. 3. At this particular site the limiting penetration of the dynamic probe was reached at a depth of 27 ft. The results of all the standard and standard (cone) penetration tests made in the borings are also given in Fig. 3. The scatter in the results of the standard (cone) penetration tests in the upper gravel deposit was large and similar over the site as a whole, and it is not possible to draw any reasonable average curve. The resistance measured with the standard (cone) penetration test tended to be much lower than that measured with the dynamic probe.

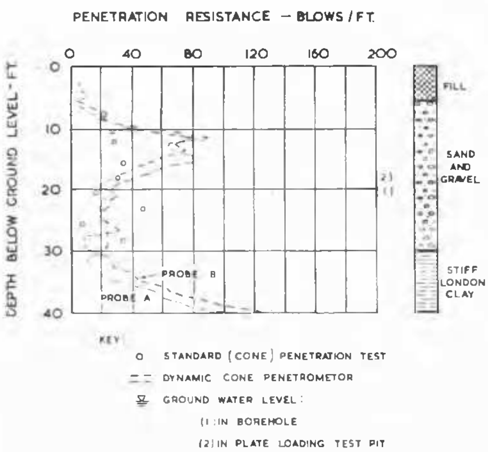


Fig. 2 Typical set of standard penetration tests and dynamic penetration tests at Site 1.
Ensemble type d'essais de pénétration normalisés et d'essais de pénétration dynamique, chantier 1.

(b) *Correlation between dynamic penetration resistance and bearing capacity*—Plate bearing tests were made at various depths in test pits at both Sites 1 and 2. At all plate test levels the width of the pit was greater than 5 × diameter

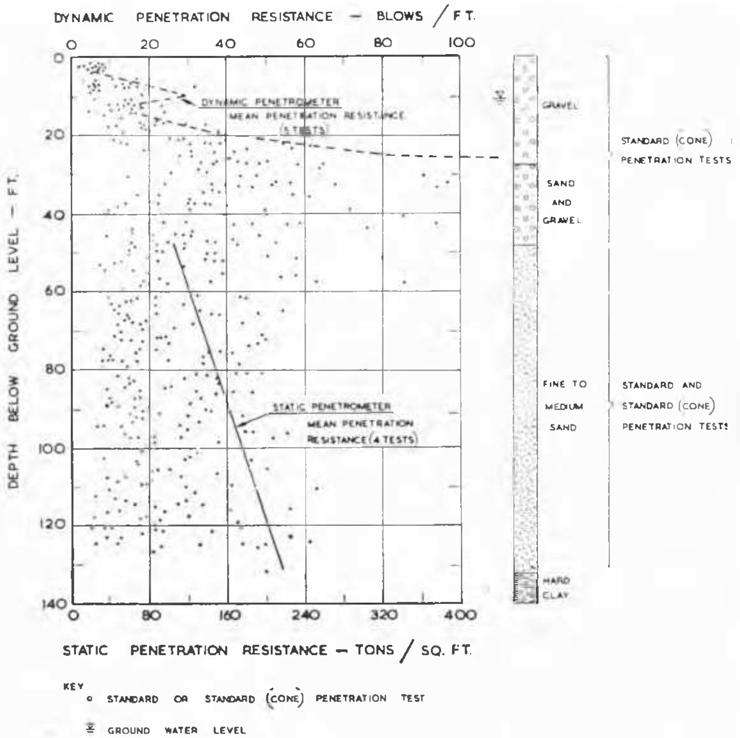


Fig. 3 Comparison of standard penetration tests and dynamic and penetration tests at Site 2.
Comparaison d'essais de pénétration normalisés et d'essais de pénétration dynamique et statique, chantier 2.

of the plate. In each test the load was applied in increments, which were maintained for periods up to 15 minutes before being increased. Where a test was to be carried out below the ground-water table the water level in the pit was lowered to the level of the test plate by pumping from shallow wells (Site 1) or well-points (Site 2) located outside the pit. The results of the loading tests are plotted in Figs. 4 (a) and (b) and are summarised in Table 2. Since different sizes of plates were used at the two sites it is not possible to compare their results directly. However, in both cases the soil possessed negligible cohesion and the ultimate bearing capacity of the plate (q_f), acting as a surface foundation, is given by TERZAGHI's equation :

$$q_f = \left(\frac{\gamma}{2} \cdot N_\gamma\right) \cdot B \qquad \ldots\ldots \quad (1)$$

where, γ = bulk density of soil below plate
N_γ = bearing capacity factor
B = diameter or width of footing

That is, for the soil conditions at each plate test, q_f is directly proportional to B. For convenience of correlation, this relation was used for the tests at Site 2 to estimate the corresponding value of q_f for a 12 in. plate, which is commonly used as a standard size for plate bearing tests.

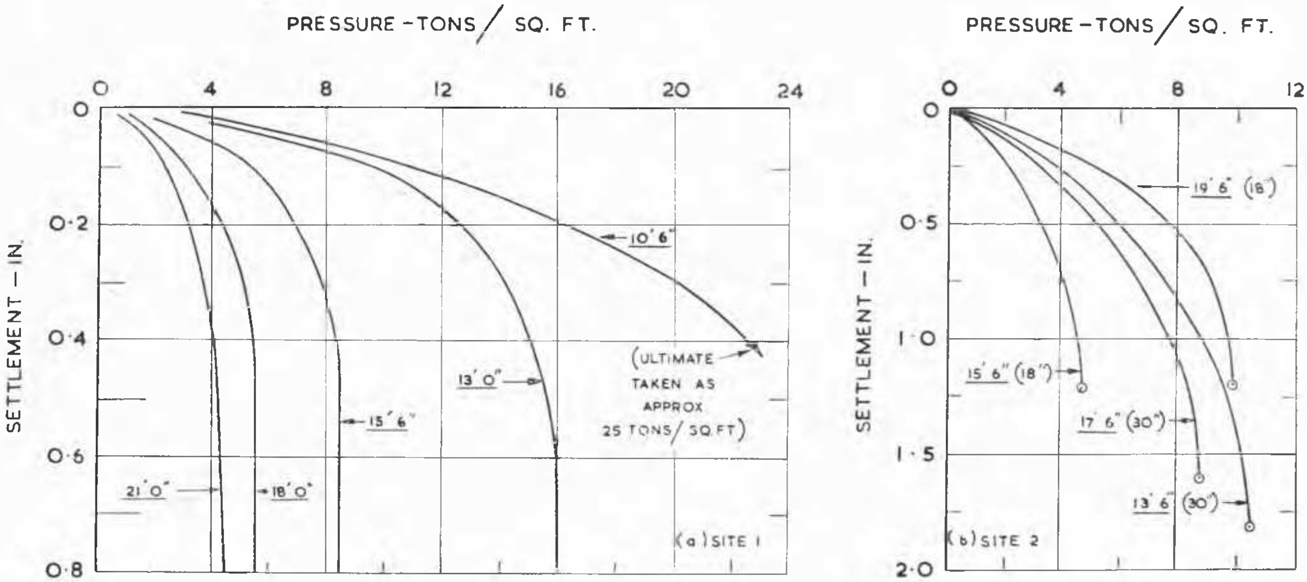
Table 2

Summary of plate bearing test results
Résumé des résultats d'essais de charge sur plaque

Depth of Test	Water Level	*Penetration Tests*[1] Standard (Cone) Penetration Test blows/ft.	*Penetration Tests*[1] Dynamic Penetrometer blows/ft.	*Plate Bearing Tests* Size of Plate	*Plate Bearing Tests* Ultimate Bearing Capacity ton/sq.ft.	*Plate Bearing Tests* Equivalent Bearing Capacity for 12 in. Plate[2] ton/sq.ft.	Wet Density lb/cu.ft.	Type of Soil
Site 1								
10′6″	18′0″	29	75	— 12″ sq.	25	25	130	Sand and gravel
13′0″	18′0″	29	70	— 12″ sq.	16	16		
15′6″	18′0″	35	58	— 12″ sq.	8·5	8·5		
18′0″	18′0″	32	32	— 12″ sq.	5·5	5·5		
21′0″	21′0″	17	25	— 12″ sq.	5	5		
Site 2								
13′6″	13′6″	22	18	30″ dia.	11	4·4	130	Gravel
15′6″	15′6″	25	22	18″ dia.	5	3·3		
17′6″	17′6″	28	31	30″ dia.	9	3·6		
19′6″	19′6″	30	37	18″ dia.	10	6·7		
Site 4								
2′9″	3′0″	—	11	12″ dia.	8	8	93	Fly-ash

[1] Average value obtained from the borings and probings located near to the plate bearing tests and at corresponding depths.

[2] Based on equation : $q_f = \left(\frac{\gamma}{2} \cdot N_\gamma\right) \cdot B$.



NOTE:
10′6″ INDICATES LOAD TEST AT DEPTH OF 10′6″ BELOW GROUND LEVEL
ALL TESTS AT SITE 1 WERE MADE ON 12 IN x 12 IN PLATES
(30″) INDICATES DIA OF PLATE AT SITE 2

Fig. 4 Plate loading tests at Sites 1 and 2.
Essais de charge sur plaque, chantiers 1 et 2.

The values of ultimate bearing capacity are plotted against the corresponding penetration resistance (i.e. the average value for the depth B below the plate) in Fig. 5. For these particular tests on sand and gravel there is a reasonably good correlation between ultimate bearing capacity and the penetration resistance measured by the dynamic penetrometer probings. The Author makes no attempt in this Paper to establish a general relationship for the interpretation of dynamic penetrometer tests. The penetration resistance of a granular deposit to a particular probing tool is a function of the relative density and overburden pressure at the depths probed. Since the plate bearing tests made at Sites 1 and 2 were carried out for the condition of zero overburden pressure, the empirical relationship between ultimate bearing capacity and penetration resistance of the submerged sand and gravel, as indicated by the curve in Fig. 5, is given for comparative purposes only. There is insufficient experimental data to establish whether this relation is independent of the position of the water table. The trend of the results plotted in Fig. 5 indicates that the bearing capacity of a footing on submerged sand and gravel is much greater than one-half of the value obtained with dry sand and gravel having the same resistance to the dynamic penetration probe. Thus a different procedure should be adopted for determining the bearing capacity of submerged sand from dynamic penetration probings than that given by TERZAGHI and PECK (1948) for the standard penetration test.

The results plotted in Fig. 5 for the standard (cone) penetration tests show a larger scatter. Where the plate bearing tests showed the sand and gravel to be in a medium dense state, the penetration resistance values (blows/ft.) given by the standard (cone) penetration tests were of the same order as those given by the dynamic penetration probes [2]. But, where the sand and gravel was shown by the plate bearing tests to be in a dense or very dense state, the relatively low resistances measured in the standard (cone) penetration tests suggest that the soil below the borehole had been loosened to a significant depth.

[2] This fact is a coincidence of the design characteristics of the two types of dynamic penetration tests.

4. Static Penetration Tests

(a) *Comparison with the standard and standard (cone) penetration tests*—A series of four tests with the Dutch deep-sounding machine was made in the deep sand deposit at Site 2, for comparison with the standard and standard (cone) penetration tests. The results of these tests are given in Fig. 3. The results of the standard penetration tests showed a large scatter in each of the boreholes and it was not possible to infer any definite trend with depth. While each of the tests with the static penetrometer also showed some large variations of resistance with depth, their results showed a much more definite trend for the resistance to increase with depth, as shown by the average curve of the four tests. For comparison with the results quoted by MEYERHOF (1956) the scale of static resistance has been drawn as :

$$\text{static resistance (ton/sq.ft.)} = 4 \times \text{dynamic resistance (blows/ft.)}$$

At Site 3 the soil conditions varied from one part of the site to another. The results of a deep-sounding test are shown in Fig. 6, together with the results of the standard and standard (cone) penetration resistance tests made in a nearby borehole. The standard penetration resistance tests did not reflect the same pattern of penetration resistance as shown by the static cone test; in general, the standard penetration tests in the borehole compare with the lower values of static cone resistance in the various horizons.

(b) *Comparison with the dynamic penetrometer*—At Site 4, fly-ash fill had been placed to a depth of about 5 ft. A number of tests were made with the Dutch deep-sounding machine and the dynamic cone penetrometer. The two penetrometers

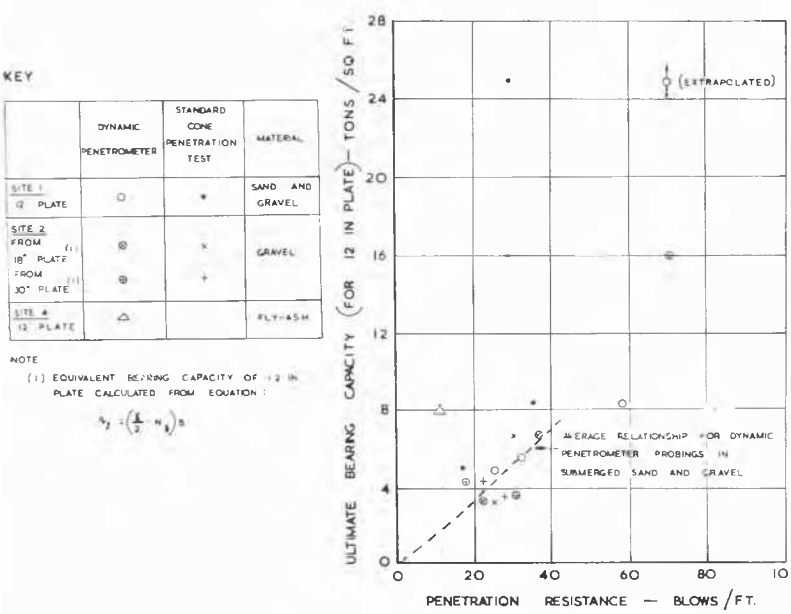


Fig. 5 Relation between ultimate bearing capacity of surface foundations and dynamic penetration resistance.

Relation entre la capacité portante maxima des fondations en surface et la résistance dynamique de pénétration.

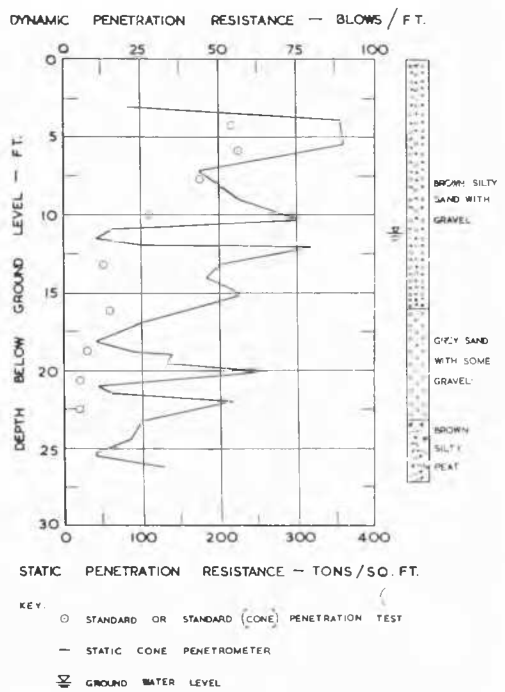


Fig. 6 Comparison of standard penetration tests and static penetration tests at Site 3.

Comparaison entre des essais de pénétration normalisé et des essais de pénétration statique, chantier 3.

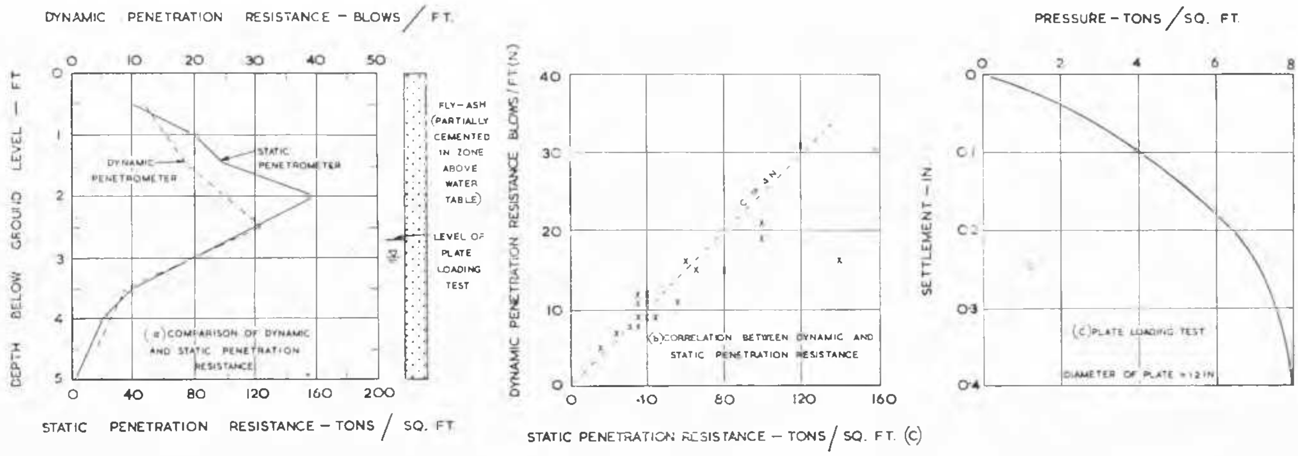


Fig. 7 Results of tests on fly-ash at Site 4.
Résultats d'essais sur cendres volantes, chantier 4.

showed a similar pattern of variation of resistance with depth, a typical pair of results being shown in Fig. 7 (a). A comparison between the static resistance and the corresponding dynamic resistance at the same depth in adjacent pairs of tests is given in Fig. 7 (b). There was a good correlation between the two tests, except where the fly-ash appeared to possess its maximum cohesion. This cohesion was the result of a natural comenting action which developed after the fly-ash had been placed.

5. Load Bearing Test on Fly-ash at Site 4

A load bearing test on a 12 in. dia. plate was made on the fly-ash at Site 4. The result of this test is given in Fig. 7 (c). As the ground-water table was only 3 in. below the plate, the test corresponded approximately to the submerged condition. The average cone resistance of the fly-ash corresponding to this test location was 45 ton/sq.ft. in the static test and 11 blows/ft. in the dynamic test. The result of the loading test is plotted in Fig. 5 for comparison with the loading tests on the sand and gravel. It should be borne in mind that the fly-ash was slightly cohesive (the cohesion was probably of the order of 100 lb/sq.ft.). Although it is not possible to draw any definite conclusions from a single test result, it is evident that the relation between ultimate bearing capacity and dynamic cone resistance will vary between different types of soil.

6. Conclusions

It is emphasised that the standard and standard (cone) penetration tests quoted in this Paper were all made in borings 6 in. or greater in diameter and sunk by means of a shell. It was found that these tests did not give a reliable indication of the relative density or bearing capacity of the sand and gravel deposits. This was particularly evident where the plate bearing tests or the static penetration tests showed the sand and gravel to be in a dense or very dense state; in such cases, the results of the standard and standard (cone) penetration tests indicated a less dense condition This indicates the unavoidable disturbance created by the shelling operation.

The dynamic penetrometer probings gave a reliable indication of the relative consistency of the sand and gravel deposits. The tests have confirmed that this tool is an inexpensive and rapid method of exploring the variation in relative density of sand and gravel deposits. Friction on the rods was not significant. The trend of the results plotted in Fig. 5 indicates that the bearing capacity of a footing on submerged sand and gravel is much greater than one-half of the value obtained with dry sand and gravel having the same resistance to the dynamic penetration probe. Thus, with dynamic penetration probings a different procedure should be adopted for determining the bearing capacity of submerged sand than that given by Terzaghi and Peck (1948) for the standard penetration test.

The test on the slightly cohesive granular material (fly-ash) at Site 4 indicates that the relationship between the bearing capacity of a footing and the dynamic penetrometer resistance depends on the type of soil.

7. Acknowledgments

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