Bearing Pressure and Penetration Tests on Typical Soil Strata in the Region of the Hirakud Dam Project

Essais de force portante et de pénétration sur des sols typiques avoisinant l'emplacement du barrage projeté de Hirakud, Indes

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Summary

The investigations on load bearing capacity and penetration resistance of the different soil strata, occurring in the Hirakud region, were carried out with the object of designing suitable foundations for canal headworks and major cross-drainage works like aqueducts, etc. It has been possible to interpret the penetration test data in terms of that obtained from the direct loading tests and that correlation has helped in the development of a workable technique for conducting exploration of foundation conditions at the sites of those works.

Sommaire

Des investigations ont été entreprises sur la force portante et la résistance à la pénétration des différentes couches de sol de la région de Hirakud en vue d'étayer le projet des sous-fondations du réseau de canaux et des principaux travaux de drainage, tels que aqueducts, etc. Il a été possible d'interpréter les résultats des essais de pénétration en fonction des résultats des essais de charge directe et cette corrélation a permis de déterminer la technique la plus indiquée pour la conduite de l'exploration des sols de fondations de l'emplacement envisagé.

Introductory

General: The Hirakud Project under construction in the State of Orissa, as a first step in the development of the Mahanadi River Valley, consists of a dam across that river with hydro-electric installations and gravity and lift canals, taking off from the reservoir on either side, to irrigate large tracts of land. Due to the uneven terrain and the presence of big and small drainage channels in the area to come under the command, the construction of a large number of cross-drainage works is necessitated. In order to economize on the design of those structures, it was considered of interest to conduct systematic exploration of the foundation conditions at the sites of those works. Such investigations were considered all the more necessary on account of the peculiar soil and sub-soil water-table features, the latter being subject to rapid fluctuations on account of the easy drainability of soil of that area.

Soil, meteorological and other features of the area: Except for a stretch of alluvial deposit along the banks of the streams, the soil of the Hirakud region is mainly derived from metamorphic gneiss and schist and manifests features similar to the soils of the semi-humid tracts. The main strata are top soil, moorum[1]), weathered rock (highly weathered in its top portion and becoming less and less weathered with depth) and finally parent rock, in that order. On account of the undulating terrain and the peculiar mode of soil formation, the relative thicknesses of those three soil strata vary from place to place from a few inches to a few feet depending upon the location and prevailing drainage conditions.

The mean annual rainfall in the area is about 54 inches, most of which comes during the monsoon period from mid-June to mid-October. A precipitation of 3 to 5 inches might occur on a number of days during that period and the intensity of rain is fairly high at times. During that rainy period the ground remains fully saturated and the water-table fluctuates near about the ground surface. The water-table falls, however, rapidly during the period October to December and then at a relatively slower rate to its lowest level to about the beginning of the next monsoon season.

The trend of movement of the subsoil water-table coupled with the change of soil strata along the depth of the profile can be expected to influence markedly the load bearing capacity of the various soil strata in that area.

A large number of direct loading and penetration tests were carried on each of the three main soil strata described above in both wet and dry seasons. The field tests were supplemented

[1]) Moorum signifies deposits of coarse-graded soil such as hillwash material containing varying amounts of gravel with clay binder.

by such laboratory tests as triaxial shear and unconfined compression on undisturbed soil samples from experimental sites and other identification tests to bring out the utility of those tests for estimating the bearing capacity of soils.

The present paper describes the results of the various investigations and the simpler penetration test technique employed for estimating the bearing capacities of soils for the purpose of designing foundations.

Experimental Technique

Load bearing tests: The equipment employed for that test consists of a rigid column with one foot square base, a loading stage, (8 ft. by 2½ ft.) four dial gauges reading upto one thousandth inch and a number of four feet long by one and a quarter inch diameter steel rods each weighing 20 lbs. for purposes of loading. The standard load test procedure i.e., a 5 feet by 5 feet pit and a 200 lbs. incremental rate of loading (*Terzaghi* and *Peck*, 1948, p. 426) with one foot soil cover at the base of the column after placing the footing to ensure stability, etc. has been adopted. Loading is continued till either the ground begins to yield or the total settlement exceeds 0.5 inch.

Penetration tests: Two types of penetration devices are employed for that test, 2 inches standard cone penetrometer (*Terzaghi* and *Peck*, p. 276) and 2.5 inches diameter split spoon sampler. In the case of the cone penetrometer two different hammering units are employed, one being the standard 140 lbs. hammer dropping 30 inches (*Terzaghi* and *Peck*, 1948, p. 265) and the other 45 lbs. hammer dropping through 18 inches. With the sampling spoon, however, only the standard hammering unit is used. A drilling unit is employed for administering repeated blows of the hammer on to the penetration outfit. In the case of the cone penetrometer, depth of penetration has been limited to a maximum of 10 feet at a time, the strata penetrated being washed and the casing advanced before resuming further penetration. A continuous record is made of the number of blows applied for every successive foot of penetration.

The sampling spoon, however, is allowed to penetrate only 18 inches at a time after which it is withdrawn to remove the sample and is reinserted. In order not to permit the disturbance caused by each withdrawal and reinsertion of the spoon to vitiate the observations, the blows applied to penetrate first six inches each time, are not taken into account only those applied for the insertion of the following 12 inches being considered for the purpose of the test. A suitable casing pipe is driven as the hole advances in depth, especially in the case of deep alluvial and sandy deposits to stop the caving-in tendency usually manifested by such strata. Care is taken to keep the cutting end of the sampling spoon, or the pointed end of the cone penetrometer as far in advance of the lower end of the casing as the nature of the strata permits, to avoid compaction of the lower layers while driving the casing.

Nature of Soil Profiles Investigated

The following typical soil profiles were selected for the purpose of this study:—

(1) Deep and homogeneous alluvial deposit of sandy loam to sandy clay loam.
(2) Deep alluvial deposit of clay loam to lean clay with kankar.[1])

[1]) Kankar signifies impure limestone generally occurring in nodular form and at times in blocky form at varying depths along soil profile.

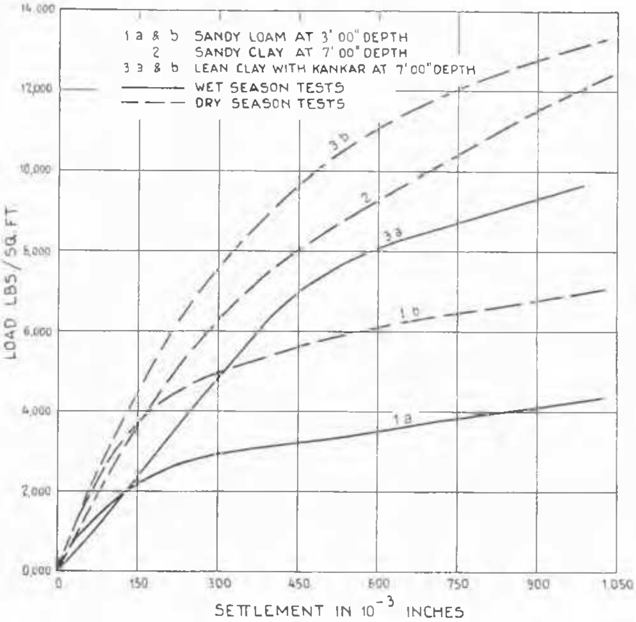

Fig. 1 Load-Settlement Curves for Alluvial Deposits
Courbe charge-tassement pour dépôts alluviaux

(3) Weathered rock material underlying out-wash deposit along hill slopes.
(4) Weathered rock material underlying hill-wash deposit in flatter terrain.
(5) Closely jointed; greenish, flaky shale underlying clayey alluvium.

Representation of Test Results

Load bearing tests: Time-settlement observations were recorded for every incremental loading and these were continued till the rate of settlement became negligible. The corresponding

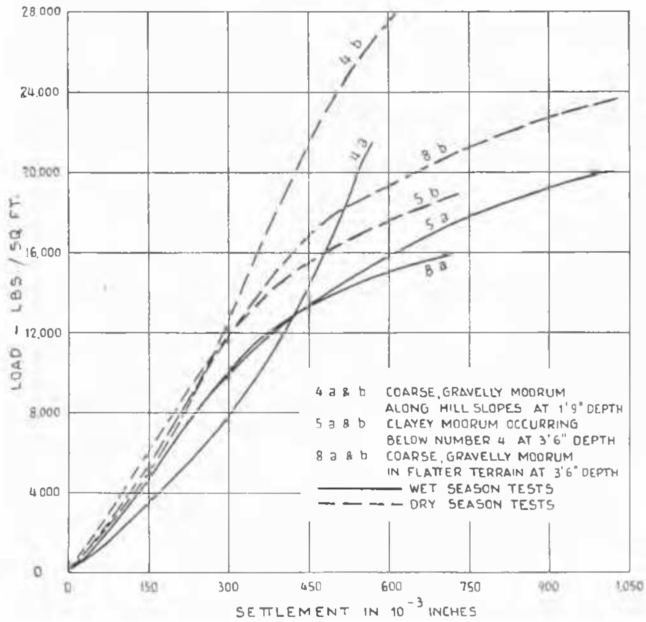

Fig. 2 Load-Settlement Curves for Moorum Strata
Courbe charge-tassement pour couches de Mooram

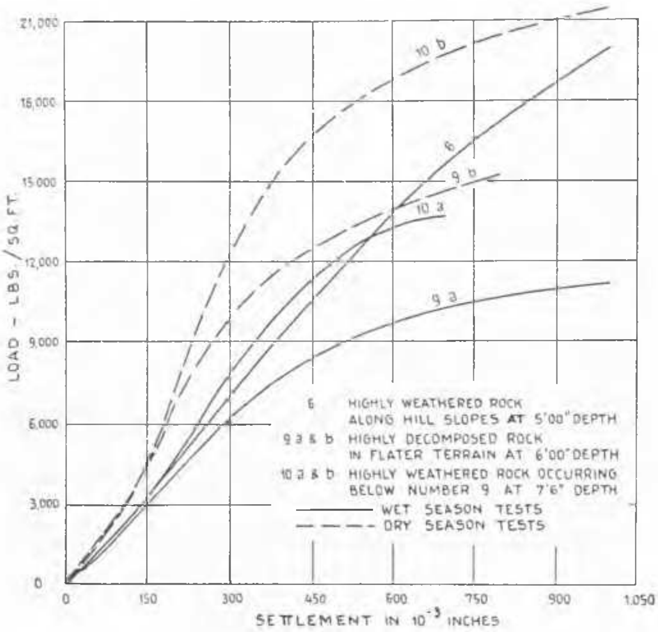

Fig. 3 Load-Settlement Curves for Highly Weathered Rock Strata
Courbes charge-tassement pour couches de rocs fortement décomposés

load-settlement curves were then plotted from this data. Two series of these load bearing tests have been carried, one during the period when the ground was wet and the other during the dry season with a view to determine the variation of the load bearing capacity of soils with change in the ground moisture conditions. The wet condition when the ground is waterlogged, represents the worst condition from the point of view of load bearing capacity.

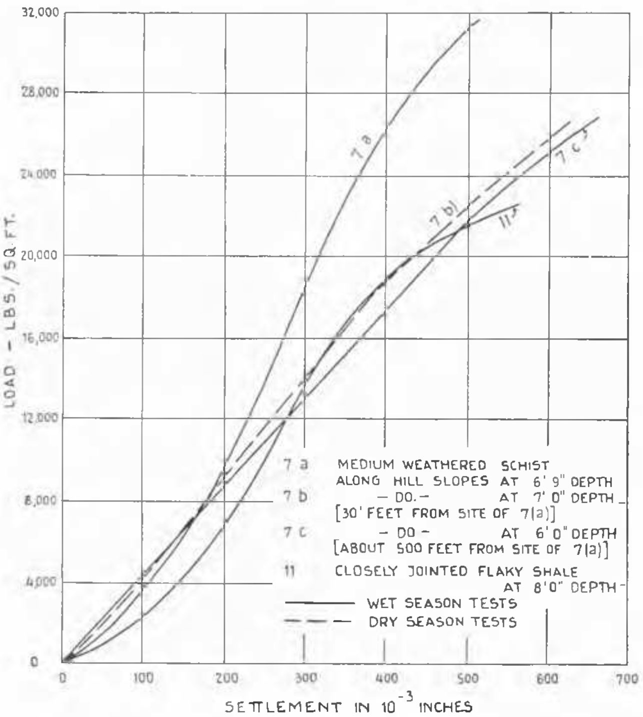

Fig. 4 Load-Settlement Curves for Medium Weathered Rock and Shale Strata
Courbes charge-tassement pour couches de rocs moyennement décomposés et de couches d'argiles schisteuses

The load-settlement curves for some of the typical soil strata are illustrated in Figs. 1 to 4. To bring out the behaviour of materials of similar nature but occurring at different sites, the curves pertaining to all such strata under different ground conditions have been plotted collectively in those figures.

That the load bearing capacity of soils is appreciably reduced on saturation of the ground is well known. That is attributable partly to decrease in shear strength and partly to uplift produced by the free water made to stand above the base of the column to ensure waterlogged condition of the ground. This reduction in load bearing capacity on saturation is represented in Figs. 1 to 4.

Disturbed samples of soil from each of the test sites were collected for identification tests. In addition, undisturbed cylindrical samples, 2.75 inch long and 1.375 inch in diameter were taken, wherever possible, by pushing thin-walled specimen tubes into the strata. They were tested for triaxial compression by subjecting to a rate of strain of 0.006 inch per minute and by keeping the drainage taps of the machine open during test. Three specimens were usually tested each of them being subjected to a different confining pressure, one of which corresponded to the estimated confining over-burden pressure on the test strata to simulate the actual field conditions and the values of cohesion and friction were calculated from those tests. The stress strain curves corresponding to the field confining pressure have been used for comparison with the field load-settlement curves as has been described later. The in-place density and moisture content were determined in every case and in some cases unconfined compression tests were also performed.

Penetration tests: As in the case of the load bearing tests, penetration tests have also been carried under both wet and dry ground conditions using, as far as possible, the two types of penetration devices listed above. Penetration diagrams

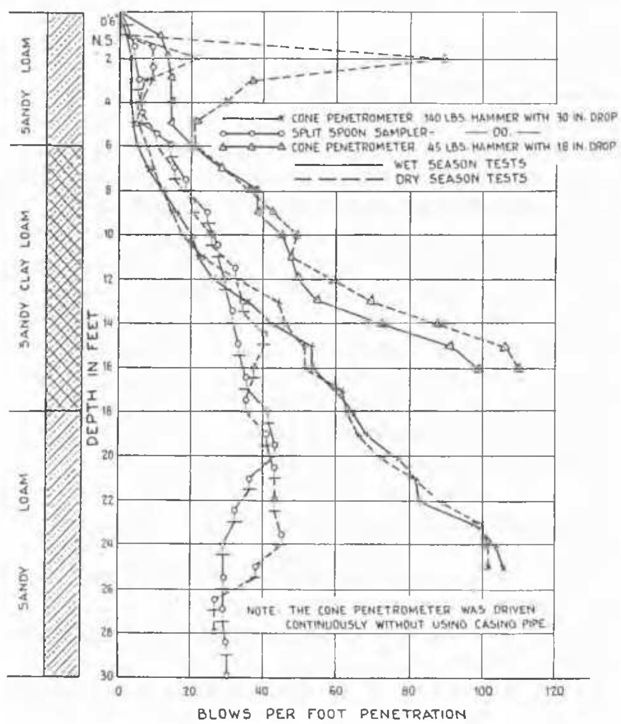

Fig. 5 Penetration Tests on Alluvial Sandy Loam Deposit
Essais de pénétration sur dépôt alluvial et sable glaiseux

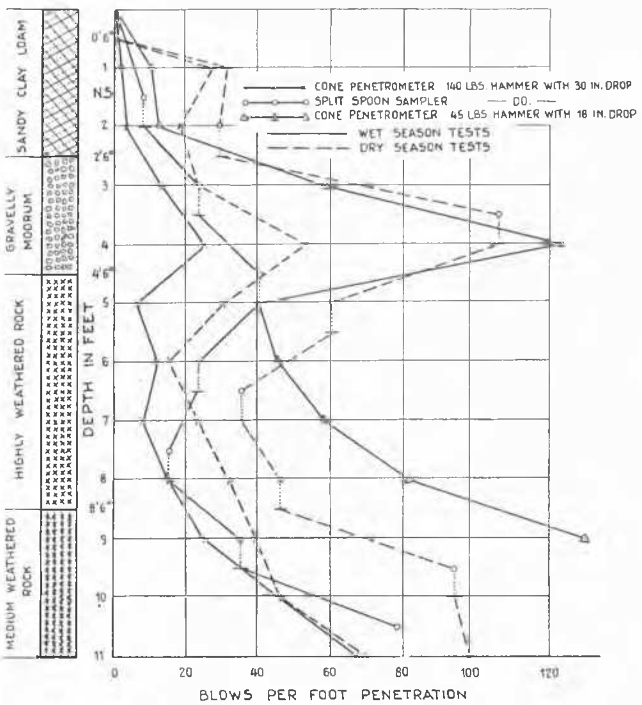

Fig. 6 Penetration Tests on a Typical Profile in Flatter Terrain
Essais de pénétration sur profil typique en terrain plat

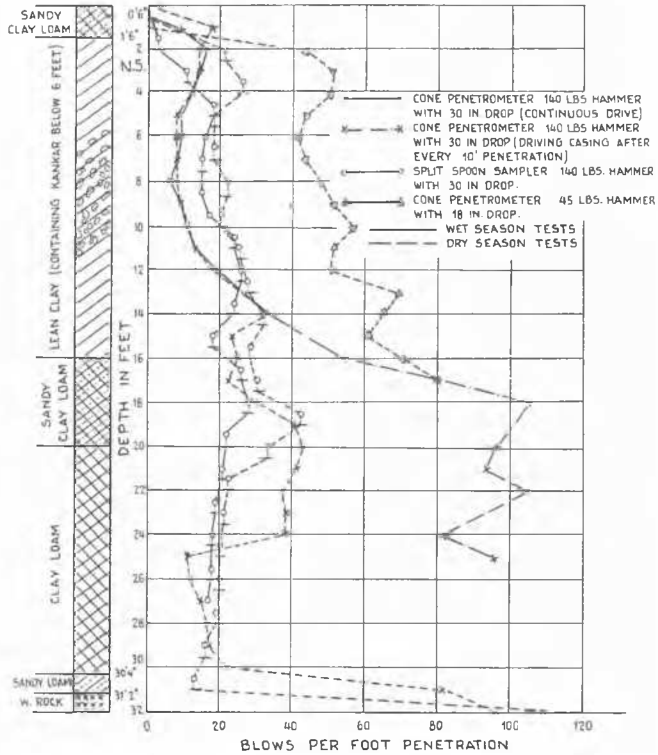

Fig. 7 Penetration Tests on Alluvial Lean Clay Deposit
Essais de pénétration sur dépôt alluvial d'argile maigre

showing the rate of penetration in terms of blows per foot against the depth along soil profile using each type of penetration equipment and under both wet and dry ground conditions have been plotted for every test site. Those diagrams for some of the typical sites are presented in Figs. 5 to 7.

Samples obtained from the spoon tests were identified in the field for preparing the logs of the profiles and also used for some of the laboratory tests.

The seasonal variation of the moisture content of soil with depth has been plotted for each of the test sites to determine the maximum depth to which the effect of such factors as evaporation, drainage, etc. is manifested. The results of that study for one average site are presented in Fig. 8.

Correlation of Load Bearing and Penetration Tests

The average values of penetration resistance corresponding to the soil strata tested for load bearing capacity were determined for each of the penetration devices employed. Those values as well as the figures of load required to produce half-inch settlement of the bearing block are given in Table 1. The assumption is that the safe bearing capacity of any soil approximates to one half the load at which the settlement of a one-foot square bearing block is of the order of half-an-inch (*Terzaghi* and *Peck*, p. 418).

The variation of load corresponding to half inch settlement and the resistance offered to each type of penetration device with ground conditions for some of the typical strata tested is also shown in Table 1. The values of penetration resistance (in terms of blows per foot) were plotted against the corresponding load at half inch settlement (in terms of tons per square foot) for each of the penetration devices separately and the curves thus obtained are shown in Figs. 9 to 11. It is seen from those figures that the points corresponding to tests conducted under wet as well as dry ground conditions approximate closely to the curves in both the cases. Some coarse gravelly soils like moorum or kankar bearing alluvial deposits show some variation from the mean values thus proving exceptions to that generalization. The difference in their case is attributable to the penetration resistance being vitiated due to the presence of gravel and/or kankar nodules, necessitating a large number of tests to arrive at an appropriate value. This deviation, is, however, conspicuous in tests conducted during dry season only.

Utility of Penetration Tests

From a large number of penetration tests conducted on a variety of strata using different devices it has been brought out that this technique affords a fairly simple and accurate method

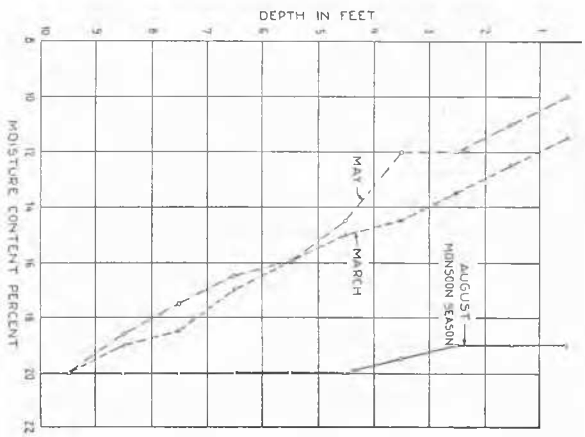

Fig. 8 Seasonal Variation of Moisture Content in an Alluvial Deposit
Variations saisonnières de la teneur en eau dans un dépôt alluvial

Table I Load Corresponding to 0.50 Inch Settlement of the Bearing Block and Penetration Resistance of Some of the Typical Soil Strata
Charge correspondant à un tassement de 0.50 pouces du bloc de charge et résistance à la pénétration de certaines des couches de sols typiques

Ser. No.	*Nature of stratum*	*Depth of footing ft./in.*	*Load corresponding to 0.50 inch settlement Tons/sq.ft.*		*Penetration Resistance (Blows per foot)*					
					Wet season			*Dry season*		
			Wet season	*Dry season*	*Using 2.5 inches sampling spoon driven by 140 lbs. hammer dropping through 30 inches*	*Using 2 inches cone penetrometer and 140 lbs. hammer dropping through 30 inches*	*Using 2 inches cone penetrometer driven by 45 lbs. hammer dropping through 18 inches*	*Using 2.5 inches sampling spoon driven by 140 lbs. hammer dropping through 30 inches*	*Using 2 inches cone penetrometer driven by 140 lbs. hammer dropping through 30 inches*	*Using 2 inches cone penetrometer driven by 45 lbs. hammer dropping through 18 inches*
1	Sandy loam (deep and homogeneous alluvial deposit)	3–0	1.50	2.56	5–6	3–4	12–15	6–8	6	25–30
2	Sandy clay loam (site same as 1)	7–0	—	3.80	15–18	11	38	18–20	11	40
3	Lean clay with *Kankar* (deep, highly clayey alluvium)	7–0	3.30	4.53	15	7	35–40	18–22	9	45–50
4	Coarse, gravelly *moorum* (occurring in a typical profile of weathered rock material overlain by outwash deposit along hill slopes)	1–9	7.68	10.75	40–50	25–30	150–180	—	—	—
5	Clayey *moorum* with fair proportion of gravel (occurring below No. 4)	3–6	6.40	7.30	28–32	20–22	110–120	35–45	30–35	—
6	Highly weathered rock (occurring below No. 5)	5–6	5.00	—	20–25	12–14	55–60	—	—	—
7(*a*)	Medium weathered blocky schist with horizontal bedding planes (occurring below No. 6)	6–9	13.93	—	110–130	70–75	above 300	—	—	—
(*b*)	Medium weathered blocky schist with vertical bedding planes (occurring at a distance of about 30 feet from site of 7(*a*)	7–0	—	10.00	—	—	—	75–85	45–50	—
(*c*)	Medium weathered schist (occurring at a distance of about 500 feet from site of 7(*a*)	6–0	9.71	—	70–75	45–50	240–300	—	—	—
8	Coarse, gravelly *moorum* (occurring in a typical profile of weathered rock material overlain by hill-wash deposit in flatter terrain)	3–6	6.25	8.10	35–40	20–25	110–120	60–80	40–50	—
9	Highly decomposed rock (occurring below No. 8)	6–0	4.00	5.80	18	10–12	40–50	30–35	18–20	—
10	Highly weathered rock (occurring below No. 9)	7–6	5.45	7.83	23–28	15–20	75–80	46	32	—
11	Closely jointed, green, flaky shale (occurring as a deep deposit below about 6 to 7 feet of highly clayey alluvium)	8–0	9.60	—	60–65	43–47	—	—	—	—

of determining the allowable load for all types of soil strata met with in that region.

The use of the cone penetrometer and sampling spoon, has brought out some of the merits and demerits of those equipments. The former allows, more or less, a continuous test and is thus quicker to use. For exploration of shallow depths upto 10 feet, its use with 45 lbs. hammering unit is simple and expedient. The use of the cone penetrometer is, however, limited by the facts that it cannot be reliably used in predominantly gravelly soils and when penetration exceeds 10 feet, frictional effects necessitate the use of casing pipe (Fig. 7). The split spoon sampler though comparatively slower in use, yields soil cores which are useful both for visual examination and identification tests in the laboratory. Another advantage, of no less importance, is the absence of friction as the spoon is driven into fresh strata every time.

Effect of the Variation of Moisture Content on Bearing Capacity and Penetration Resistance of Soils

The variation of moisture content with season has been recorded in the case of some typical test profiles as already indicated. In general, it has been observed that the effect of desiccation, consequent upon the recession of water-table after monsoon season becomes inconspicuous below a depth of 8 to 10 feet (Fig. 8). This has been corroborated by the observations

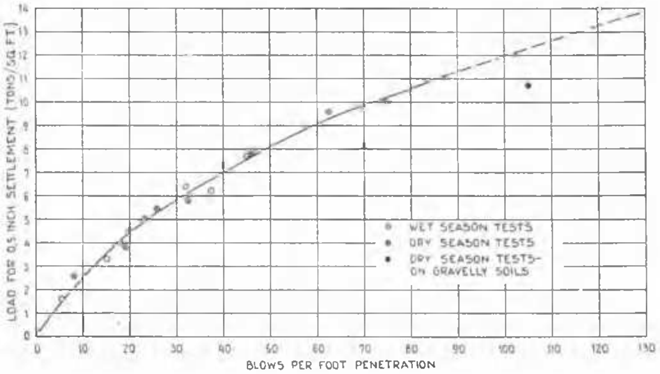

Fig. 9 Curve Showing the Relationship Between Load for 0.5 Inch Settlement and Blows per Foot Penetration Using 2.5 Inches Diameter Split Spoon Sampler Driven by 140 Lbs. Hammer Dropping Through 30 Inches
Courbe illustrant le rapport entre la charge, pour un tassement de 0,5 pouces, et le nombre de coups battus par pied de pénétration, employant un extracteur d'échantillons enfoncé à l'aide d'un marteau de 140 livres avec hauteur de chute de 30 pouces

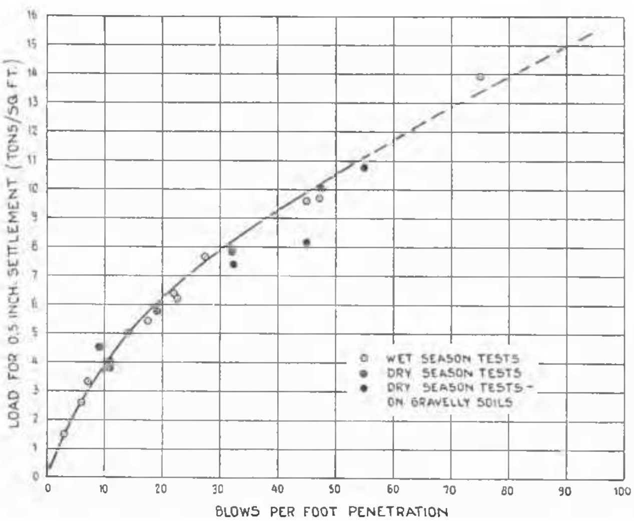

Fig. 10 Curve Showing the Relationship Between Load for 0.5 Inch Settlement and Blows per Foot Penetration Using 2 Inches Cone Penetrometer Driven by 140 Lbs. Hammer Dropping Through 30 Inches
Courbes illustrant le rapport entre la charge, pour un tassement de 0,5 pouces, et le nombre de coups battus par pied de pénétration, employant un cône-pénétromètre de 2 pouces enfoncé à l'aide d'un marteau de 140 livres avec hauteur de chute de 30 pouces

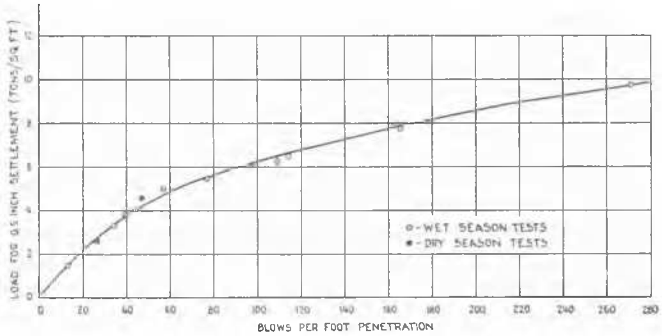

Fig. 11 Curve Showing the Relationship Between Load for 0.5 Inch Settlement and Blows per Foot Pentration Using 2-inch Cone Penetrometer Driven by 45 Lbs. Hammer Dropping Through 18 Inches
Courbe illustrant le rapport entre la charge, pour pénétration de 0,5 pouces, et le nombre de coups battus par pied de pénétration, employant un cône-pénétromètre de 2 pouces enfoncé à l'aide d'un marteau de 45 livres, hauteur de chute de 18 pouces

of penetration resistance which, too, do not manifest any wide variation with season below those depths (Figs. 5 to 7). As regards the variation of load bearing capacity with ground moisture conditions, it may be pointed out that this investigation has so far been limited to soil strata lying within the range of the effect of desiccation. As already indicated, both the load bearing capacity as well as penetration resistance for the strata lying within this range, change with season. However, the values of load bearing capacity, as interpolated from the curves (Figs. 9 to 11) by using the penetration test results, closely agree with the values obtained from direct loading tests. The reduction in load bearing capacity on saturation, ranges from 25 to 40 percent depending upon the extent of desiccation and the nature of the material. In the case of structures like head regulators of canals and aqueducts, the depth of foundation is expected to be well below the zone of desiccation and values of bearing capacity as estimated from the penetration test data can be taken to represent the actual values, barring the effect of submergence of the strata (if not already below the water-table during test) which may reduce the bearing capacity by as much as 50 percent in the case of sands (*Terzaghi* and *Peck*, 1948, p. 420).

Adoption of the Penetration Test Technique for Estimation of Allowable Loads for Foundations

Penetration tests using the sampling spoon and the cone penetrometer are being employed at the Hirakud Project in connection with the foundation exploration at the sites of the proposed head regulators and major and minor aqueducts to locate strata having bearing capacity sufficient to carry safely the superimposed loads.

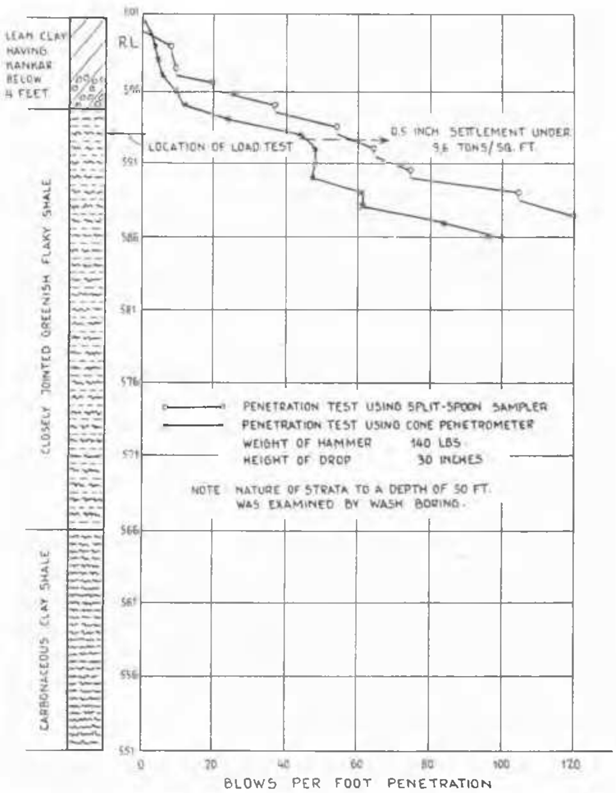

Fig. 12 Foundation Exploration at the Site of Head Regulator of Left Flow Canal
Exploration du sous-sol de l'emplacement de la vanne de fond du canal de dérivation gauche

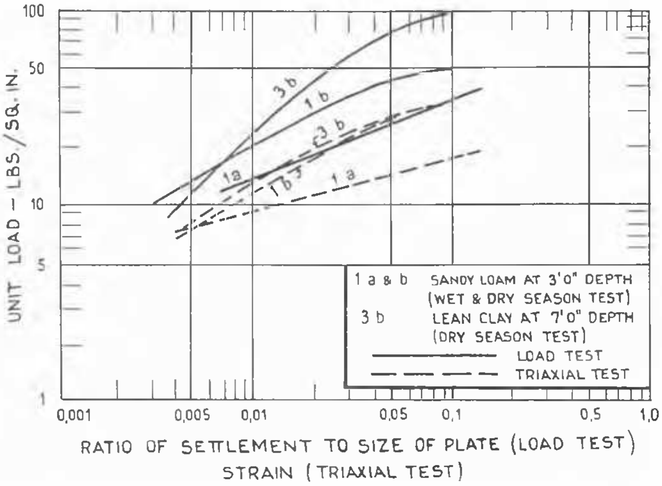

Fig. 13 Comparison of Load Bearing Tests on Alluvial Deposits and the Corresponding Triaxial Compression Tests
Comparaison entre les essais de charge sur dépôts alluviaux et les essais triaxiaux de compression correspondants

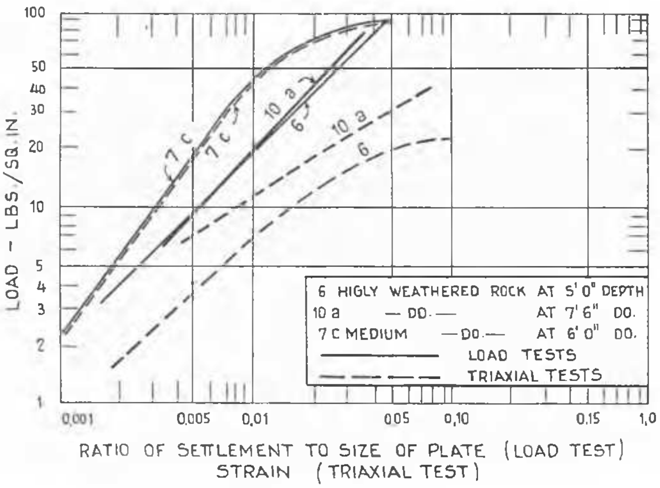

Fig. 14 Comparison of Load Bearing Tests on Weathered Rock Strata and the Corresponding Triaxial Compression Tests
Comparaison entre les essais de charge sur couches de rocs décomposés et les essais triaxiaux de compression correspondants

One such case is illustrated in Fig. 12 which represents the results of exploration at the site of the head regulator of one of the irrigation canals. The penetration tests at that site were discontinued at a depth of 15 feet only as the material encountered at that level offered considerable resistance to the penetration of either of the two equipments employed. A direct loading test was conducted on that material at a depth of 8 feet and it gave a value of 9.6 tons/sq.ft. for 0.5 inch settlement. The corresponding values estimated from the penetration test data were found to be 9.30 and 9.85 tons/sq.ft. for the split spoon sampler and the cone penetrometer respectively.

Interpretation of Load Test Data

The settlement and load bearing capacity of soils depend on a number of factors such as the nature and size of the footing, nature and depth of the soil material under test, etc. One of the methods of obviating the effect due to the size of the footing under homogeneous ground conditions is to plot the values of unit load against the ratio of the settlement to the size of the plate on log-log scale. Such plots were tried for a large variety of strata tested and the points were found to lie along a straight line as shown in Figs. 13 and 14.

Triaxial Compression Tests

Undisturbed specimens from the strata tested for load bearing capacity, were subjected to triaxial compression tests as described already. The stress-strain relationships corresponding to the tests conducted at the estimated confining overburden pressure in the field were plotted alongside the load test data on log-log scale. Some of the results thus obtained are illustrated in Figs. 13 and 14. As is seen from those figures, the curves pertaining to the field and triaxial compression tests mostly run approximately parallel to each other, the former always lying above the latter. There were, however, cases in which these two curves were found to intersect one another. In the case of one medium weathered rock stratum, however, those curves were found to coincide.

The utility of the triaxial compression tests for the estimation of load bearing capacity of soils appears to suffer from certain limitations mainly due to the small size of the test specimen (which effect becomes all the more important in the case of coarse-grained soils) and the disturbance caused during sampling operations. Further work to investigate this aspect of the problem is in progress.

Conclusions

It has been possible, as a result of the series of investigations detailed above, to define the load bearing capacities of the various types of soil strata in terms of their resistance to penetration by the two inch cone penetrometer and the two and a half inch diameter split spoon sampler. The technique of direct loading tests being rather too elaborate and cumbersome, its replacement by the relatively much simpler penetration tests for the purpose of estimation of allowable loads of foundations of structures like canal headworks and aqueducts to be constructed in connection with the Hirakud Project has yielded quite satisfactory results.

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