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Risk Analysis of Bearing Capacity and Settlement of Shallow Foundations

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ABSTRACT: Field load tests are regarded as the most suitable technique to obtain load-settlement response of foundations resting on soil/rock, and find its place in several codes of practice worldwide. The load-settlement data obtained from plate load tests is routinely used in the evaluation of several design parameters of soil, such as bearing capacity, settlement of foundations, modulus of sub grade reaction, Young's modulus, etc. However, these tests often produce unrealistic results, due to various sources of uncertainties in testing procedures, and may create difficulties in the design decisions, if not properly accounted. In this paper, a failed field plate load test is discussed and various uncertainties associated with the field testing are identified. The effects of these uncertainties on the load-settlement behavior are systematically analyzed. By comparing the results obtained from the laboratory and field load tests, it is observed that the bearing resistance of the soil is highly overestimated due to non-maintained load testing. Based on laboratory load test data, resistance factors are derived for each stage of loading.
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KEY WORDS: Field load tests, load-settlement, bearing capacity, settlement of foundations, modulus of sub grade reaction, Young's modulus

I. INTRODUCTION

Risk analysis is a design tool to consider the effect of various sources uncertainties on the performance of a system. Geotechnical engineering is considered as a good example of an engineering discipline where every stage of it invariably encompasses several uncertainties. Uncertainties in geotechnical engineering may arise from using a geological model developed for a site based on information obtained from limited bore logs, use of soil properties measured/interpreted through in-situ and laboratory testing, use of simplified transformation models for bearing capacity and settlement predictions, to name a few. Keeping in mind the scale of these uncertainties effecting the foundation design, it is rightly said that the subject of foundation engineering is an art and science of moulding materials we do not fully understand into shapes we cannot precisely analyse to resist forces we cannot accurately predict, all in such a way that the society at large is given no reason to suspect our ignorance (Coduto, 1994). Field plate load test is considered as one of the most suitable techniques to obtain load-settlement response of foundations resting on soil/rock, due to high degree of uncertainties associated with other in-situ and laboratory testing procedures, and errors due to simplified transformation models developed for estimation of bearing capacity and settlement of shallow foundations. Table 1 summarizes the results from a prediction symposium on behaviour of shallow foundations held at Texas A & M University, USA.

The predicted bearing capacities of footings resting on a medium dense, fairly uniform, silica sand deposit, are presented for 5 different footings, and compared with the load test results. The wide scatter of predicted bearing capacities may partly be attributed to the simplified modelsadopted (Briaud and Gibbens, 1999). Similarly, errors in field and laboratory testing, and statistical errors due to limited sampling may also result in greater differences between the measured and predicted performance of foundations. Figure 1 shows the effect of uncertainty on the performance of a shallow foundation. It can be noted from the figure that the footing with higher factor of safety in fact exhibits a higher probability of failure, and a realistic assessment of the safety of the foundation is only possible if the effect of various sources of uncertainty is properly accounted in the foundation design process. The past three decades of research in the area of geotechnical risk and reliability identified that the conventional factor of safety approach alone cannot quantify the risk associated with various foundation design decisions, and strongly emphasized the need for a systematic study of various sources of uncertainty, and quantification of their influence on the probability of unsatisfactory performance of a foundation system. An attempt is made in this paper to demonstrate the level of uncertainty associated with a field plate load test, and its effect on the load-settlement response.

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It is common practice to conduct field plate load test under reaction loading, as it is a simple loading method compared to other alternatives, such as gravity loading. In this, a series of incremental loads is applied through a hydraulic jack working against a reaction loading in the form of a Kentledge assembly/anchor piles, with a definite time lag between consecutive load increments. These loads on the plate shall be applied in cumulative equal increments of 100 kPa or one-fifth to one-tenth of the estimated bearing capacity (IS: 1888-1982, ASTM D1194- 94). IS 1888, in the case of clayey soils, suggests that the load should be increased to the next stage either when the curve indicates that the settlement has exceeded 70 to 80 percent of the probable ultimate settlement at that stage or at the end of 24 hours period. For granular soils, each load increment should be kept for not less than one hour or up to a time when the rate of settlement gets appreciably reduced to a value less than 0.02 mm/minute, and there is no mention on maintaining the load constant during loading stages. However, ASTM specifies that after the application of each load increment, the cumulative load be maintained for a selected time interval of not less than 15 minutes. Such shortcomings in the codalprovisions may prove wrong consequence , if the codal provisions are followed blindly, without insight. Moreover, due to various sources of uncertainties in testing procedures, i,e., lack of suitable equipment and experimental awareness, inadequate codal provisions, these tests often produce unrealistic results, and create confusion in the design decisions.

II. AIM OF PROJECT

For jack-reaction type of loading, with application of load on the plate, the plate penetrates into the soil with a corresponding reduction in the applied pressure. In principle, the load on the plate should be maintained constant during each loading stage.

Methods for predicted bearing capacity (1)	1.0 m footing (MPa) (2)	1.5 m footing (MPa) (3)	2.5 m footing (MPa) (4)	3.0 m (north) footing (MPa) (5)	3.0 m (south) footing (MPa) (6)
Briaud-CPT (1993)	1.743	1.608	1.737	1.892	1.892
Briaud-PMT (1992)	0.872	0.779	0.781	0.783	0.783
Hansen (1970)	0.772	0.814	0.769	0.730	0.730
Meyerhof (1951, 1963)	0.832	0.991	1.058	1.034	1.034
Terzaghi (1943)	0.619	0.740	0.829	0.826	0.826
Vesic (1973, 1974)	0.825	0.896	0.885	0.885	0.855
Measured pressure @ s = 150 mm after 30 min of load application	1.740	1.511	1.136	1.000	1.139

Table 1. Measured and predicted bearing capacity of shallow foundations(Briaud and Gibbens,1999)

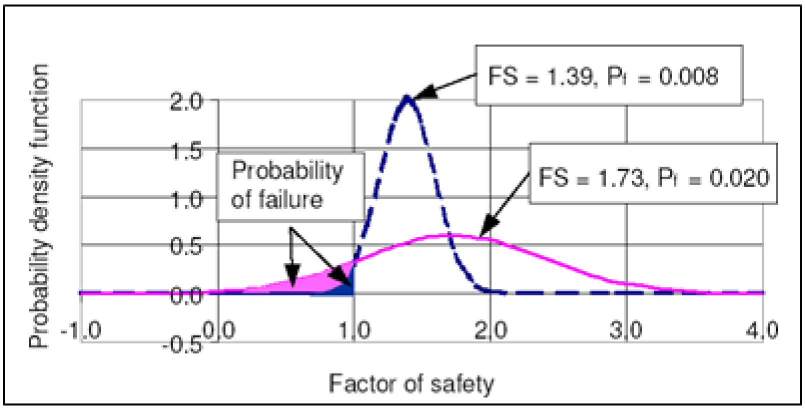

Figure 1. Effect of uncertainty on the failure probability (Lacasse, 2001)

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However, in the routine practice, due to negligence, lack of technical awareness of the crew, and inadequate testing equipment, this condition is not often satisfied, and goes unnoticed and not reported elsewhere. This research work is emanated from the recent experience of the first author at a power plant site, where few field plate load tests were conducted, for which he played an advisory role. The details of the field plate load test, and observed major deviations from the standard code of practice are delineated in the following sections. Few well controlled laboratories tests are conducted to understand the effect of maintained and non- maintained load tests on the load-settlement response. The effect of the above uncertainty on the load-settlement response is analysed, and a set of resistance factors are derived for each loading. These resistance factors, when multiplied with the corresponding observed maximum settlement, can partially compensate the error associated with using the conventional hydraulic pumping units, which cannot hold the applied pressure during the loading stages.

III. LITERATURE REVIEW

Nadarajah Ravichandran, VahidrezaMahmoudabadi, Shweta Shrestha., The ultimate bearing capacity of shallow foundation supported by unsaturated soil depends on the degree of saturation of the soil within the influence zone because the strength and deformation parameters of soil are affected by the degree of saturation. As the degree of saturation varies with rainfall, surface runoff, evapotranspiration and other climatic and geotechnical parameters, these parameters must be systematically incorporated for accurately computing the ultimate bearing capacity. In this study, a framework is proposed to compute the ultimate bearing capacity of a shallow footing in unsaturated soil considering site specific rainfall and water table depth distributions. The randomness in rainfall and water table depth is systematically considered using Monte Carlo method. The infiltration of water through the unsaturated zone is modelled using Richards equation considering infiltration and water table location as the top and bottom boundary conditions, respectively. The results show that the bearing capacity calculated using the proposed method is approximately 2.7 times higher than that calculated using the deterministic approach with fully saturated soil parameters.

Juan Carlos TiznadoA Danilo Paillao In the context of engineering practice, the problem of the seismic bearing capacity of shallow foundations has been solved indirectly, either due an increase of the static allowable soil pressures related to the probability of occurrence of the design earthquake or by adopting an equivalent pseudo-static approach. However, during last decades, a series of analytical methods that directly address the problem from the seismic point of view has been developed. This paper presents a parametric comparative analysis of different methods for estimating seismic bearing capacity of shallow strip foundations. Analytical methods, developed in the framework of both limit equilibrium and limit analysis theories, and also simplified design procedures typically used in practice were considered. The results obtained show an important decrease of the bearing foundation capacity with increasing of the maximum earthquake acceleration, which highlights the need to obtain a measure of the reliability associated with both calculation methods and safety factors commonly used for seismic design.

Nadarajah Ravichandran: The ultimate bearing capacity of shallow foundation supported by unsaturated soil depends on the degree of saturation of the soil within the influence zone because the strength and deformation parameters of soil are affected by the degree of saturation. As the degree of saturation varies with rainfall, surface runoff, evapotranspiration and other climatic and geotechnical parameters , these parameters must be systematically incorporated for accurately computing the ultimate bearing capacity. In this study, a framework is proposed to compute the ultimate bearing capacity of a shallow footing in unsaturated soil considering site specific rainfall and water table depth distributions. The randomness in rainfall and water table depth is systematically considered using Monte Carlo method. The infiltration of water through the un-saturated zone is modelled using Richards equation considering infiltration and water table location as the top and bottom boundary conditions, respectively. The results show that the bearing capacity calculated using the proposed method is approximately 2.7 times higher than that calculated using the deterministic approach with fully saturated soil parameters.

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IV. ANALYSIS

A series of plate load tests were conducted at a Power plant site as part of in-situ studies for selection of a suitable foundation system for supporting important plant structures. The plate load tests were required to be carried out as per the specifications outlined in Indian Standard Code of Practice (IS 1888:1982). The size of the plate selected was 0.6 m x 0.6 m, and the test was conducted at 4 m depth below the natural ground level. No ground water table was observed in the vicinity of the plate, as the test was conducted during a post-monsoon period.

The load was applied on the plate through hydraulic jacking against a heavy kentledge of sand bags, in 5 equal load increments of 100 kPa. A pressure gauge is attached to the hosepipe connecting manually operated pumping unit and the hydraulic jack, to control the pressure applied to the plate assembly. The pumping unit was operated manually at the start of every load stage, till a corresponding pressure was reached in the pressure gauge, and left unattended till the next loading stage. For the hydraulic jack used in the present study, to apply a pressure of 100 kPa on the plate of 0.6 m x 0.6 m, the pressure of the oil in the hosepipe should correspond to 80 kg/cm2. Settlement of plate was measured using two manually recording dial gauges placed on the plate at diagonally opposite locations. It was noted during every loading stage, that there was a drop in the pressure on the plate, as the plate settles into the soil. The rate of decrease of pressure on the plate may be directly proportional to the rate of settlement of the plate. In order to illustrate the above effect, 4th loading stage was considered. A pressure of 400 kPa was initially applied on the plate, with the corresponding pressure gauge reading of 320 kg/cm2. If the pressure on the plate was maintained constant, the pressure gauge reading (320 kg/cm2) must be constant throughout this loading stage. However, due to the fact that the hydraulic jack was not able to hold the applied pressure constant, a reduced pressure gauge reading of 250 kg/cm2 was noticed (Figure 2), after almost 12 hours from the application of 4th load increment, which would correspond to a pressure of 312.5 kPa on the plate. A similar drop in the pressure gauge reading was noticed with elapsed time at all the loading stages. Adding a simple servo- controller or any other pressure holding device to the pumping unit, could be a possible solution to maintain the load on the plate constant during each loading stage, and obtain reliable load-settlement data.

Figure 2. Observed pressure drop during 4th loading stage

V. OBSERVED UNCERTAINTIES DURING FIELD TESTING

The following are some of the major uncertainties noticed during the field plate load test.

1. The pressure on the plate was not maintained constant during loading stages
2. The supports of the datum bar carrying the dial gauges were placed very close the edges of the plate, and rested in the influence zone.
3. The influence zone surrounding the plate was highly disturbed due to movement of crew, and placement of testing related accessories.
4. The positioning of the dial gauges was wrong

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VI. EXPERIMENTAL PROGRAMME

To demonstrate the effect of the observed loading mechanism on the load-settlement behavior, two types of laboratory plate load tests are conducted on remolded marine clay, obtained from a site in the west coast in Mumbai. In the first test, the load on the plate during each loading stage is maintained constant and in the second test the load at each stage is not maintained, simulating the observed loading behavior, obtained by using a conventional hydraulic manual pumping unit. The comparison between the two test results are reported in terms of time-settlement and load-settlement response, and the details are presented below.

Test bed preparation

The clay bed for all the tests is prepared in a test tank of plan dimensions 46 cm×46 cm and 41 cm in depth. The inner surface of the tank is coated with metal paint to reduce the boundary effects. Apart from this, a fine thin layer of oil is also applied to its internal walls. The moist soil in the tank was compacted in layers and for each layer 9 kg of soil having water content 30% is used. Each layer of soil is then compacted with a special hammer with equal number of blows so as to achieve clay bed with uniform density and consistency.

Load tests

For the load-maintained tests, the tank with clay bed is mounted on a reaction frame and a lever arm based incremental loading, which helps to maintain the load during each increment of loading, is used. A plate of size 10 cm×10 cm×0.7 cm is kept at the centre of the tank and then load is applied by keeping appropriate load on the lever arm to get the desired load on the plate. The load was maintained during each loading stage for a duration of 1 hour. Settlements are observed with the help of two diagonally placed LVDTs at 1, 2.25, 4, 6.25, 9, 16, 25, 36, 49, 55 and 60 minutes from the start of each loading stage. A typical view of the test setup and the reaction frame is shown in Fig. 3(a), and Figure 3(b) shows a close view of the arrangement of LVDTs, load cell, and plate arrangement

(a) (b)

Figure 3 (a). Laboratory plate load Test setup with lever arm mechanism for maintained loading; (b). Detailed view of the load cell and plate arrangement

To simulate non-maintained load tests, the tank was mounted on a self-supporting reaction frame and load is applied on the plate through a hand operated pumping unit-hydraulic jack assembly. The load during each loading stage is applied by operating the hand-held lever of the pumping unit, till the corresponding pressure is reached in the pressure gauge, and unattended until the next load increment. The displacements are continuously recorded with the help of LVDTs. The duration of each loading stage is kept as 1 hour, similar to the case of load-maintained tests. Figure 4 shows the loading mechanism, and arrangement of LVDTs, load cell, and plate arrangement.

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(a) (b)

Figure 4 (a). Laboratory plate load test setup with hydraulic jack-reaction load mechanism for non-maintained loading; (b). Detailed view of the load cell and plate arrangement.

VII. RESULTS AND DISCUSSION

The time vs. load response is plotted for both the cases, described in the above section, and shown in Figure 5. It is obvious that a stepped pattern is observed when the load is maintained constant at each loading stage. For the case of non-maintained load, upon each load increment a gradual and steep reduction in applied load is observed, with an associated settlement of plate

Figure 5 shows the time versus settlement profiles for both loading cases. In the case of maintained loading, the settlements increased rapidly upon loading and reach a rate less than 0.02mm/minute, within an hour of loading, for each loading stage. Whereas for non- maintained loading, after a high initial settlement a rebound of plate is observed, which gradually increased with time and finally attains a near constant value.

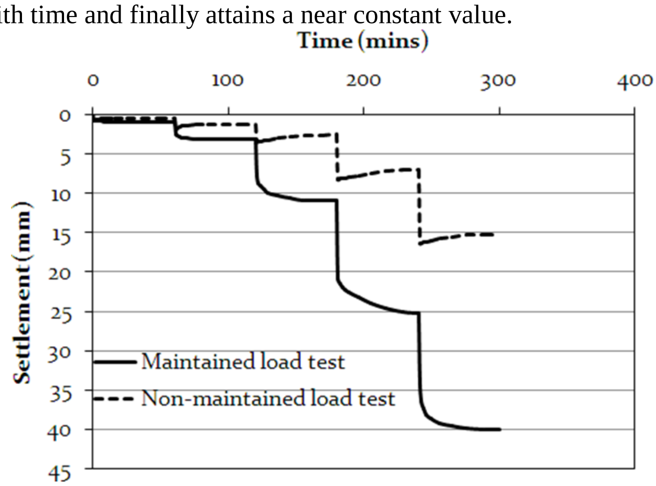

Figure 5. Variations in settlement profiles with time

A typical load vs. settlement response is shown in Figure 6 for both loading cases. It is clearly seen from the figure that the load-settlement response for both the cases is quite different. Based on the above observations, it can be noted that the load tests with conventional hydraulic pumping units, which cannot hold the pressure constant during

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loading stages, lead to flatter load-settlement response. The data obtained from such tests may overestimate the bearing capacity and underestimate the settlements corresponding to any load on the plate

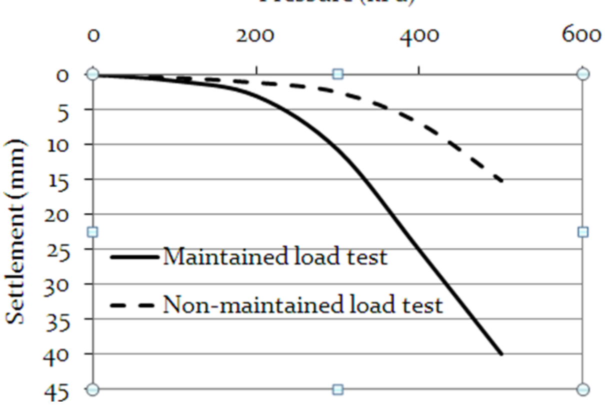

Figure 6. Observed pressure-settlement response

By visualizing the load-settlement response observed in the laboratory, it is prudent to conclude that had there been a servo-controller based hydraulic pumping unit or a similar mechanism to maintain the pressure applied on the plate constant, the observed settlements under each loading stage would have been still higher, than that were observed in the field study. Based on the above results, a set of resistance factors is derived for bearing pressures, as shown in Table 2, where resistance factor is defined as the ratio of observed load for maintained case to that of non-maintained case, for an assumed settlement level. The resistance factor varies from 0.63 to 0.67, with an average of 0.65, for settlements in the range of 4 to 12 mm. These resistance factors, when multiplied with the loads of non- maintained load test corresponding to any given settlement, can partially compensate the gross overestimation of loads obtained from non-maintained load tests. However, these factors should be used with caution, as they are derived based on limited test data. Similar studies are also conducted in cohesion less soils, and the same trend is observed.

Allowable settlement (mm)	4	8	12
Resistance Factor for load	0.63	0.66	0.67

In conclusion, due care should be taken by the contracting agencies while following the specifications mentioned in the Codes of Practice. It is also mandatory that the local codes should be reviewed in view of the above-mentioned uncertainties, and revised from time to time for the benefit of the geotechnical community.

VIII. CONCLUSIONS

Plate load test, which is revered as most reliable in-situ testing technique to obtain load- settlement response, may give rise to unrealistic results if not properly conducted. This paper focuses on the analysis of laboratory plate load test results, to understand the effect of maintained and non-maintained load during each loading stage. Following are the salient conclusions drawn from the study.

1. From both stresses maintained and stress not-maintained laboratory plate load tests on remoulded marine clay, it is observed that the load-settlement response for both the cases are different.
2. Load tests with conventional hydraulic pumping units, which cannot hold the pressure constant during loading stages, lead to flatter load-settlement response.
3. Had there been a servo-controller based hydraulic pumping unit or a similar mechanism to maintain the pressure on the plate during each loading cycle, the observed settlements under each loading stage would have been still higher, than that were observed in the present study.

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4. The resistance factor for bearing pressure varies from 0.63 to 0.67, with an average value of 0.65, for settlements in the range of 4 to 12 mm. These resistance factors, when multiplied with the loads of non-maintained load test for any given settlement, can partially compensate the gross overestimation of loads obtained from non- maintained load tests.

REFERENCES

[1] ASTM D 1194-94, Standard Test Method for Bearing Capacity of Soil for Static Load and Spread Footings, Annual Book of ASTM Standards, ASTM International, West Conshohocken, PA., 2003.

[2] Briaud, J-L and Gibbens, R. (1999). Behaviour of five large spread footings in sand, Journal of Geotechnical and Geoenvironmental Engineering, ASCE, 125(9), 787-796

[3] Coduto, D.P. (1994). Foundation Design: Principles and Practices. Second Edition, Prentice-Hall Inc.

[4] Dasaka, S.M., and Jain, A. (2012). Uncertainty analysis of bearing capacity of soils from field plate load tests. Asian-Pacific Symposium on Structural Reliability and its Applications (APSSRA-2012), Singapore, CD-ROM proceedings.

[5]IS: 1888-1982: Indian Standard Practice on Method of Load Test on soils, Bureau of Indian Standards, 2003.

[6] Jain, A., Effect of Loading Mechanism on Plate Load Test Results, M.Tech. thesis, IIT Bombay, 2011.

[7] Lacasse, S. (2001). Karl Terzaghi Lecture

[8] Principles of foundation engineering by BrajaM.Das