Experimental and Theoretical Investigations of the Influence of Rough Rigid Layer on Settlement of Pile Foundations*

by

B.S. Khadilkar and Swarajyamal Humad

(1) SHENBAGA R. KANIRAJ**

The writer read with interest the paper 'Experimental and Theoretical Investigations of the Influence of Rough Rigid Layer on Settlement of Pile Foundations', by B.S. Khadilkar and Swarajyamal Humad. The writer is afraid that the authors' major experimental finding with respect to group efficiency does not conform to established theoretical principles and experimental facts.

The two important aspects to be considered in the design of pile foundations are the settlement ratio and the group efficiency. Usual definitions adopted for these two criteria are as follows.

Settlement ratio is the ratio of the settlement of the pile group to the settlement of the single pile at the same average load per pile.

Group efficiency is the ratio of the ultimate load of the pile group to the ultimate load of a single pile multiplied by the number of piles in that group, i.e.,

$$\eta = \frac{P_g}{P \times n}$$

where, η = group efficiency

P_g = ultimate load of the group

P = ultimate load of single pile

n = number of piles in the group.

Theoretical explanations and experimental investigations (Skempton 1953 ; Meyerhoff 1961 ; Hanna 1963 ; Vesic 1969) have conclusively established that the settlement ratio for pile groups in any sand deposit is more than 1 whereas the value of group efficiency is less than 1 in dense sand deposits and more than 1 in loose sand deposits (Hanma 1963 ; Beredugo 1966).

The authors have adopted a definition different from the above one for group efficiency as,

$$\text{Group efficiency} = \frac{\text{Group load at particular deformation}}{\text{Single pile load for the same deformation} \times n}$$

The authors have reported group efficiency values more than 1 for their investigations which means that the average load per pile in a group is more than the single pile load for the same deformation. This connotes that the settlement ratio is less than 1. This as already pointed out has

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not been an observation in practice and is not within a theoretical explanation.

The writer also wants to point out that for the test tank and pile dimensions mentioned in the paper the maximum H/L values for $L/d=9$, 15 and 21 can be only 5·5, 3·3 and 2·34 respectively which are not large enough to be considered as infinity. This is evident from the data for $L/d=21$ where the data for $H/L=2$ and $H/L=\infty$ tend to coinside. This is because the maximum H/L value possible in this case is only 2·34 which is not much different from $H/L=2$.

It would have also been preferable if the authors had given single pile load versus settlement curves for $L/d=15$ instead of for $L/d=21$ in Figure 2. This would have facilitated comparison of single pile behaviour with Figures 3 and 4 which show the group load-settlement curves for $L/d=15$.

References

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(2) DR. GOPAL RANJAN* and P.K. JAIN**

The authors deserve an appreciation for reporting the theoretical analysis and a systematic experimental programme for the study of influence of rigid layer on settlement of pile foundations. The discussors wish to offer following comments :

(1) The authors have not reported the properties of rigid layer. As the sand deposit has a high relative density (94·5 percent). It would have been of interest to compare the modulus of elasticity of the rigid layer with that of the sand used.

(2) The authors have presented excellent experimental data for piles in dense state (relative density 0·945—Table I). The use of piles in such a dense deposit has a very limited use. It would have been interesting to see these test results in loose sand deposits also.

(3) A study of pile properties and Table II indicate that for L/d ratio of 21 the length of single pile works out to be 53·34 cm. As the depth of tank used during the investigation was 1·24 m, the maximum ratio of H/L for the length of 53·34 cm is 2·52. It is

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not clear as to what is meant by $H/L=\infty$ and how this was achieved with this set-up.

(4) The authors have defined the non-dimensional term "Group Efficiency" as

$$= \frac{\text{Group load at particular deformation}}{\text{Single pile load for the same deformation} \times \text{number of piles in a group}} \times 100$$

The term efficiency commonly defined is :

$$= \frac{\text{Group failure load}}{\text{Failure load of single piles} \times \text{number of piles}} \times 100$$

This does not bring the concept of settlement in the equation. It is suggested that the ratio used in the paper should be called as the load ratio for a particular settlement rather than the efficiency.

(5) Table III gives the load carrying capacity for single "free-standing" pile at a deformation of 2·54 mm and 5·0 mm in presence of rigid layer. However, for the "free-standing" pile group of 2×2 piles load carrying capacity is tabulated (Table IV) for a deformation of 2·54 mm only. It will be of interest to see the load carrying capacity of the group for other deformation, i.e., 5·0 mm also and see that if the same trend (as in Figure 5) is followed.

(6) Discussing the effect of spacing the authors state that the presence of rigid layer not only affects the settlement of pile groups but it also considerably influences the pattern of load transfer and mechanism of failure of different spacing of piles. It will be appreciated if the authors could throw some more light on this statement since it is not clear as to how the pattern of load transfer and mechanism of failure at different spacing of piles influence is observed.

AUTHORS' REPLY

(1) The authors thank R. Kaniraj for his interest in their paper. The points mentioned by him are briefly discussed below.

In this paper, the authors have presented data from laboratory tests and theoretical analysis for the problem of influence of rigid layer on the settlement of pile foundations. Model piles were fabricated out of 25·4 mm outside diameter aluminium tubes. Loads supported by these piles for different settlements were recorded and comparative values were given for settlements equal to 2·54 mm, 5·00 mm, etc., i.e., for 10 percent and 20 percent of the shaft diameter respectively.

Settlement of the order of 10 percent of pile diameter is usually considered adequate for fully mobilizing their limiting loads. Since in the present study, these comparisons are made for settlements equal to 10 percent or more, thereby allowing for the development of almost ultimate strengths, the authors do not see any significant difference in the definitions for group efficiency (η) as used in this study and as given by the discussor. The main point to be noted is that this efficiency has to be obtained only after ensuring adequate settlement of the piles, a point which is well taken care of in this paper.

Data obtained from pile load tests can be presented in terms of group η or in terms of settlement ratio depending on the convenience/preference for one or the other. Both these terms are obviously interdependent. As stated by the discussor, in certain cases of sandy deposits, the group η is more than 1·0 and in certain cases it is less than 1·0 which indirectly implies that in certain cases the settlement ratio will be less than 1·0 and in certain cases it will be more than 1·0.

In fact, after conducting several tests, Schiff (1961) has reported that for equal penetration, the pile in groups carried 1 to 7 times higher loads and furthermore, while thus the group efficiency was considerably more than 100 percent, the settlement ratio was much less than unity, a fact which is in agreement with the results reported in this paper.

Meyerhoff (1961) has explained that Schiff's results could have been due to the following factors—heterogeneity of soil, arching action between the piles, block failure, etc. The conditions of soil around and below the piles in relation to its density, and the change in development of frictional resistance, confinement conditions are also some of the other important points in this respect. Thus the present experimental data can be explained in the light of the above factors and is consistent with 'theoretical principles as also experimental facts'.

The authors agree with the discussor that the test tank does not allow for a very high ratio of H/L particularly for long piles. It may however be pointed out that the influence of rigid layer is felt only for a certain distance below the pile tip and therefore provision of extra depth beyond such distance is unlikely to alter the results. It is in this sense that the ratio H/L is considered to be infinite, i.e., the provided distance H is more than adequate for the examination of the influence of rigid layer for the length of embedment 'L' under consideration.

Finally, authors had included in their paper typical data covering all aspects of the study by including 10 figures and 7 tables and the length restrictions prevented them from giving any additional details. Authors wish to thank the discussor once again for his keen interest and hope that with further investigations on large scale tests it would be possible to examine all aspects of this problem in details.

References

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SCHIFF, S.C. (1961): "Discussion Ref. (2)." *Transactions, A.S.C.E.*, Vol. 126, pp. 1323-1324.

(2) The authors thank the discussors for the active interest they have shown in the paper and for their comments. Some of the points mentioned by them are already covered in the reply to the earlier discussion and only the remaining ones are therefore briefly discussed below.

In the laboratory tests, the rigid layer was provided by placing bricks up to the required thickness at the bottom of the tank. This brick layer obviously has a substantially high modulus of elasticity in comparison