Behaviour of Isolated Footings on Partially Saturated Soils*

by

M. Krishna Murthy and C. Venkatramaiah

(1) GOPAL RANJAN**

The authors deserve appreciation for having tackled an interesting topic of Behaviour of Footings. However, I wish to offer the following comments :—

1. The tests reported, have been carried out at the optimum moisture content and maximum dry density. It appears that these were carried out with the idea of finding the influence of condition of the soil (i.e., partially saturated, submerged, etc.). In discussor's opinion, identical tests should have been carried out on dry state also, so that the results of two series could have been compared and the influence of one variable only, i.e., degree of saturation could have been studied. The degree of saturation of the soil is also not mentioned.

2. On page 329 it is stated that the model footings used in the investigations had machined smooth surface and edges. Subsequently, the experimental results have been compared with those of theoretical Terzaghi's equation (Table I). Since Terzaghi's bearing capacity equation [Equation (1) for continuous footing] assumes rough footings which the model footings are not, it would have been more realistic to use the bearing capacity factors, especially N_γ given by Meyerhof (1955).

$$q_d = cN_c + \gamma D_f N_q + \tfrac{1}{2}\gamma B N_\gamma \qquad \ldots(1)$$

Where q_d = bearing capacity of continuous footing

c = unit cohesion

γ = unit weight of soil

D_f = depth of footing

N_c, N_q, N_γ = bearing capacity footing.

It may not be out of place to mention that the Indian Standard Code of Practice on Plate Load Test (IS : 1888-1971) also recommends the use of a treated plate, i.e., criss-crossed or chequered.

3. In the present tests since the value of $c_u = (1{\cdot}0\ \text{kg/cm}^2)$ is small the component due to cohesion in Equation (1) may be neglected. Also as all the tests have been carried out at zero depth, the component due to surcharge is also neglected. Equation (1) for this particular case then reduces to Equation (2).

$$q_d = \tfrac{1}{2}\gamma B N_\gamma \qquad \ldots(2)$$

This shows that for footings, the ultimate bearing pressure is directly proportional to footing width (Equation 3).

$$q_d \propto B \qquad \ldots(3)$$

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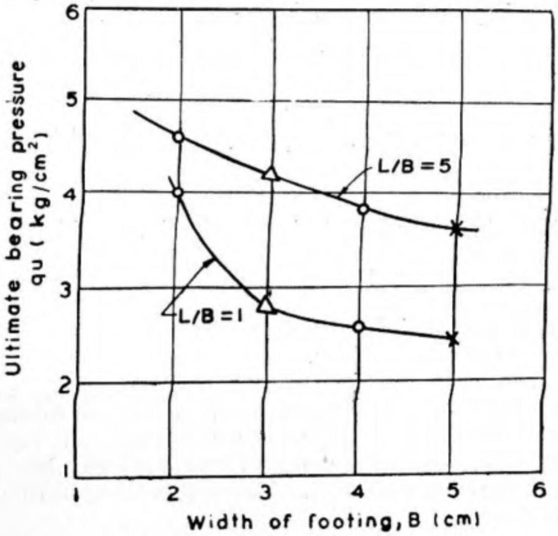

FIGURE : 1 Width of footing versus ultimate bearing pressure.

Plotting the results from Figure 7(*a*) for *L*/*B* ratio of 5 and 1 for various footings of width *B*, Figure 1 is obtained. This figure shows that for strip footings on loamy sand (as classified by the authors) the ultimate bearing pressure q_u decreases with the increase in the width of footing. This is contrary to the common belief and also shown by Equations (2) and (3) above. It will be appreciated if the authors could suggest the possible reason for this anamoly.

4. The authors have referred to IS : 1888-1962. A reference to the revised code IS : 1888-1971 should have been made. Also, it is suggested that instead of classifying the soil as loamy sand, the soil classification should have been done on the basis of respective Indian Standard Soil Classification System, IS : 1498-1971.

References

MEYERHOF, G.G. (1955) : "Influence of Roughness of Base and Ground Water Conditions on the Ultimate Bearing Capacity of Foundations". Geotechnique, Vol. 5, pp. 227-242.

IS : 1888-1971—Load Test on Soils.

IS : 1498-1971—Classification and Identification of Soils for General Engineering Purposes.

(2) K. N. VENKATAKRISHNA RAO*

While noting with interest, the results presented and conclusions drawn by the authors, the writer wishes to offer the following comments :

1. As could be seen from Table I, the theoretical value of '*q*' increases from 4·08 to 4·2 kg/sq cm for *L*/*B*=5, as *B* increases from 2

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to 5 cm, for the particular soil used, while the experimental value of 'q' decreases from 4·5 to 4·7 kg/sq cm in the tangent intersection method. As reported by the authors, when $L/B \geqslant 5$, the footing can be considered as a strip footing. For a strip footing, the general expression for 'q' is:

$q = CNc + 1/2\gamma \; BN\gamma + \gamma Df \, Nq$, with the usual notations. Knowing the value of C and ϕ, theoretical value of q can be calculated by the above expression, substituting the values of Nc, Nq, and $N\gamma$, for the corresponding ϕ, the diamensions of the model, and the density of the soil used. The theoretical value of q depends upon the particular theory used. Irrespective of theory used, the general trend of behaviour of the footing should be the same, for the particular values of c, γ, Df, B and ϕ. Similarly, between the theoretical and experimental values, because of many inevitable reasons, while there could be much divergence, it is reasonable to expect that the trend must be the same, even though the rate of variation may be different. Therefore, the writer requests the authors to explain how they can justify the behaviour of models for which there is a decrease in q as B increases for the same L/B ratio, while there is an increase in the theoretical value of q for the same L/B ratio.

2. Also as could be seen from the Table I, for example for $L/B=1$, in the tangent intersection method, the value of q decreases from 4·00 to 2·4 kg/sq cm when B is increased from 2 to 5 cm. With the usual shape factors [using for example Equation (3·2) of Teng], for the same L/B, since $D=0$, and $H=0$, the value of q increases with increase in B. In the light of this, the writer requests the authors to please explain why such a reverse trend and decrease in the value of q to the tune of 40 percent is there in their experimental values.

3. The shape factors which are being currently used have been established based on experimental and field observations. Since there is no theoretical justification for the particular numerical values suggested, they are always questionable. Hence, the writer agrees with the authors that it is probably wrong to always assume that the bearing capacity of a strip footing is less than that of a square or rectangular as is generally accepted. However, the writer feels that to contradict the generally accepted values, a much thorougher examination of the problem is required. The authors have reported the test results for one type of soil sample only, and a limited number of model tests. Effect of soil *type, field studies, different degrees of saturation*, different sizes, are all to be thoroughly investigated.

4. Much attention given in the paper is with regard to shape and size of the footings, whereas the nomenclature of the paper suggests that there is study of footings on the partially saturated soils, i.e., with various degree of saturation, etc.

(3) M.V.B. RAMANA SASTRY*

The authors have made interesting studies on Isolated Footings on partially saturated soils. The writer has the following comments :

1. In any loading test on footings the size of the tank should be sufficiently big so that the sides of the tank do not interfere with

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the failure surfaces. In field loading tests (Dinesh Mohan, 1961) the soil anchors are fixed at a minimum distance of 8 times the width of the plate so that the anchors neither disturb the soil nor come in the way of failure planes. Size of tank 40 cm × 40 cm would have been ideal in the case of tests with 4 cm and 5 cm wide footings.

2. From the results presented in all most all the cases the bearing capacity values obtained from Theoretical Terzaghi's equation are agreeing fairly well with experimental values ($L/B=5$) (obtained by tangent intersection method) when general shear failure is considered. This may not be the case when local shear condition are taken into account as some of the failures [Figure 11 (*b*)] are local shear. It was observed by the writer (Sastry, 1961) that in the case of local shear failures the Terzaghi's Theoretical equation gives too conservative values.

3. The authors have used mostly tangent intersection method for obtaining the bearings of soils. However, the writer feels, it is better to use the Log-Log plot method as it gives a better and accurate method of locating failure load.

4. From the analysis of the load test results made by the writer for the Steel Plant at Vizag, the author feels that when the plots are made carefully, results of ultimate bearing capacity obtained by intersection of tangents and Log-Log method would agree fairly well.

5. The moisture content in different tests at the time of actual loading and testing may not be the same as that of the O.M.C (used for compacting the soils). This will have considerable effect on the results of the tests. A determination of actual moisture content below footing immediately after tests would have been of some value in this direction. In order to avoid the complex effects of moisture content on the test results most of the studies made on the determination of bearing capacity are carried out on dry sand only.

6. It is felt that use of atleast two dial gauges one on either side of the loading plates to record settlements would have been better to account for any possible eccentricity, while loading, even in the load tests by the conventional method conducted by the authors.

References

DINESH MOHAN (1961): "Building Foundations Part II : Bearing Capacity of Soils, Technical Information Series 5 (*b*)". Published, *National Buildings Organisation.*

SASTRY (1961) : "An Experimental Investigation of Ultimate Bearing Capacity of Footings under Centric and Eccentric Loads in Dry Sand." *Thesis submitted in partial fulfilment of the Requirements for the Degree of Master of Technology to I.I.T.*, Kharagpur.

(4) SUDHENDU SAHA*

The authors have reported that the ultimate bearing pressure tends to increase with L/B ratio and it is wrong to assume that the bearing capacity of a strip footing is less than that of square or rectangular footing.

But the writer wants to point out that it may not be the right approach to look into the problem. According to Terzaghi's theoretical solution, for purely cohesive soils the bearing pressure of a square footing is greater than that of a strip footing, whereas for cohesionless soils the reverse is true. In case of C-ϕ soils, the bearing pressure of any type of footing will depend upon the relative values of C and ϕ.

Therefore, without ruling out the results obtained by the authors, it may be stated that the results are so obtained, only because the authors carried out the investigation with the loamy sands with very high value of angle of internal friction and very low value of cohesion, which may practically be considered as cohesionless soils for the present analysis of experimental results.

The writer requests the authors to please clarify the above.

AUTHORS' REPLY

(1) The authors wish to thank Dr. Gopal Ranjan for the keen interest evinced by him in their paper. It is not the intention of the authers to investigate the influence of degree of saturation but to study the behaviour of rectangular footings in relation to shape, size, and L/B ratio, although the authors do agree with the discussor that it is quite interesting to study the influence of degree of saturation by keeping shape and size parameters constant.

Though many authors agree that there is marked influence of roughness of base on bearing capacity, the same has not been established qualitatively and quantitatively. Whereas, Meyerhof suggested that ultimate bearing capacity of a perfectly smooth strip footing on sand (cohesionless material) is one half that for a perfectly rough base and no influence on clays, according to Terzaghi, the bearing capacity of a smooth strip footing is greater than that of a rough base on sand and vice versa for clays. Therefore, the experimental results have been compared with those of *Terzaghi's equation due to* its wider application in practice.

As was already mentioned in the 'Discussion of Test Results', any theoretical formula for bearing capacity is valid only for very dense soil, where the rupture surface is well defined, agreeing with the assumed shape as closely as possible. The load settlement curves obtained indicated a state of stress somewhat intermediate between general shear and local shear, while the coefficients for general shear were used in the computation of theoretical values. The L/B ratio of 5 for which the present comparison between experimental and theoretical values is made is in the transition zone between rectangular and strip footings. These factors are perhaps sufficient to cause divergence between the experimental and theoretical values, not only in magnitude but also in sign, thus warranting more work in this direction to confirm the trends. The authors thank the discussor for the various suggestions with reference to latest IS specifications. The

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soil used for the investigation falls under the group 'SP' according to Indian Standard Soil Classification System, IS : 1498-1971.

(2) In regard to Shri Venkatakrishna Rao's comments, the authors wish to state the following :

The method of evaluation of 'q' itself could be often the single most important factor which could cause discrepencies of the type mentioned when compared with theoretical values computed by using empirical factors.

The authors agree that a more thorough investigation with greater number of model tests varying a number of parameters is necessary to contradict the generally accepted shape factors, etc. The work presented by the authors merely tries to focus the attention of research workers in the field to the problem and stress the need for more work in this direction.

While the term 'partially saturated soils' is included to describe the condition of the soil used in the investigation, it is not meant to attach under significance to the degree of saturation in the present investigation. As regards the first point raised by Shri Venkatakrishna Rao, it is covered by the authors' reply to the discussion of Shri Gopal Ranjan.

(3) The authors thank Shri Ramana Sastry for the interesting comments. While agreeing with him that it would have been better to use a bigger tank to avoid possible edge effects, the authors felt that soil compaction in the mould would involve practical difficulties. In the model tests it was observed that the failure zones were not close to the edges.

The authors fail to appreciate the significance of the moisture content below the footing immediately after the test as long as it is ensured that the water content in the various model tests just before loading, is almost the same, although it might be slightly different from the O.M.C.

In respect of the number of dial gauges used to record the settlement of the plates, only one dial gauge was used by the authors owing to the small size of the plates.

(4) The authors wish to state that the points raised by Shri Sudhendu Saha are well covered by their replies to the discussion of Shri Gopal Ranjan and Shri Venkatakrishna Rao.

The authors finally thank all the discussors for the keen interest evinced by them in their work.

Reference

MEYERHOF, G G. (1951) : "The Ultimate Bearing Capacity of Foundations". Geotechnique, London, Vol. 2, December 1951 issue, pp. 301-330.

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