Short Communication

Influence of Capillary Zone on Settlement of Footings on Sand

by

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Introduction

The effect of capillary water in the capillary zone of a sand deposit is to increase the in situ effective vertical stress. This results in an increase in stiffness of the soil. As a consequence, a test plate resting on a capillary sand bed will undergo smaller settlement as compared to a footing resting on a dry or submerged deposit. For this reason, the results of load tests conducted on capillary bed will load to an underestimation of footing settlement. Though this fact is known, no work has been reported in literature to estimate, quantitatively, the effect of capillarity on settlement of test plates or footings resting on sand. Though a load test is not to be conducted on a capillary bed, sometimes, tests are conducted inadvertan tly on capillary beds due to misjudgement on the height of possible capillary rise. It can be pointed out here that the height of capillary rise in a silty sand could be of the order of 2 to 3*m*. (Kezdi 1974, McCarthy and David 1977) and if a load test is to be conducted at the level of the water table to aviod the effect of capillarity, the depth of excavation for the load test may become too large and the cost of conducting a load test may become prohibitive. Therefore, there is a need to estimate the effect of capillarity quantitatively and the same is attempted based on a simple and approximate analytical treatment.

There is no experimental evidence on the effects of capillarity. Therefore tests on a small plate resting on capillary sand bed are conducted and the results are presented. Results of a field load test on a 60 cm plate which was possibly resting on a capillary bed is also presented. These results illustrate the effect of capillarity on footing settlement.

Analytical Estimation of Effect of Capillarity

The sand bed upto the significant depth below the footing is divided into a number of thin layers. The elastic modulus at the mid point of

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each layer is computed using the equation,

$$E \propto \sigma_v \left(\frac{1+2k_o}{3} \right)^n \quad ...(1)$$

where

σ_v = insitu effective normal stress computed taking into account the capillary tension.

k_o = coefficient of earth pressure at rest

n = *a* constant which may vary from 0.4 to 1.0 ; *A* value of 0.5 has been suggested as reasonable by Lamb and Whitman (1969).

The vertical stress p_v due to the footing load is computed using $2v : 1H$ load dispersion and the strain at each layer is obtained as,

$$\epsilon = \frac{P_v}{E} \quad ...(2)$$

The compression of each layer is obtained by multiplying the strain by the thickness of that layer. The settlement of the footing is then obtained by adding the compressions of the layers within the significant depth.

In view of the approximations involved in the above procedure and uncertainities on the values of k_o and n, numerical estimation of settlement will be unrealistic. However, the procedure is considered adequate for estimation of relative settlement of footings of various sizes.

The results are therefore presented in the form of nondimensional parameters in Figs. 1 and 2. These results can be used to estimate footing settlements from the resultsof a load test conducted on capillary sand bed. Figure

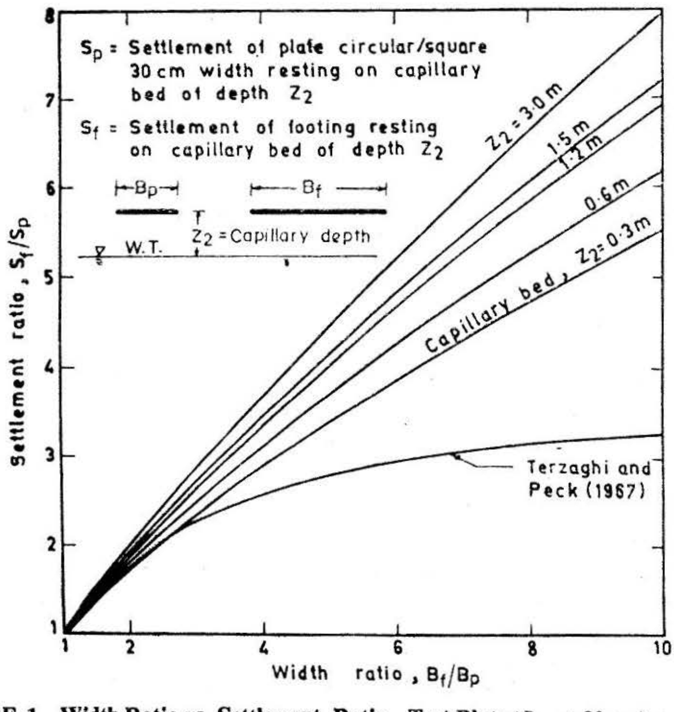

FIGURE 1 **Width Ratio vs Settlement Ratio—Test Plate (B_p = 30 cm) as well as Footing (B_{fcm}) on Capillary Bed.**

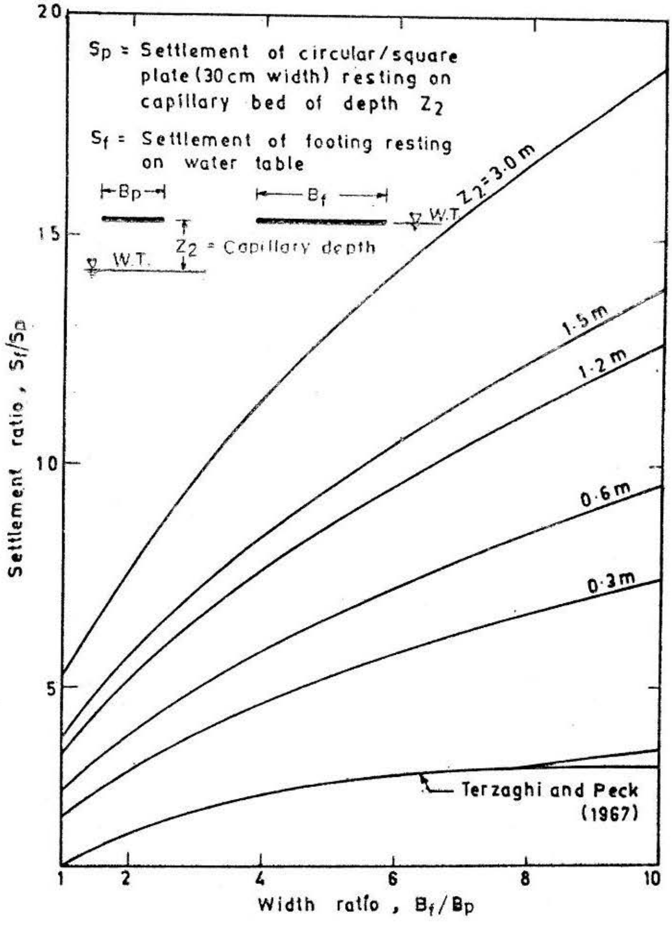

FIGURE 2 Width Ratio vs Settlement Ratio—Test Plate (B_p = 30 cm) on Capillary Bed and Footing (B_{fcm}) on Submerged Bed.

1 can be used when the test plate and the footing rest on capillary beds of same thickness. Figure. 2 can be used to estimate the settlement of footing when the load test is conducted on capillary bed, but there is a possibility of water table rising upto the base of the footing.

The use of the charts presented in Fig. 1 and 2 requiries data on the thickness of capillary zone (or capillary head). Kezdi (1974) reports that the capillary head can be of the order of 2 to 3 *m* in silty sand. There are other empirical data on capillary head based on grain size (Lambe and Whitman 1969 ; McCarthy and David, 1977). These can aid a preliminary estimate of possible capillary head for a given site. The capillary head depends on factors other than grain size such as the nature of the fines and other impurities present in soil and the manner in which the capillary equilibrium is achieved (Lambe 1951, Kezdi 1974). Therefore, wherever it is suspected that the test plate is resting on capillary bed, the capillary head should be determined from the data on variation of water content with depth upto water table. Samples may be collected from ground level upto the water table for water content determination. The degree of saturation may be calculated and the same may be plotted as a function of depth as shown in Fig. 3. The point 'A' in Fig. 3 where the curve tends to be vertical is the elevation upto which the capillary water exists (Lambe, 1951). Therefore, the distance from point 'A' to the free water surface may be taken as the capillary head.

Experimental Evidence

There is no experimental evidence in literature on the effect of capillarity on footing settlements. An experimental investigation was therefore carried out on 12 cm diameter mild steel plates in a circular test tank of 60cm diameter. The sand used was poorly graded sand and the test bed was prepared at 82 per cent relative density.

The results of the load tests on dry/submerged/capillary sand beds are presented in the form of load-settlement curves in Fig. 4. The load-settlement curves indicate that for a given load intensity, the magnitude of settlement decreases with increase in thickness of capillary beds. The magnitude of reduction in settlement due to the capillarity is substantial. The load settlement curves also indicate that the ultimate bearing capacity of the test plate is increased substantially due to the capillarity in soil.

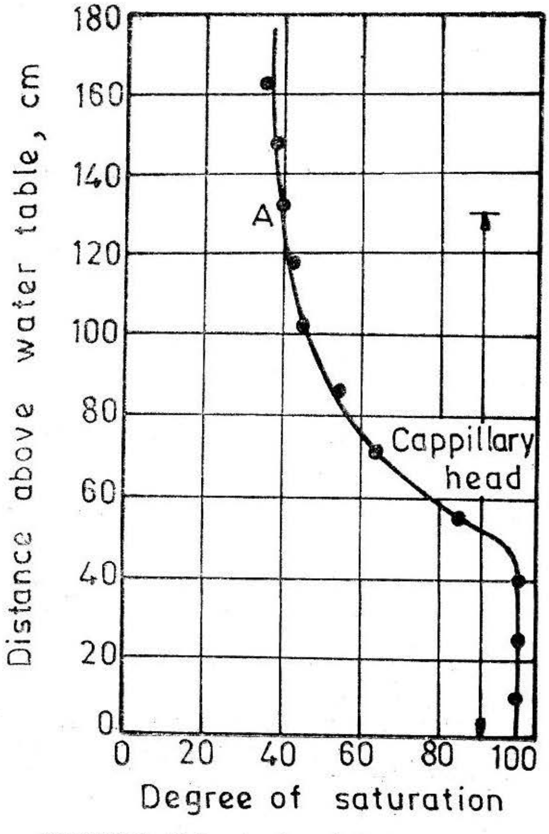

FIGURE 3 Determination of Capillary Head.

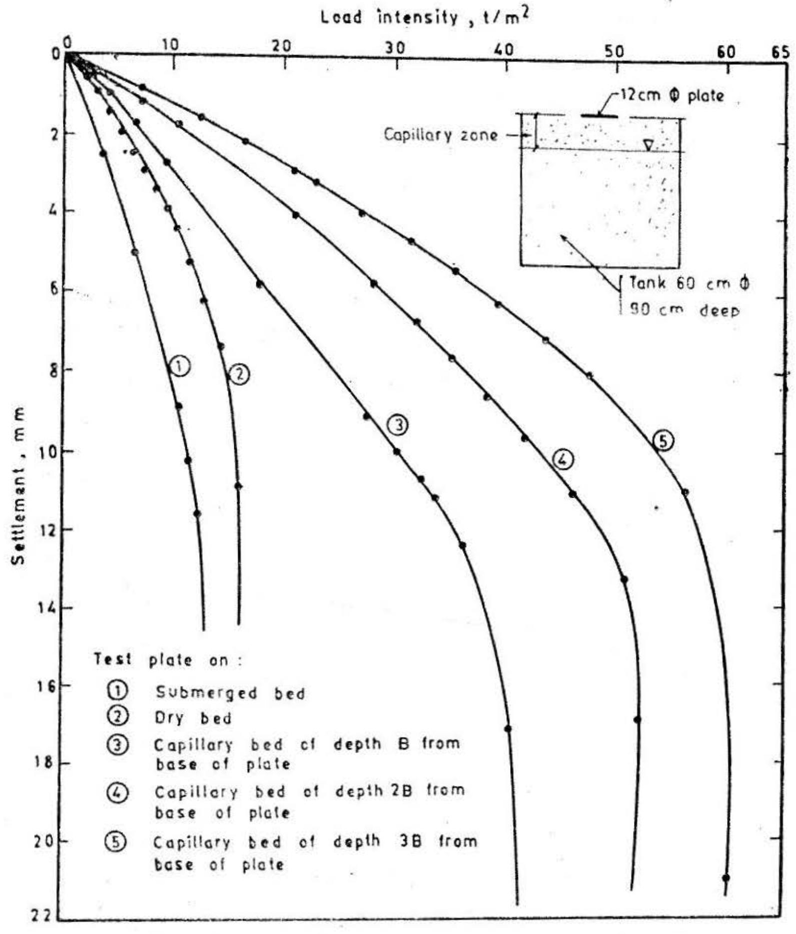

FIGURE 4 Results of Laboratory Load Tests on Capillary Bed.

No attempt has been made to make a comparison of the results of model tests with those analytically predicted for two reasons viz., (1) the analytical procedure outlined, in view of the assumption made is considered good only for estimating footing settlement when the settlement of a test plate is known and (2) the results of tests on plates small than 30cm can be considered good at best for qualitative prediction.

Figure 5 shows the results of a set of load tests conducted at a project-site (Prakash et al. 1976). The soil at the site was a poorly graded sand. The values of standard penetration resistance, N corrected for overburden pressure, the positsion of water table, and the location of the test plates are also shown in Fig. 5.

The results presented in Fig. 5 indicate that the settlements observed in test no. 2 and test no. 3 are much smaller than that in test no. 1. For example, at a load intensity of 5 t/m^2, test no. 1 shows a settlement of 6.2 mm whereas test no. 2 shows a settlement of 1.3 mm. If the usual water table correction is applied to the results of test no. 2(to make it correspond

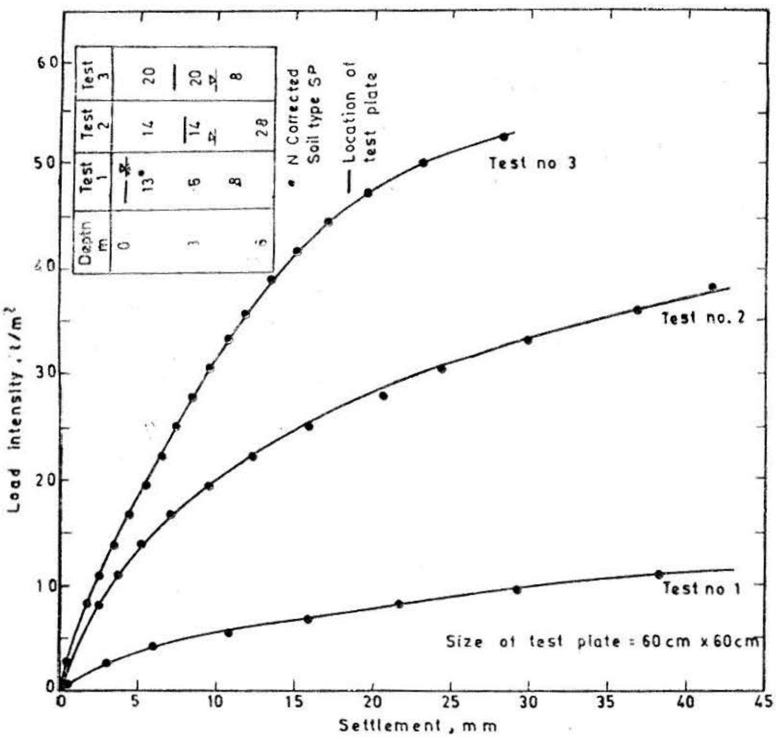

FIGURE 5 Results of Field Load Tests on Capillary Bed.

to test no. 1) the settlement will become 2.6 mm. Thus even after accounting for the submergence, the observed settlement of test no. 2 is much less than for test no. 1. The values of the corrected standard penetration resistance, *N* just below the test plate in test no. 1 and 2 are 13 and 14 respectively. Hence the difference in settlement cannot be attributed to ony difference in relative density. The difference can only be explained by the fact that the test plate in test no. 2 was resting on a capillary bed. In the same way the smaller values of settlement observed in test no. 3 can be attributed only to the possible effect of capillary zone.

Conclusions

1. Capillarity in a sand bed reduces the settlement of a footing substantially. The magnitude of reduction is dependent on the thickness of capillary zone.

2. A plate load test conducted on a capillary bed of sand may, under certain conditions, lead to an underestimation of settlement of a footing to an extent of 400 per cent or more.

3. The settlement ratio vs width ratio relationship presented herein on the basis of analytical investigation, can be used to estimate settlement of footings from the results of load tests conducted on capillary bed.

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