Interference between Adjacent Square Footings on Cohesionless Soil

by

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Introduction

VERTICAL forces generally form a major part of the loading system for structures supported on columns and walls. These forces become more important when they are influenced by the proximity of the relative position of the footings. The calculation of bearing capacity and settlement characteristics are usually carried out by conventional methods applicable only to isolated footings. In practice, the footings may not be isolated, which lead to the interference between them. A study of interference between adjacent footings is, therefore, of significant importance.

Stuart (1962) examined the state of interference, between two parallel strip footings placed at varying distances from each other on cohesionless soil. Mandel (1965) investigated a more general problem with structures on either side of a footing. He used the method of characteristics and considered the soil having both cohesion and friction. Both Stuart and Mandel demonstrated that a decrease in spacing between strip footings produced an increase in the bearing capacity. They introduced factors reflecting the efficiency of interference for bearing capacity between footings. Rao (1965) studied the interference when three adjacent square footings were loaded simultaneously. His results were contrary to those given by Stuart and Mandel. Agarwal (1970) investigated the interference effect for both strip and rectangular footings. An increase in the bearing capacity and a simultaneous increase in the settlement characteristics was observed when the centre to centre spacing between the footings was reduced. Murthy (1970) obtained his results by loading one of the rectangular footings to its safe bearing capacity, and the other one to failure. It was observed that for a given load the bearing capacity increased and the corresponding settlement decreased as the spacing between the footings was reduced. These investigations, however, contribute little to the interference between square footings.

The investigations reported herein envisaged an experimental study of the interference effect of two adjacent smooth, square footings subjected to vertical load on cohesionless soil. The behaviour of two adjacent footings

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have been compared with that of an isolated footing and the factors reflecting the efficiency of interference for bearing capacity as well as for settlement have been introduced. It is observed that the interference changes both the load at failure and the settlement characteristics to values different from those of isolated footings.

Development of Test Programme

SAND

Clean coarse-medium sand with the following characteristics was used as the soil medium : coarse fraction (1.18 mm—600 micron)=43 percent, medium fraction (600 micron—212 micron)=51 percent, fine fraction (212 micron—75 micron)=6 percent, effective size=0.27 mm, uniformity coefficient=2.4, coefficient of curvature=0.9, maximum void ratio=0.44, relative density=80 *percent, angle of shearing resistance*=47°. The *grain-size* distribution curve is shown in Figure 1.

FOOTINGS

Square footings of sizes 4 cm × 4 cm, 4·9 cm × 4·9 cm and 6 cm × 6 cm were cut from aluminium alloy plates. The faces of these footings were sufficiently smooth enough to be treated as smooth footings. Each footing was 13 mm thick.

TANK

The tests were conducted in a tank, 100 cm × 50 cm in plan and 50 cm in depth. The tank was made of wooden planks, 2.5 cm thick, stiffened with angle sections provided at bottom, top and all corners. The sectional elevation of the tank, along with the loading device, etc., is shown in Figure 2.

LOADING DEVICE

The loading system was so designed as to apply the load to the centre of a rigid beam, and transfer in turn to the spherical balls placed at the

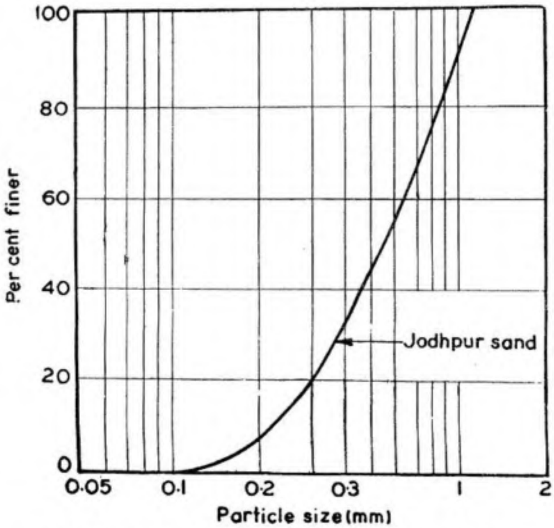

FIGURE 1 : Particle-size distribution of sand.

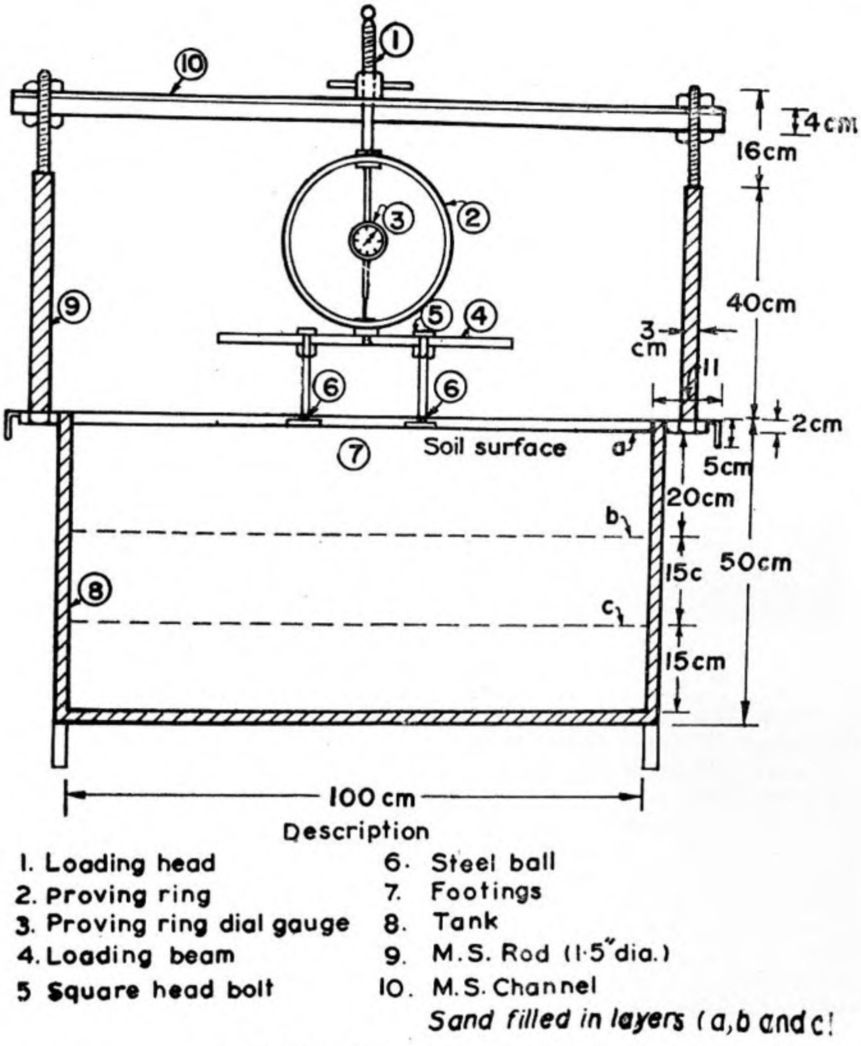

FIGURE 2 : Sectional elevation of tank.

centre of the footings by square headed bolts fixed at equal distances from the centre of the beam. A loading head consisting of a 20 mm diameter threaded steel rod with a handle, was rigidly fixed to the steel frame with nuts and bolts. It transmitted load to the centre of the rigid beam through a calibrated proving ring (Figure 2). Two slots, each of 13 mm width, were milled in the rigid beam so as to allow a perticular spacing, ranging from one to six times the width of footing. A steel strip was fixed with araldite to each bolt-head to adjust the dial gauges against it for measuring settlement of each footing. The set-up for the load settlement test on single footing is shown in Figure 3 and that for adjacent footings in Figure 4.

Test Procedure

Initially, dry sand was poured into the tank through a large size funnel in three layers. Each layer was compacted by vibrating it with the

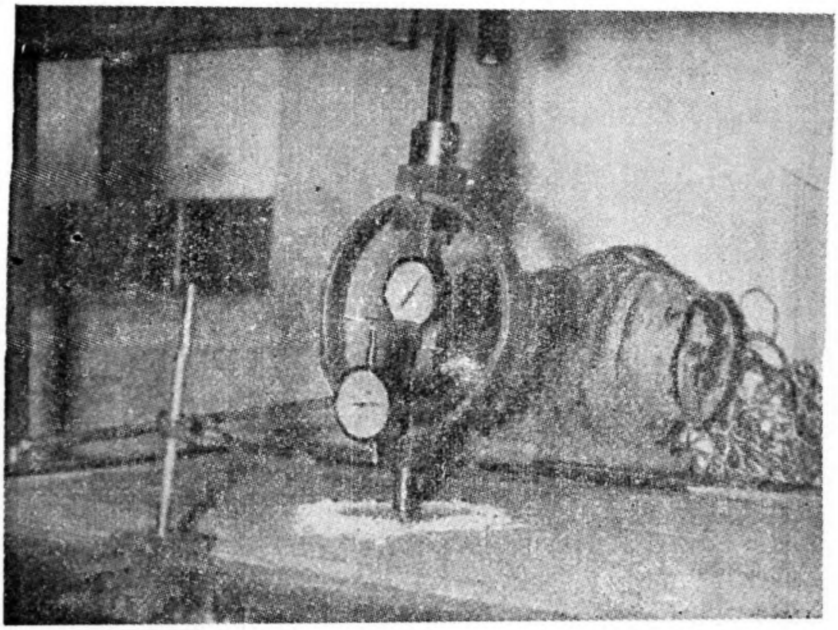

FIGURE 3 : Experimental set-up for isolated footing.

simultaneous working of two form-vibrators for one minute having a common base plate. For subsequent fillings, the tank was emptied to a depth of 20 cm, leaving 30 cm of sand in the bottom. The whole assembly of the loading arrangement was suspended vertically downward from the loading frame, so as to act as a rigid unit. The footings were carefully placed at the required spacing. The load was applied in convenient increments. Settlement of each footing was observed by two dial gauges by setting them against the steel strips. The settlement was observed till the soil failed in shear. Tests on isolated footings were also performed in similar manner. Each test was repeated thrice to ensure their reproducibility. The centre to centre spacing of adjacent footings was varied from one to six times the width of the footings.

Test Results and Discussions

Important changes in the ultimate bearing capacity and settlement characteristics of foundations occur if they are placed in a group. The centre to centre spacing of individual footing is the most significant influencing factor although surface roughness, soil density and group shape have also important secondary effects on the group behaviour. In dense sands the failure may be considered as general shear failure and the load intensity at failure is taken as ultimate bearing capacity.

Based on test results the following factors have been introduced :

(a) INTERFERENCE EFFICIENCY FACTOR (F_r) FOR BEARING CAPACITY

It is the ratio of the ultimate bearing capacity of the footings group to

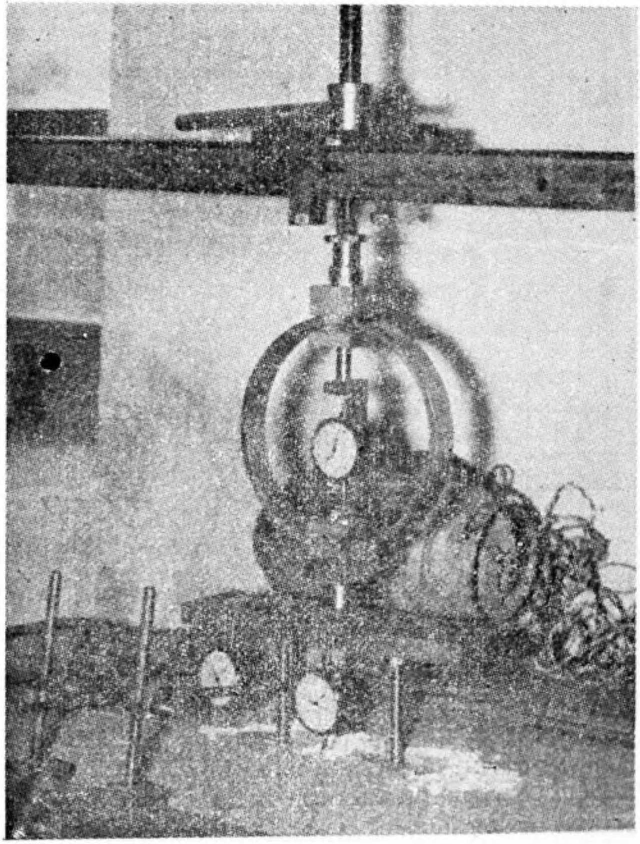

FIGURE 4 : Experimental set-up for adjacent footings.

that of an equal number of identical isolated footings (Stuart, 1962), i.e.,

$$F_r = \frac{q_f\,(\text{group})}{n \times q_f\ (\text{isolaled})} \qquad \ldots(1)$$

The ultimate bearing capacity of the smooth square footings can be predicted by introducing the interference efficiency factor (F_r) for bearing capacity in the Terzaghi's ultimate bearing capacity relationship as follows :

$$q_f = 0{\cdot}4\ \gamma\ B\ F_r\ N_r \qquad \ldots(2)$$

Figure 5 shows the average curve of variation of the interference efficiency factor (F_r) for bearing capacity, based on the experimental observations on isolated footings as well as adjacent square footings. The equation of the curve may be expressed as follows :

$$F_r = 2{\cdot}25 - 0{\cdot}31\,\frac{S}{B}, \text{ for } \frac{S}{B} \leqslant 3{\cdot}25 \qquad \ldots(3)$$

$$\text{and } F_r = 1{\cdot}04, \text{ for } \frac{S}{B} = 5 \qquad \ldots(4)$$

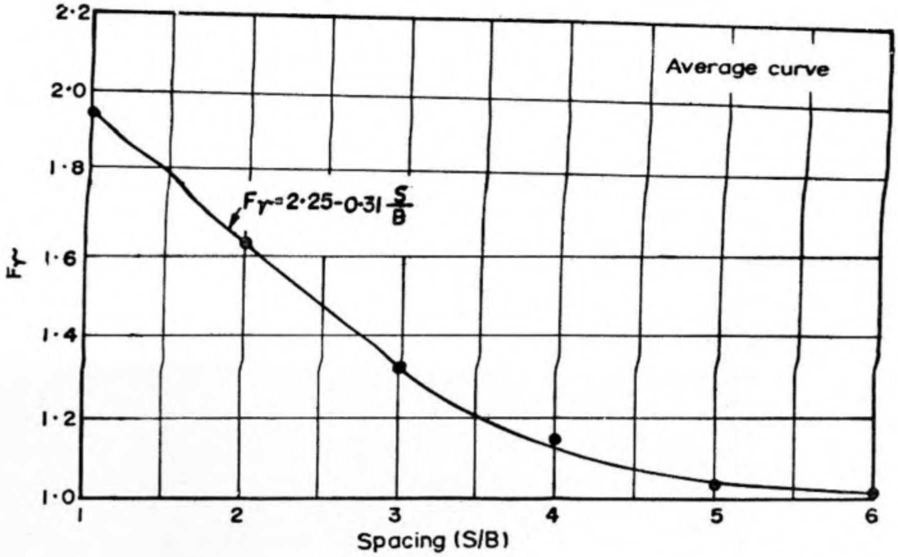

FIGURE 5 : Interference efficiency factor for bearing capacity versus $\frac{\text{spacing}}{\text{width}}$ (average curve).

(b) INTERFERENCE EFFICIENCY FACTOR (F_ρ) FOR SETTLEMENT

It is the ratio of the settlement of the footings group at a given intensity of pressure to that of an identical isolated footing at the same intensity of pressure multiplied by the number of footings in the group. The intensity of pressure should be within the elastic limit, i.e.,

$$F_\rho = \frac{\rho_{(\text{group})}}{n \times \rho_{(\text{isolated})}} \qquad \ldots(5)$$

The probable settlement of a pair of smooth square footings can be obtained by introducing the interference factor (F_ρ) for settlement in the semi-empirical inter-relationship as follows

$$\rho = \rho_f \left[\frac{B\,(B_f + 30{\cdot}5)}{B_f\,(B + 30{\cdot}5)}\right]^2 . \, F_\rho \qquad \ldots(6)$$

$$\rho = \rho_f \, . \, F_\rho, \text{ for } B = B_f \qquad \ldots(7)$$

Figure 6 shows the average curve for variation of interference efficiency factor (F_ρ) for settlement, based on experimental observations on isolated footings as well as adjacent footings. It is observed that factor F_ρ increases almost linearly with the increase in $\frac{S}{B}$ ratio. The equation of the curve may be expressed by the following equation :

$$F_\rho = 0{\cdot}4 + 0{\cdot}10 \, \frac{S}{B} \, , \text{ for } \frac{S}{B} \leqslant 5 \qquad \ldots(8)$$

Figure 7 shows the load-intensity/settlement average curve for isolated footings of various sizes. It is observed that for the same load intensity,

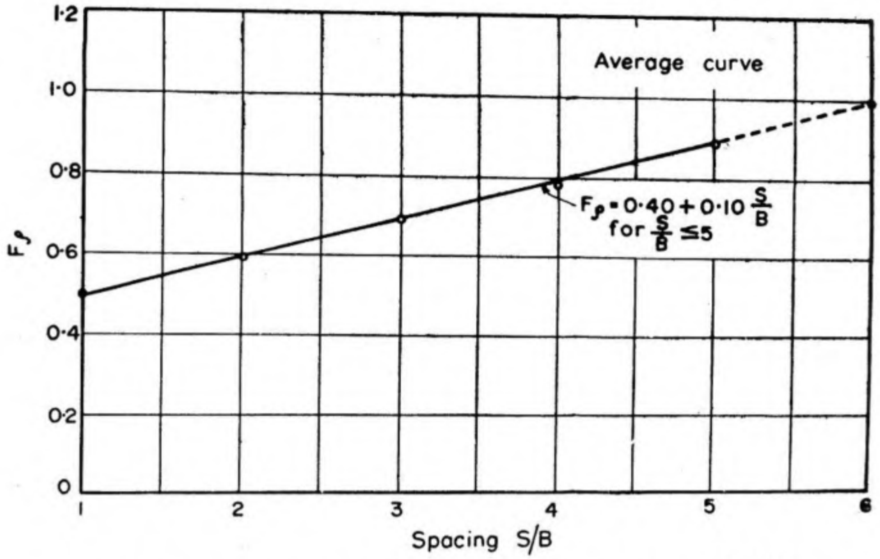

FIGURE 6 : Interference efficiency factor for settlement versus $\frac{\text{spacing}}{\text{width}}$ (average curve).

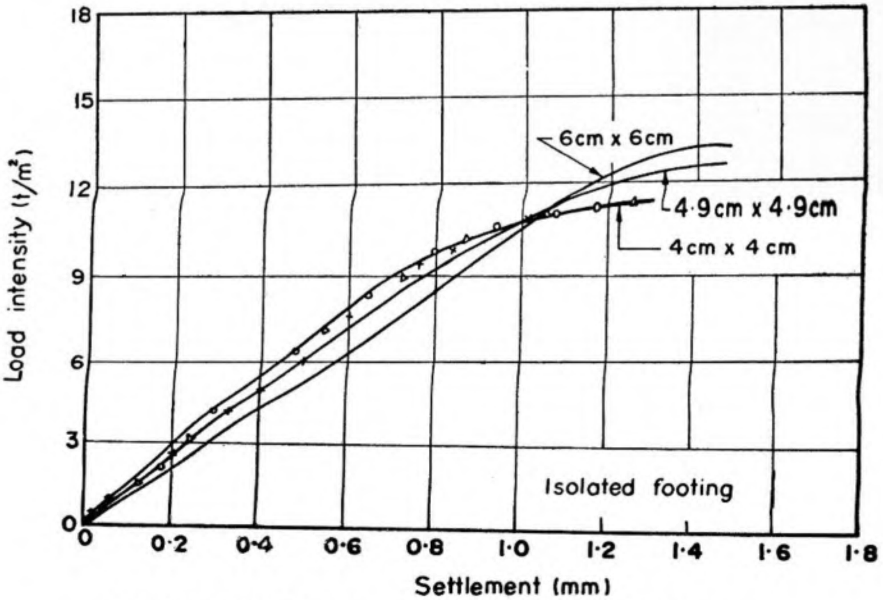

FIGURE 7 : Load intensity versus settlement for isolated footings.

the settlement increases with the increase in the size of the footing. Figures 8, 9 and 10 show the load-intensity/settlement average curves, for each footing of the group, respectively for the following sizes of footings : 4 cm × 4 cm, 4·9 cm × 4·9 cm and 6 cm × 6 cm. In each of these figures, the load-intensity/settlement curve for isolated footings of that size has also been given for comparison. A study of these curves lead to the following inferences :—

(*i*) The average ultimate bearing capacity of the footings in a group is greater than the ultimate bearing capacity of an isolated footing of the same size. When the footings are placed in a group, the individual foundation failure mechanism becomes distorted due to the overlapping of the failure surfaces. The presence of an adjacent footing causes the resultant soil reaction as the footing's base to become both eccentric and inclined. The normal symmetrical failure pattern becomes asymmetric and the failure occurs predominently to the free side of each footing.

(*ii*) The settlement for a given load intensity decreases as the centre to centre spacing between footings decreases. As the footings sink into the ground, the soil compresses to a certain distance on both sides of the footing. This results in an increase in the strength of soil. The increase in strength of soil plays its role in the settlement characteristics.

(*iii*) The ultimate bearing capacity and settlement of adjacent square footings on sand are not significantly affected when the spacing between them is more than five times the width of the footing.

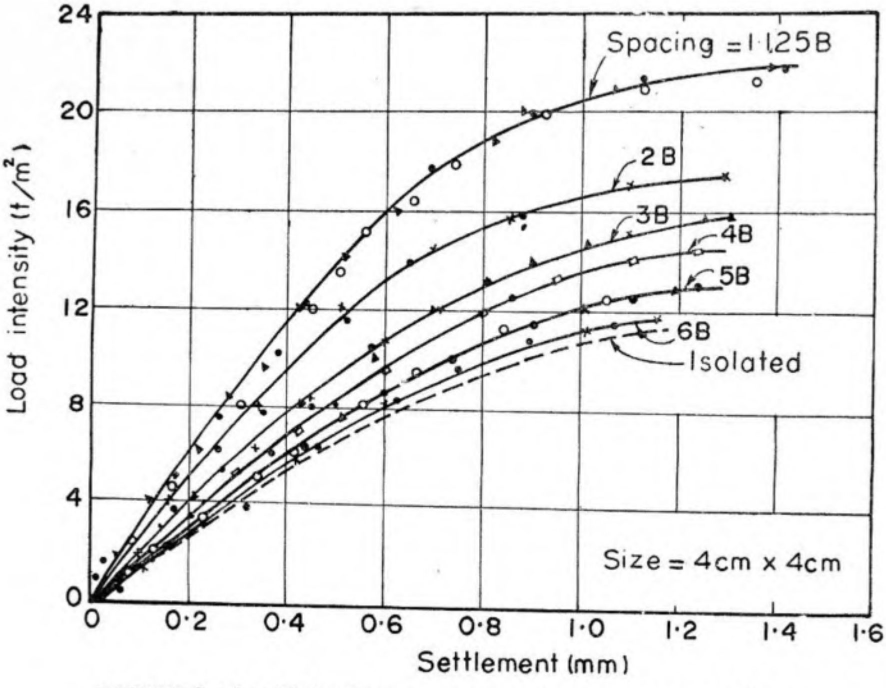

FIGURE 8 : Load intensity versus settlement for 4 cm × 4 cm footings.

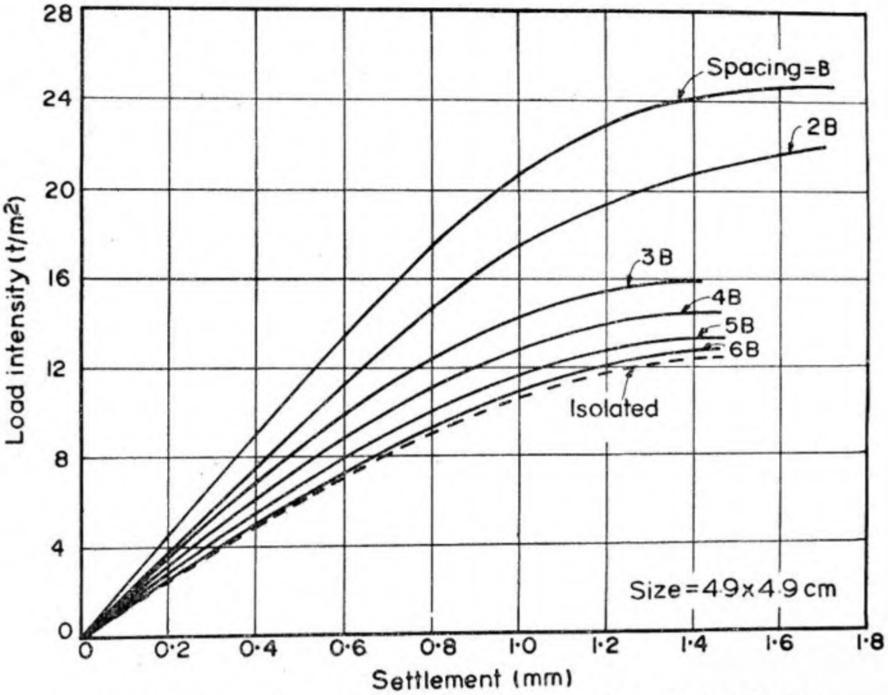

FIGURE 9 : Load intensity versus settlement for 4·9 cm×4·9 cm footings.

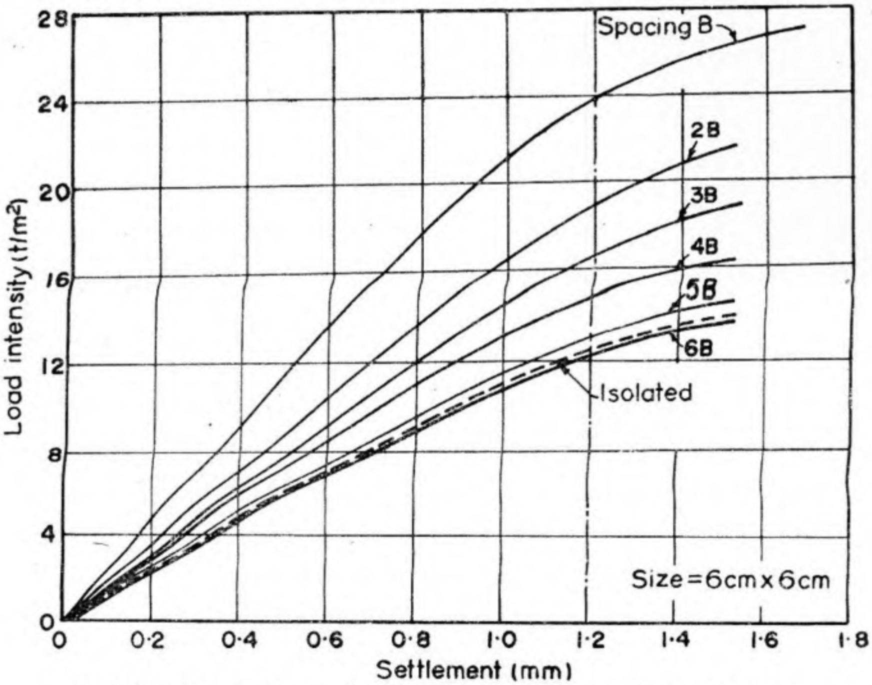

FIGURE 10 : Load intensity versus settlement for 6 cm×6 cm footings.

Conclusions

The bearing capacity and settlement characteristics of the footings are affected when they are placed in a group. Out of the various factors affecting these characteristics, the spacing of the footings is the most significant one. The interference of footings on dense sand is observed to cause an increase in bearing capacity and decrease in settlement with reduction of spacing. In the absence of rigid theoretical solutions for group action of square footings, experimental investigations serve very useful purpose and the empirical efficiency factors developed herein may be used to predict the group behaviour from that of an isolated footing.

List of Symbols

B = width of footings,
B_f = width of test footing,
F_r = interference efficiency factor for bearing capacity,
F_ρ = interference efficiency factor for settlement,
n = number of footings in a group,
N_r = Terzaghi's bearing capacity factor for general shear,
q_f = ultimate bearing capacity,
γ = unit weight of soil,
ρ = probable settlement of a pair of smooth square footings, and
ρ_f = settlement of test footing.

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