Interference of Surface Footings in Sands

by

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Introduction

THE load on a footing resting on soil stresses a particular prism of the soil. Usually, at failure this zone extends to 2.5 times the width of the footing on either side of the footing in horizontal direction and twice the width of the footing in the vertical direction. An adjacent footing placed at spacing less than 2.5 *B*, *B* being the width of footing, the failure zones of two footings will interfere each other. Due to this fact, the bearing capacity and settlement characteristics of such interfering footing will be changed from that of isolated footings.

This phenomenon of interference in foundation is of greater practical interest in closely built in areas where there may be interference of stress distribution in the foundation soils. Where a particular area goes on developing, the proximity of buildings to each other will have a definite influence on the bearing capacity of soil for a set of given foundation conditions.

The calculations of the bearing capacity of a foundation are usually carried out using the methods which are developed on the basis of isolated footings (Terzaghi 1943, Meyerhof 1951) even in the case of closely spaced footings. The non-recognition of the phenomenon of interference is perhaps due to the understanding that it will give the results on safe side and therefore, will provide additional factor of safety on the already conservative values obtained by the theories developed for isolated footing.

So far, the phenomenon of interference of footings has been studied by very few investigators. The analytical study was first done by Stuart (1962), who examined the state of affairs of two footings in cohesionless soils. He developed the mechanism of rupture surface for analysis on the basis of the concept given by Hill (1950) for isolated footings and suggested the rupture surfaces for different spacings as shown in Figure 1. At wide spacings [Figure/(*a*)], no interference takes place and each footing acts as an individual footing. As spacing is reduced, a condition shown in Figure 1(*b*) arises, where the passive zones penetrate. Since the stresses on the vertical section 'ge' remain same as for isolated case, no

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change in bearing capacity value is apparent. At closer spacing, an intermediate condition arises [Figure 1 (*c*)], in which passive zones between the footings are curtailed and changes in the stress values result. At very close spacings [Figure 1(*d*)], the outer spirals come into contact. At this spacing block occurs and the pair will act as a single footing.

Stuart (1962) gave the results in the form of non-dimensional charts. His results indicated that blocking of foundations occur when the clear spacing between the two footings lie between 0 to 0. 5 *B*,*B* being the width of footing. It is seen that this spacing depends on the value of angle of internal friction. For lower values of $\phi(<30°)$, blocking occurs when the two footings are just in contact. For higher values of $\phi(>40°)$, the blocking occurs up to the spacing of 0.5 *B*. Up to this spacing, the bearning capacity is found to increase rapidly. Beyond which the bearing capacity reduces to the value of bearing capacity corresponding to isolated footing which occurs approximately at spacing 4.5 *B*.

Stuart (1962) was concerned only with the interference between two footings (Figure 1). Mandel (1963) investigated the more general problem with structures on either side of a footing. He developed the

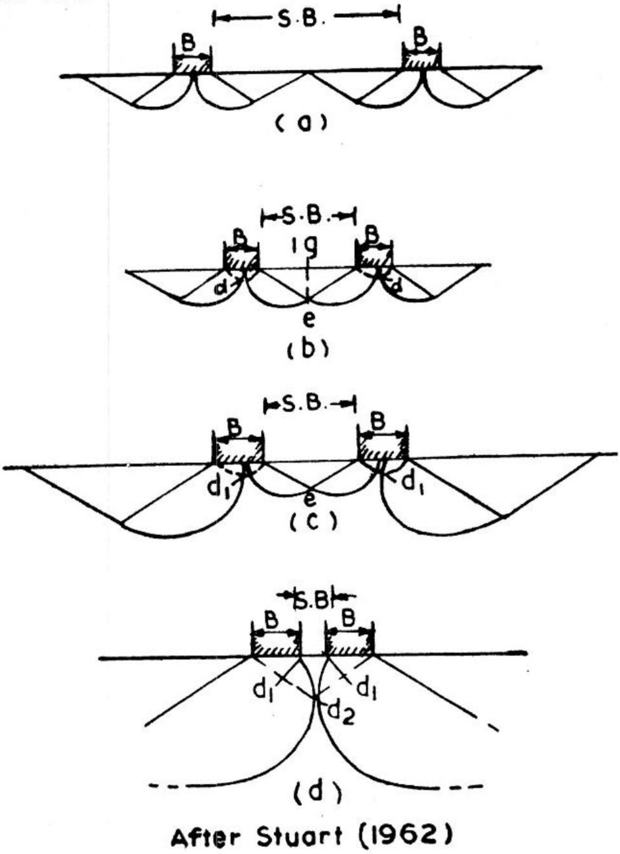

FIGURE 1 (a,b, c&d): **The development of the failure surfaces as two rough based foundations approach each other on the surface of a cohesionless soil.**

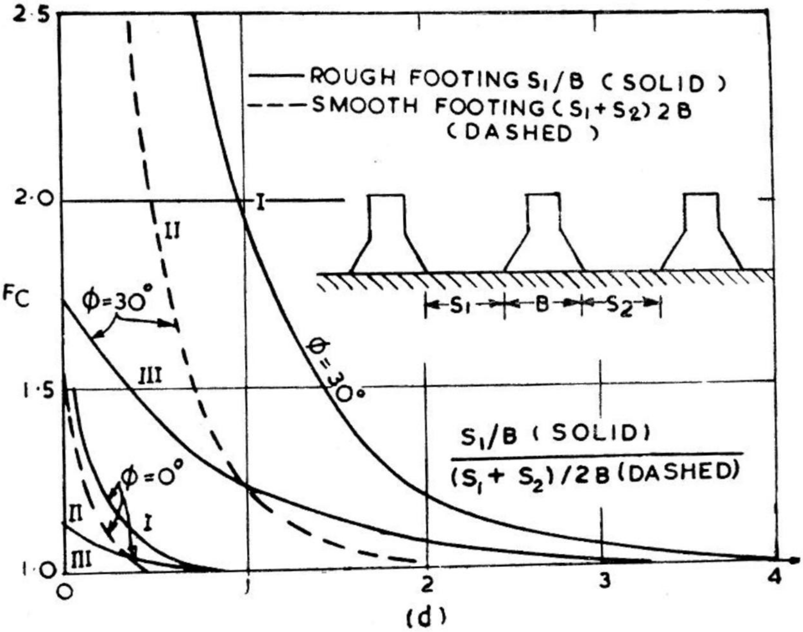

FIGURE 2 : Fc verius S.'B.
(After Mandel, 1963)

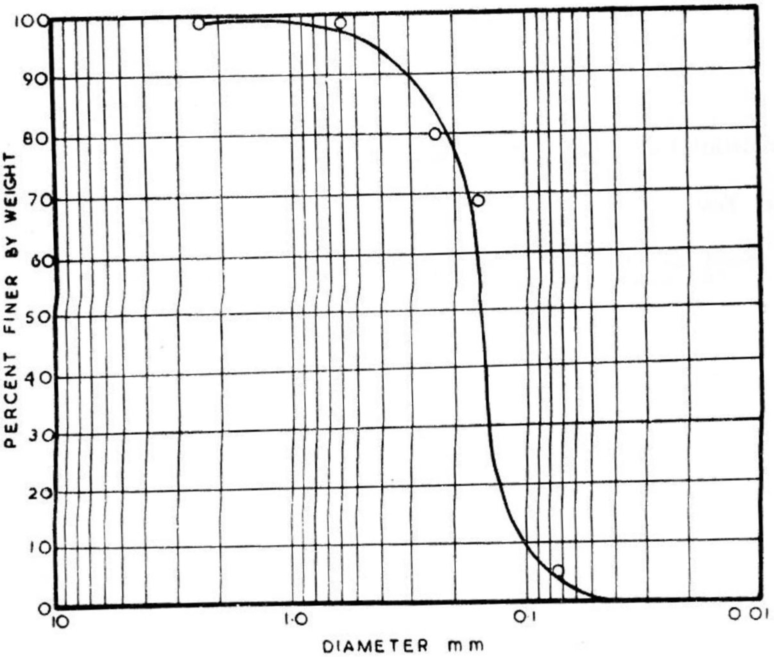

FIGURE 3: Grain-size distribution of Ranipur sand.

solution for an ideal soil considering it as a weightless material. His results are shown in Figure 2. The curves labelled I are for rough footing with $S_1=S_2$ and with abscissa scale of S_1/B. Curves II apply for footings having unequal spacing with abscissae as $\frac{S_1+S_2}{2B}$. Curves III are for the condition that S_2 is infinity with $\frac{S_1}{B}$ on the horizontal scale. This last case resembles to the case analysed by Stuart (1962). It is evident from these curves, that as the spacing between the footings decreases, the bearing capacity increases. This is in general agreement to the work of Stuart (1962).

West and Stuart (1965) analysed the problem of interference of the two surface footings with the concept that the contact pressure below such footings becomes non-symmetrical. Due to this reason the load on the footing becomes eccentric. Their results follow the similar trend as of Stuart (1962) but their values of bearing capacity quantitatively were lesser than the values obtained by Stuart (1962).

Stuart (1962) studied this problem with model tests also. They conducted the tests on two footings taking dry sand as the medium. His test results follow the similar trend as predicted by his theory. But it is seen that experimental values are on low side when compared quantitatively with his theory. He assigned the three possible reasons for this difference: (*i*) the footing could not be prevented completely from rotating and spreading, (*ii*) the surface of sand could have been slightly looser than the mass and (*iii*) placing of the footings on the surface may have caused same disturbance to the sand.

West and Stuart (1965) conducted similar type of tests and confirmed the results of Stuart (1962).

The above discussion of all the available literature on the topic indicates that model test data available is too meagre. In addition to this no attempt has been made to study the settlement characteristics of such footings. To study the phenomenon of interference in footings in more detail, this problem was taken for study.

Model Tests

Both the two-and three-dimensional tests were conducted in this study. The tests were performed on uniform, dry Ranipur sand at relative density (*RD*) of 75 percent. The grain size curve is shown in Figure 3. Ranipur sand ($D_{10}=0.13$ mm, $C_u=2.10$, $G_s=2.66$) has angle of shearing resistance 41° at *RD* of 75 percent. Angle of shearing resistance was obtained by slow triaxial test.

The three-dimensional tests were conducted in a tank 114 cm × 114 cm × 49 cm deep constructed of wood, with angle iron stiffners provided at bottom, top and all corners for added strength (Figure 4). Two-dimensional tests were conducted in a box 80 cm × 41 cm × 7.5 cm wide, constructed of perspex sheets and three angle iron stiffners provided at equal spacing for added strength (Figure 5).

In the three-dimensional tests, the footings were 10 cm × 10 cm, 7.5 cm × 7.5 cm, 7.5 cm × 10 cm, 7.5 cm × 15 cm and 10 cm × 30 cm. In two-dimensional tests, footing of width 7.5 cm was tested.

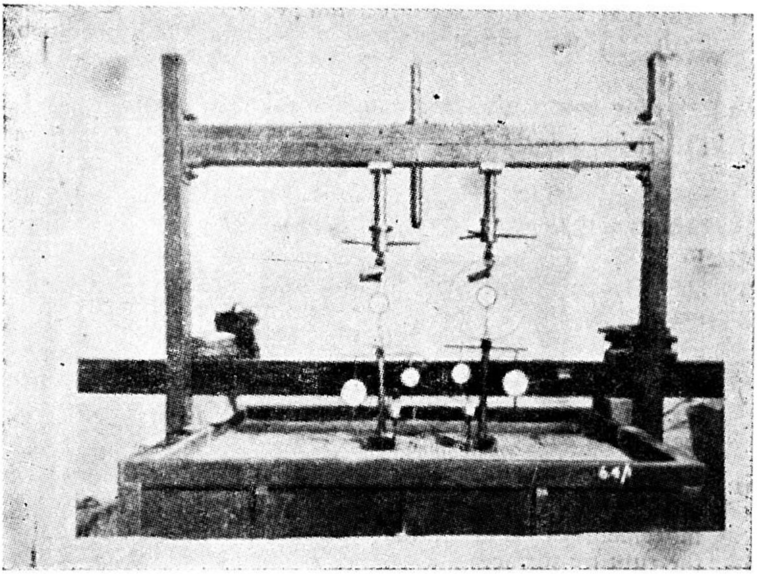

FIGURE 4 : Set-up for three-dimensional tests.

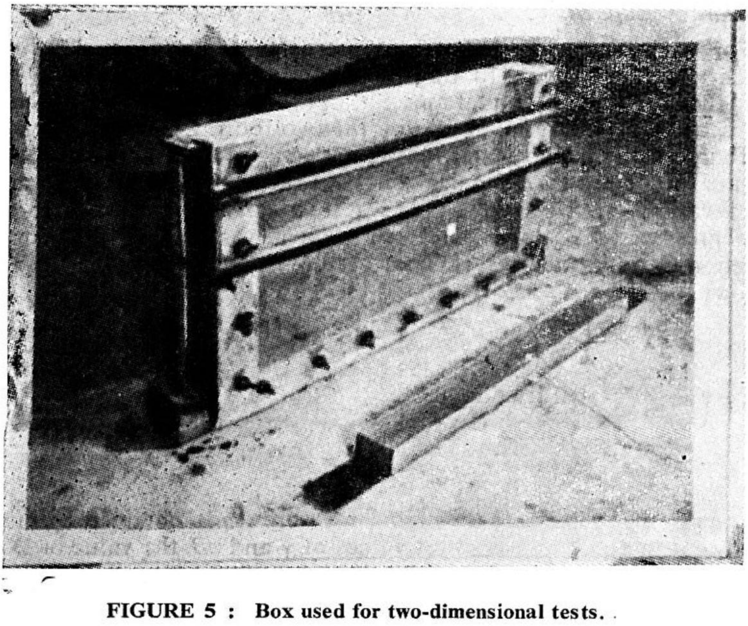

FIGURE 5 : Box used for two-dimensional tests.

Tests Performed

Effect of the interference of footings is studied in this investigation on the two footings of the same size placed at clear spacings of 20 cm, 25 cm, 30 cm, 35 cm, 40 cm and 50 cm. The sizes of the footings are already described earlier. Each footing in isolated position was also tested. It will pertain to the case of the infinite spacing between the two footings. Each test was repeated thrice to ensure the reproducibility of tests.

The following observations were made during the tests :

(1) The loads on the two footings positioned as shown in Figure 4 were applied simultaneously by means of screw jacks calibrated through proving rings. Loads were applied in small increments and the next increment was applied when the settlement became constant.

(2) The settlement of each footing was recorded at the point of load application, i.e., at the centre of footing by mean of gauges mounted as shown in Figure 3.

(3) A specially designed and fabricated tiltmeter was mounted on each of the footing to measure the tilt. The least count of tiltmeter was 20 seconds.

(4) A grid of black lines consisted of dyed Ranipur sand was made on the sand surface in each test. This helped to observe the movement of sand grains during the test and to photograph the rupture surface.

Interpretation

Bearing Capacity

For each test, pressure versus settlement curves were obtained for each of the two footings. Due to a simultaneous loading of the footings by equal amount and same size of footing, the load versus settlement curve of each of the two footings of a particular test were found same. A typical pressure versus settlement curve is shown in Figure 6. The small vertical lines on the curves indicate the magnitude of variation in observations of a test when it is repeated three times. Failure pressure (*qd*) is obtained from the load versus settlement curve by intersection-tangent mehtod (Leonard, 1962), Figure 6. It is expressed as follows :

$$qd = \frac{1}{2} \gamma B N_\gamma \qquad \ldots(1)$$

where, γ = density of soil
B = width of footing
N_γ = bearing capacity factor.

Using the values of the failure pressures (*qd*) obtained by intersection tangent method, and relevant values of γ and B, the value of $N\gamma$-factor is obtained from Equation (1) for each test. These values are plotted with respect to S/B ratio in Figure 7, S being the clear spacing between two footings.

It is evident from this curve that N_γ -factor first decreases as the spacing increases. After a certain spacing which is approximately equivalent to 4.75 B in this particular case, the bearing capacity shows a slight increase with the increase in spacing and the curve becomes almost horizontal after the spacing is greater than $8B$ and the value of N_γ at this spacing coincides with the N_γ value corresponding to an isolated footing. The decrease in foctor with the increase in spacing is reported by the previous investigators (Stuart 1962, West and Stuart 1965, Mandel 1963). Although their theoretical results did not indicate any increase in bearing capacity factor after a certain spacing, some of their model tests did show the same trend as observed in the present model tests.

A comparison with the theoretical results of Stuart with the observed results is shown in Figure 8. Although, the trends of two are same, but the observed bearing capacity factor values are much less as compared to the theoretical values of N_γ. This point was also referred by Stuart (1962) and again stress by West and Stuart (1965) that the observed bearing capacity factor values come out less than thecomputed values.

The difference in the results can be attributed partly to two reasons (*i*) the surface of sand could have been slightly looser than the mass and (*ii*) placing of the footings on the surface may have caused some disturbance to the sand. Authors feel that these two reasons are not enough to explain the quantitative difference between the experimental and theoretical results. Due to this reason, it is felt that there is a necessity of further research in the analytical analysis of this problem.

Settlement

A plot of settlement at failure obtained from pressure versus settlement with respect to $\frac{S}{B}$ ratio is shown in Figure 9 for a footing of 10 cm × 10 cm size. It is evident from the figure that the settlement of the footing decreases as the spacing between the footings increases. An exactly similar trend was observed for the footings of other sizes.

Authors have also computed the settlements corresponding to the pressures equal to half the failure pressure ($qd/2$) and one-third failure

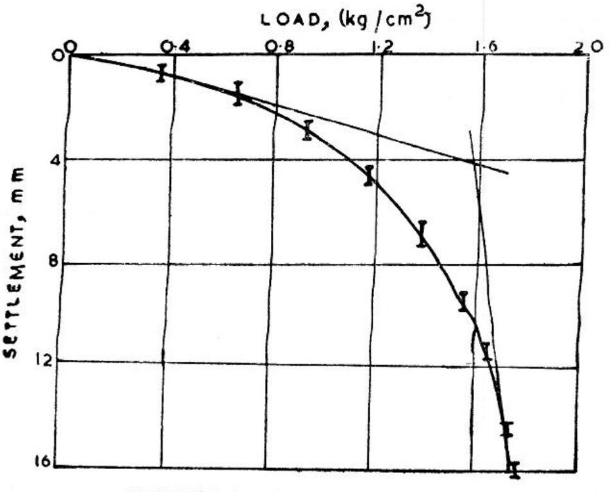

FIGURE 6 : Tangent intersection method.

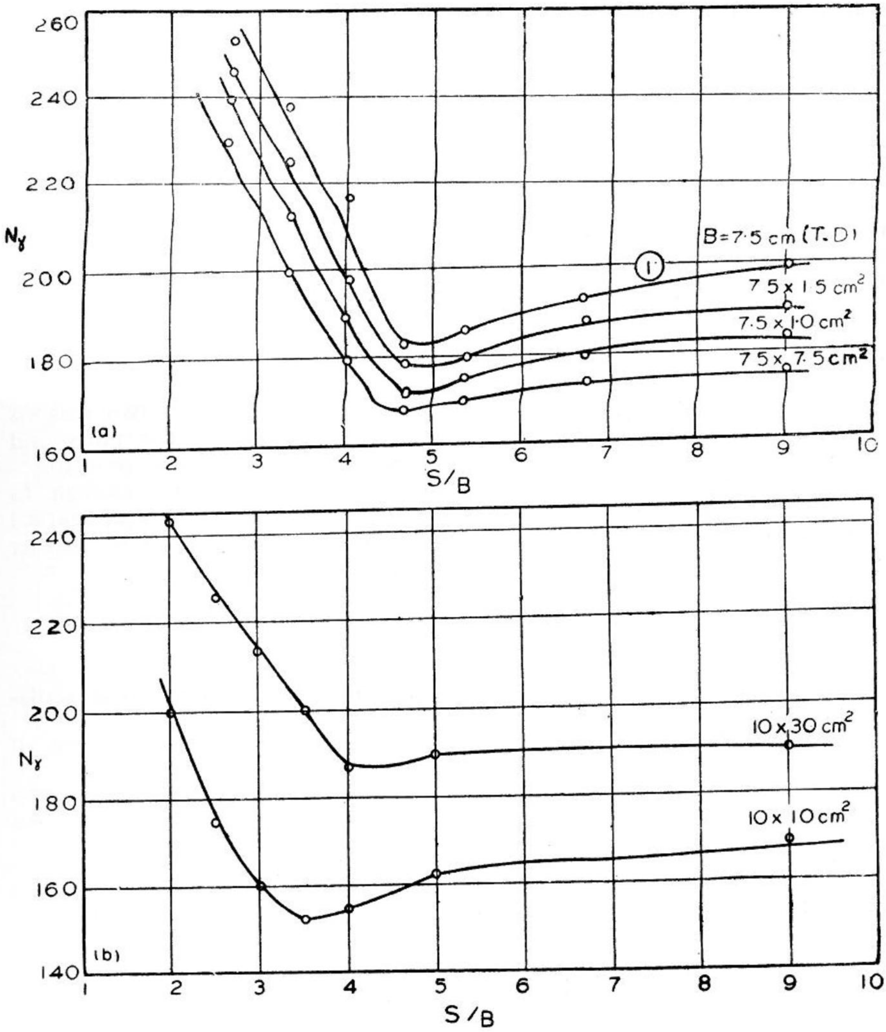

FIGURE 7 : S/B versus bearing capacity factor Nγ.
(a) Top : B=7.5 cm.
(b) Bottom : B=10 cm.

pressure $\left(\frac{qd}{3}\right)$. It has been found that the settlements computed for loads $\frac{qd}{2}$ and $\frac{qd}{3}$ vary with the spacing in similar way as shown in Figure 9.

Mechanism and Extent of Failure Surface

The study of mechanism of rupture surface has been attempted by observing the deformation of the grid made on the surface of the sand at various load intervals. Typical deformation patterns of the grid at failure in two-dimensional and three-dimensional tests are shown in Figures 10 and 11. Photographs of the rupture surfaces were taken for every test.

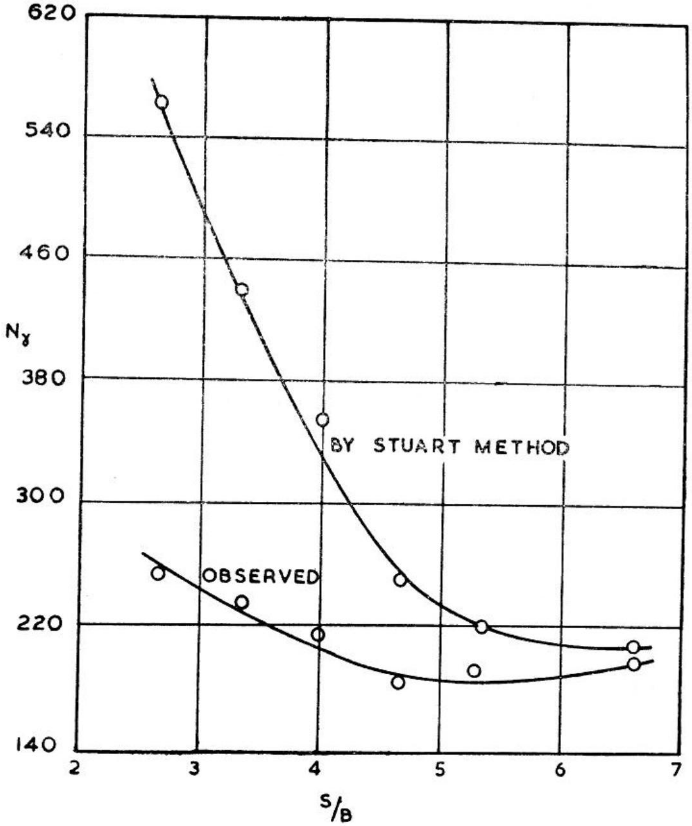

FIGURE 8 : Observed Nγ values versus Stuarts Nγ values.

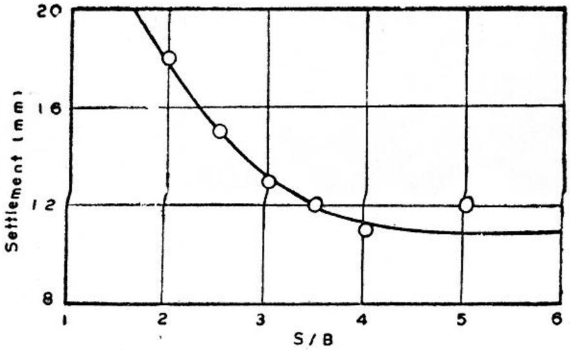

FIGURE 9 : Settlement versus S/B.

An examination of these rupture surfaces indicated that at failure clear rupture surface develops which can be made by joining the kinks of the grids (Figures 10 and 11). The overlapping of the rupture surfaces increases as the spacing between the two footings decreases.

The extent of rupture surface is defined as the maximum distance of the rupture surface from the footing. These distances observed in different tests are listed in Table I.

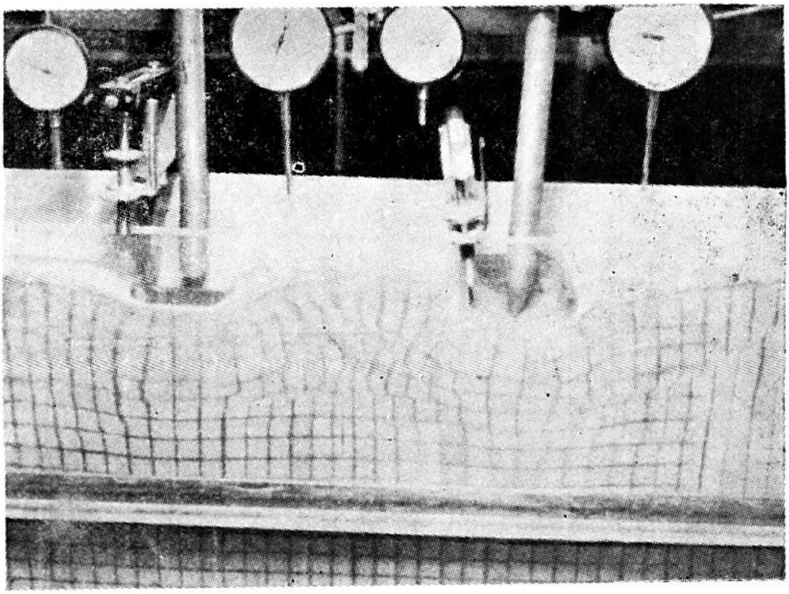

FIGURE 10 : Deformation of grid in a typical two-dimensional test.

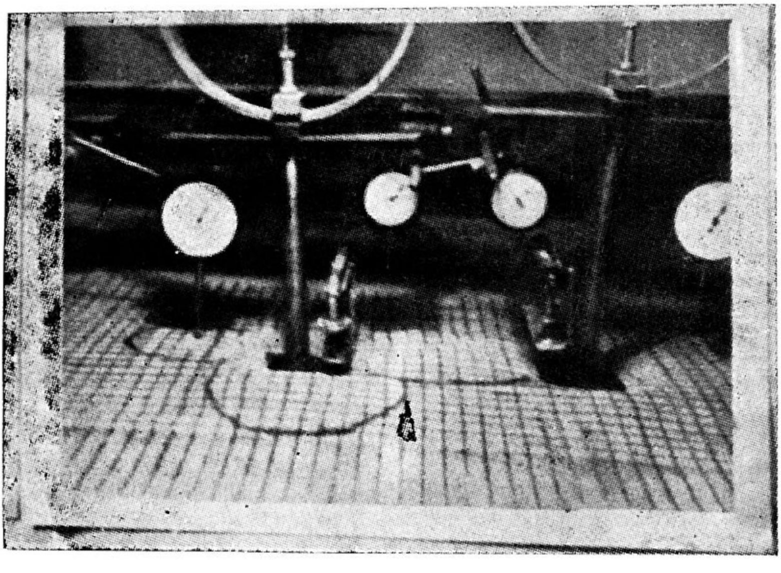

FIGURE 11 : Deformation of grid in a typical three-dimensional test.

TABLE I

Extent of Failure Surfaces.

	Extent of Failure Surface (cm)						
	Isolated	50	40	35	30	25	20
Square							
7.5 cm×7.5 cm	11	11.5	13	14.5	16	19	20
10 cm×10 cm	20	22	23	24.5	26	27	28
Reetangular							
7.5 cm×10 cm	13	14	16.5	14	18	20	22
7.5 cm×15 cm	22	24	25	26.5	28	28.5	29.5

It can be seen from Table I that the extent of failure surface decreases as the spacing increases.

Conclusions

(1) Bearing capacity of two interfering footings decreases rapidly with the increase in spacing up to a certain spacing ($S=4.5\ B$) beyond which it increases slowly up to the value of the bearing capacity of isolated footing.

(2) Settlement of the footings decreases as the spacing between the footings increases.

(3) The extent of failure surface decreases with the increase in the spacing.

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