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Interference Effect of Two Nearby Strip Footings on Reinforced Sand

Priyanka Ghosh

Assistant Professor, Dept. of Civil Engineering, IIT Kanpur, India
Department of Civil Engineering, Indian Institute of Technology, Kanpur
Kanpur – 208 016, India
priyog@iitk.ac.in

Pawan Kumar

Former PG Student, Dept. of Civil Engineering, IIT Kanpur, India
Kanpur – 208 016, India

Abstract

In this study, a number of model tests were conducted to study the interference effect of two near-by strip footings on dry, reinforced Ennore sand bed. Single layer of uniaxial geogrid was used for reinforcing the foundation bed. To study the interference effect between the two footings, first, the bearing capacity of single isolated footing was obtained and later on, that of closely spaced footings was determined. The experimental study indicates that the bearing capacity of single footing on the reinforced soil decreases with increase in D/B, where D and B are the depth of reinforcement and width of footing, respectively. The bearing capacity factor due to the unit weight of soil is found to decrease with increase in the width of footing. The effect of centre to centre spacing (S) between two footings, on their bearing capacity and settlement is mainly focused in this paper. The settlement behaviour of the interfering footings is found to follow the same trend as the bearing capacity. The results are presented in terms of efficiency factors (ξ_γ, ξ_δ) and their variation was obtained with the change in S. The present experimental observations are generally found in good agreement to those theoretical and experimental results available in the literature.

Keywords: Geosynthetics, interference effect, strip footing, bearing capacity, reinforced soil

1 Introduction

On many occasions, it is unavoidable to place footings with quite close spacing, to accommodate the structural details or to limit the footing loads. In such cases, the interference of failure zones could alter the bearing capacity and load-settlement behaviour of footings from the isolated footing condition. Therefore, the problem of interaction between adjacent footings is of great practical significance, as several times the footings in field generally interfere with each other to some extent and are rarely isolated. The interference effect on the ultimate bearing capacity of two nearby strip footings was studied theoretically by Stuart [1] considering limit equilibrium method, which could be considered as the pioneering work in this area. In this analysis, in contrast with the available theories for an isolated rough footing, a partial non-plastic trapped wedge was considered below the footing base. In order to examine the effect of interference, the zone below the two interfering rough footings was assumed to comprise of partly a small non-plastic wedge and partly a plastic shear zone. The shape of failure surface was chosen as a combination of logarithmic spiral and straight line in this approach. Later, by using the failure mechanism similar to that earlier used by Stuart [1], West and Stuart [2] employed the method of stress characteristics so as to obtain the solution for the interference of two strip footings. The values of the efficiency factors obtained by West and Stuart [2], on the basis of method of characteristics for $\phi = 35^0$, were shown to be smaller than those obtained earlier by Stuart [1] by using the limit equilibrium method; where ϕ is the angle of internal friction of soil and the efficiency factor is defined by the ratio of load carried by the single footing in presence of the other footing to that of the single isolated footing of same size. Murthy [3] studied the interference effect of surface footings on sand, but both the footings were not loaded simultaneously, i.e. one of the two footings was first loaded to its safe bearing capacity and the load on the other adjacent footing was then increased up to the ultimate load. Later on, in order to study the effect of the interference of two closely spaced footings on unreinforced soil, a number of investigations were conducted by various researchers ([4], [5], [6], [7], [8], [9]). However, from the available theoretical and experimental studies, it is now understood that the magnitude of ultimate bearing capacity as well as settlement of foundation generally increases at close spacing on account of the interference of other footing. Therefore, the importance of study on the reduction of settlement of interfering footings by reinforcing the soil bed cannot be ignored as it mainly governs the behaviour of interfering footings. Khing et al. [10] and Al-Ashou et al. [11] studied experimentally the effect of interference on the bearing capacity of closely spaced footings resting on reinforced sand bed. The study of pressure, settlement and tilt characteristics of closely spaced footings on reinforced soil bed was studied by Kumar and Saran [12]. Kumar and Saran [13] also presented an analytical method to determine the pressure corresponding to a given settlement for closely spaced strip footings on reinforced sand. In present investigation, the experimental study on the effect of interference between two adjacent surface strip footings was carried out by conducting a number of laboratory scaled model tests on dry, medium dense, reinforced Ennore sand bed. Ennore sand is widely available in the southern part of India. Therefore, the study of interference of footings on Ennore sand was found to be significant. The model strip footings are made of mild steel, which were expected to behave like rigid footings and the roughness of base was ensured by gluing sand paper beneath the footings. Single layer of uniaxial geogrid was used for reinforcing the soil. The effect of a range of parameters such as depth of reinforcement layer (D) and centre to centre spacing between the footings (S) was studied in this paper.

2 Definition of the Problem

Two sets of rough strip footings, where the first set is having two footings of width 75 mm each and the second set consists of two footings of width 50 mm each, are placed on the top of dry, medium dense, reinforced Ennore sand bed. The L/B ratio for both 75 and 50 mm footings were kept as 2.0 to simulate the nature of strip footing, where L is length of footing. The single layer of geogrid is placed at a depth of D from the surface. In each case, the footings are spaced at a centre to centre distance of S as illustrated in Figure 1. Both the footings are loaded simultaneously to the failure at the same time. Due to symmetry, both the footings are expected to carry the same ultimate failure load P_u. The objective is to determine the magnitude of the ultimate failure load P_u (per unit length of footing) for each footing and the settlement corresponding to the ultimate failure.

3 Properties of Foundation Soil and Experimental Set-up

For the model tests, cohesionless, dry Ennore (Tamilnadu, India) sand of grade-II was used as the foundation material. The grain size distribution and engineering properties of Ennore sand are shown in Figure 2 and Table 1, respectively. The angle of internal friction was obtained as 38.9^o by conducting the direct shear test on dry Ennore sand placed at a relative density (D_r) of 65%. In the present study, commercially available uniaxial geogrid (55RE) was used for reinforcing the soil bed. The geogrid is made of high density polyethylene (HDPE), whose ultimate tensile strength is 64.5 kN/m and approximate strain is 11.5% at the ultimate failure.

The experimental setup was designed and fabricated in-house to facilitate the study of interference effect of footings in the laboratory. The main consideration, which was kept in view during fabrication, was that the load should be always centric during loading and no boundary effect should be caused by the dimension of tank. The complete experimental setup is shown in Figure 3.

4 Experimental Procedure

The sand pouring technique plays an important role in the process of achieving the desired density of sand bed as the reliability of results would depend upon the uniformity of density. The sand was poured in the tank by rainfall technique keeping the height of fall as 35 cm to maintain the constant relative density throughout the bed. The tank was emptied and refilled after each test. The fixed volume method and dynamic penetrometer were employed to verify the relative density and uniformity of density of sand, respectively.

A manually controlled hydraulic jack with activated loading piston, installed between the sliding beam and strong reaction beam (Figure 3), was used to provide the required load on the footings. Both the footings were simultaneously loaded vertically through the extension rods attached to the sliding beam. The sliding beam was guided by the guiding rods, so that it would remain always horizontal during the loading process. The tilting of footings was checked with the help of bubble tube. The vertical displacement of each test footing was measured by taking average readings of two dial gauges placed on each footing. In order to simulate the rough base of footing, sandpaper strips of similar texture of Ennore sand was glued to each footing base. By gradually increasing the load, a series of tests were carried out so as to monitor the complete load-deformation plots till the ultimate shear failure. Each test was carefully controlled by the displacement of each footing through dial gauge reading and was repeated at least three times in order to ensure the repeatability of the test. First, the bearing capacity of single isolated footing was obtained and later on, that of closely spaced footing was determined.

5 Results and Discussions

5.1 Single Isolated Footing

The load-settlement relationship for 75 and 50 mm single isolated footing at $D/B = 0.75$ and $D/B = 1.0$ are presented in Figure 4. It can be observed that the applied load (P) on the footing continuously increases with the increase in settlement (δ) of foundation and generally reaches the maximum value at certain magnitude of δ. However, after reaching the maximum value, the load generally decreases but the settlement goes on increasing. It is important to note here that the ultimate load was determined from the load-settlement plots either by double tangents or single tangent method depending on the nature of curve. It can be also seen that the ultimate load and settlement are found to be higher at $D/B = 0.75$ than those at $D/B = 1.0$. It is worth mentioning here that for each value of D/B, the magnitude of ultimate load obtained from Figure 4, added with the weight of the footing and other accessories attached to the footing was considered as the ultimate failure load (P_u) of the foundation.

5.1 Footings under Interference

Figure 5 shows the variation of load-settlement curves for closely spaced 75 and 50 mm footings on the reinforced soil deposit with different values of *S/B* and *D/B*. It can be seen that for both 75 and 50 mm footings, the ultimate failure load becomes maximum at *S/B* = 2.0; irrespective of the magnitude of *D/B*.

The variation of efficiency factor due to bearing capacity (ξ_γ) and due to settlement (ξ_δ), with *S/B* for different values of *D/B* is shown in Figures 6 and 7, respectively; where ξ_γ and ξ_δ can be defined as

$$\xi_\gamma = \frac{\text{Ultimate bearing capacity of single footing in presence of other footing}}{\text{Ultimate bearing capacity of single isolated footing}} \tag{1}$$

and

$$\xi_\delta = \frac{\text{Settlement of single footing at failure in presence of other footing}}{\text{Settlement of single isolated footing at failure}} \tag{2}$$

It was reported by several researchers that the value of efficiency factors, in case of unreinforced soil, initially increases with the increase in spacing up to a maximum value and then decreases with the increase in spacing. In the present study, it is also observed that in reinforced bed the magnitude of ξ_γ and ξ_δ initially increases with the increase in *S/B* and generally reaches the maximum at *S/B* = 2.0, and then decreases with increase in spacing. This indicates that the bearing capacity as well as settlement of single footing at failure on the reinforced soil bed, in presence of other footing first increase and then decrease with the increase in spacing between the footings. It is worth mentioning here that the magnitude of ξ_γ and ξ_δ are eventually expected to be equal to 1.0 at larger spacing, which indicates the behavior of single isolated footing free from any interference effect.

6 Comparison

A number of tests were also performed on unreinforced sand bed with both 75 and 50 mm footings for the sake of comparison. The comparison between load-settlement characteristics on reinforced and unreinforced bed is shown in Figure 8; where RB and URB represent the reinforced and unreinforced bed, respectively. It can be noted that at *D/B* = 0.75, the footing takes the maximum load at failure with the highest ultimate settlement; whereas the ultimate load as well as the settlement are found to be the lowest on unreinforced soil bed. The same observation was also reported by Koerner [14].

In Table 2, the magnitude of $N_\gamma^{'}$ obtained from the present experimental study for 75 and 50 mm isolated footing on the reinforced bed are compared with the values reported by Michalowski [15], where $N_\gamma^{'}$ is the bearing capacity factor due to the unit weight of soil on the reinforced bed. The bearing capacity factor $N_\gamma^{'}$ is defined by

$$N'_\gamma = \frac{P_u}{0.5\gamma L B^2} \tag{3}$$

Where, γ is the unit weight of soil. It can be seen that the present values are compared reasonably well with the theoretical results proposed by Michalowski [15].

In Figure 9, the present values of ξ_γ for 75 and 50 mm footings with different *S/B* on the reinforced bed for $\phi = 38.9^0$ are compared with those reported by Kumar and Saran [12] for $\phi = 37^0$. The values obtained from the present experimental study are found to be significantly smaller than those proposed by Kumar and Saran [12], which might be caused by the use of high tensile biaxial geogrid (SS20) in the study of Kumar and Saran [12].

Table 3 shows the comparison of present maximum value of ξ_γ for 75 and 50 mm footings with those given by Al-Ashou et al. [11]. It is important to mention here that Al Ashou et al. [11] used aluminium strips as the reinforcing material.

7 Conclusion

In the present study, a number of laboratory scaled model tests were performed to determine the ultimate bearing capacity of an isolated and two nearby rough strip footings on reinforced Ennore sand. The foundation bed was reinforced with a single layer of geogrid (55RE) at different *D/B*. By reinforcing the soil, not only the ultimate bearing capacity of footing increases, but a significant enhancement happens in the settlement characteristics also. The magnitude of N'_γ for single isolated footing on reinforced soil bed decreases with increase in the width of footing. It is noted that under the interference effect, the ultimate bearing capacity and settlement of footing generally becomes maximum at a certain critical spacing between the footings. The results are provided in terms of efficiency factors (ξ_γ and ξ_δ) with respect to the variation in centre to centre spacing between the footings. It can be observed that the variation of both ξ_γ and ξ_δ generally follows the same trend but differs in the magnitude. For 75 mm footing, the magnitude of ξ_γ and ξ_δ initially increases with the increase in *S/B* and reaches the maximum at *S/B* = 2.0, and then decreases with increase in spacing. However, the magnitude of ξ_γ and ξ_δ are eventually expected to be equal to 1.0 at larger spacing, which indicates the behaviour of single isolated footing free from any interference effect.

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Properties	
Uniformity coefficient (C_u)	1.56
Coefficient of curvature (C_c)	0.96
Effective size, D_{10} (mm)	0.45
Specific gravity, G_s	2.66
Maximum density, ρ_{max} (gm/cm^3)	1.68
Minimum density, ρ_{min} (gm/cm^3)	1.47
Maximum void ratio, e_{max}	0.80
Minimum void ratio, e_{min}	0.58
Relative density, D_r (%)	65

Table 1**:** Engineering Properties of Ennore Sand

Footing width (mm)	$N_\gamma^{'}$			
	Present analysis ($\phi = 38.9^0$)		Michalowski [15]	
	$D/B = 0.75$	$D/B = 1.0$	$\phi = 38.9^0$, $D/B = 0.76$	$\phi = 40^0$, $D/B = 1.0$
75	136.80	114.04	165.40	165.10
50	150.40	145.34	162.90	209.70

Table 2**:** Comparison of $N_\gamma^{'}$ for An Isolated Strip Footing on Reinforced Bed

Footing width (mm)	Present study (55RE, $\phi = 38.9^0$)		Al-Ashou et al.[11], (Al strips, $\phi = 41^0$)
	$D/B = 0.75$	$D/B = 1.0$	$D/B = 0.4$
75	1.21	1.38	2.5
50	1.20	1.21	

Table 3: Comparison of Maximum Value of ξ_γ

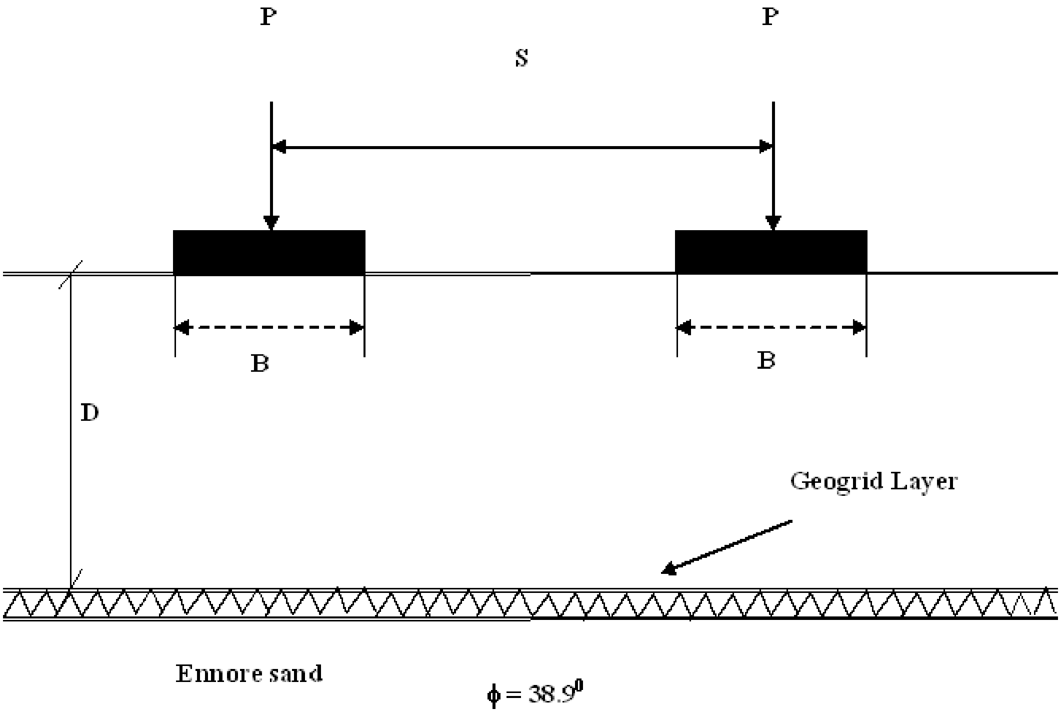


Figure 1: Outline of Problem

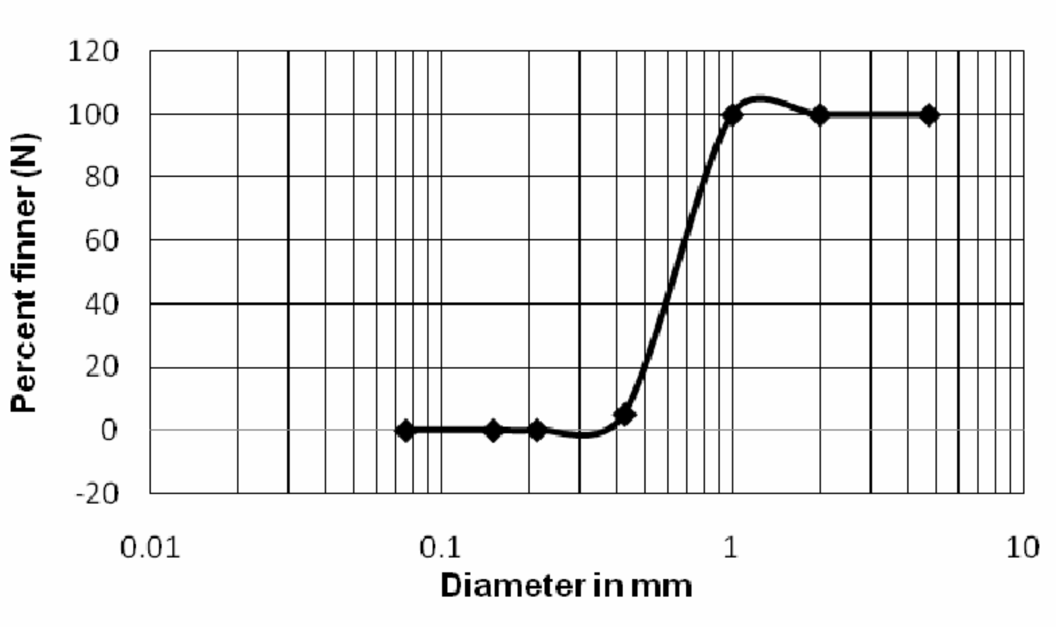
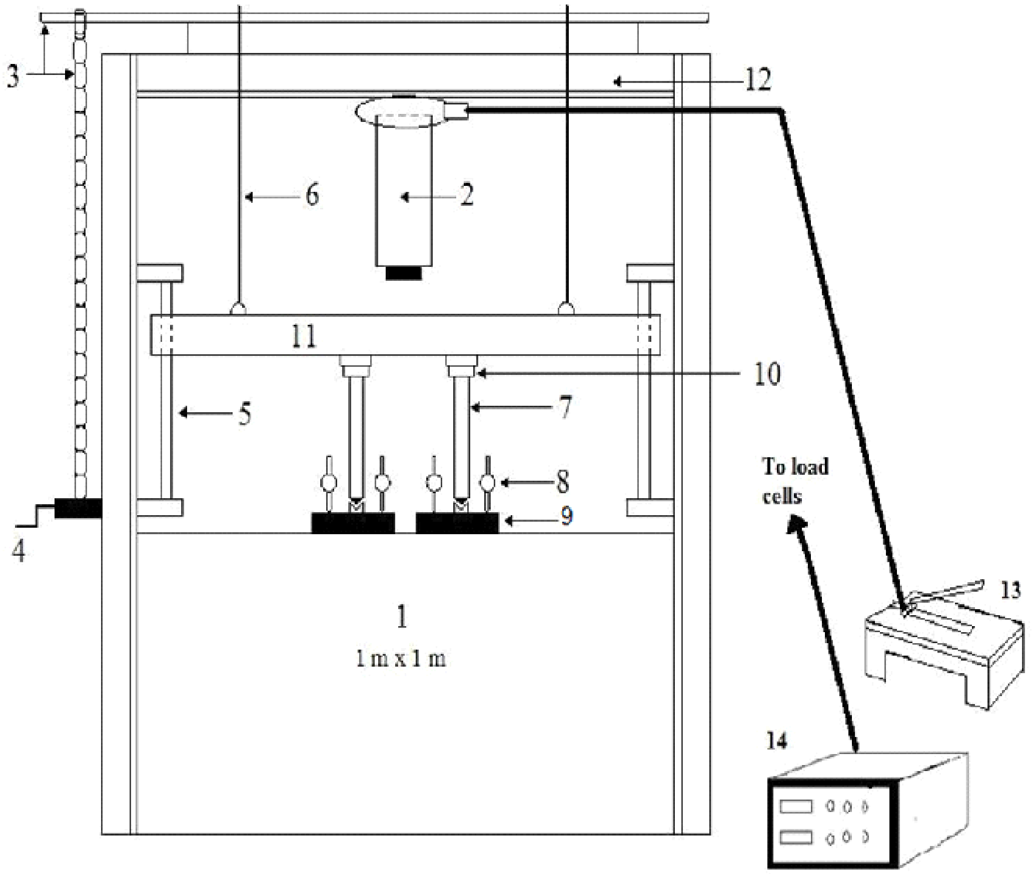
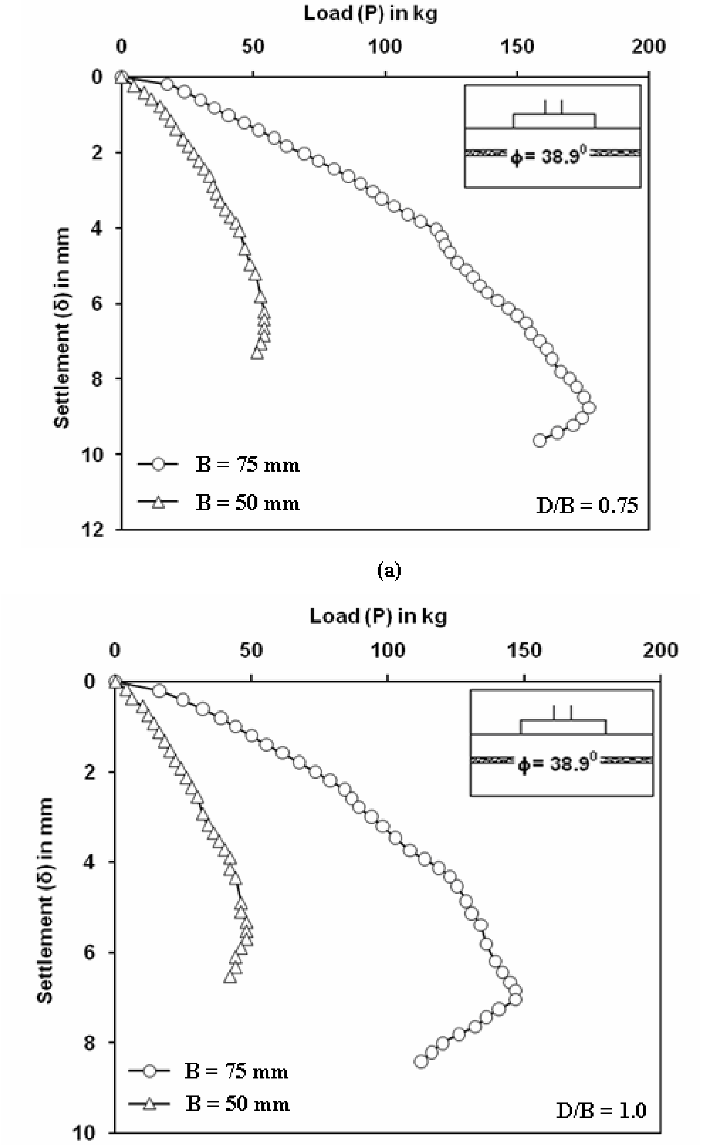


Figure 2: Grain Size Distribution Curve of Ennore Sand



1. Model tank (1m x 1m x 1m)
2. Hydraulic jack
3. Chain-pulley system
4. Manually operated wrench
5. Guiding rods
6. Supporting flexible cables
7. Extension rods
8. Dial gauges
9. Steel footings
10. Load cells
11. Sliding beam
12. Reaction beam
13. Manually operated loading mechanism
14. Load cell indicator

Figure 3: Schematic Diagram of Experimental Setup



(a)

(b)

Figure 4: Variation of Load-settlement Curves for Different Isolated Footing with (a) $D/B = 0.75$, (b) $D/B = 1.0$

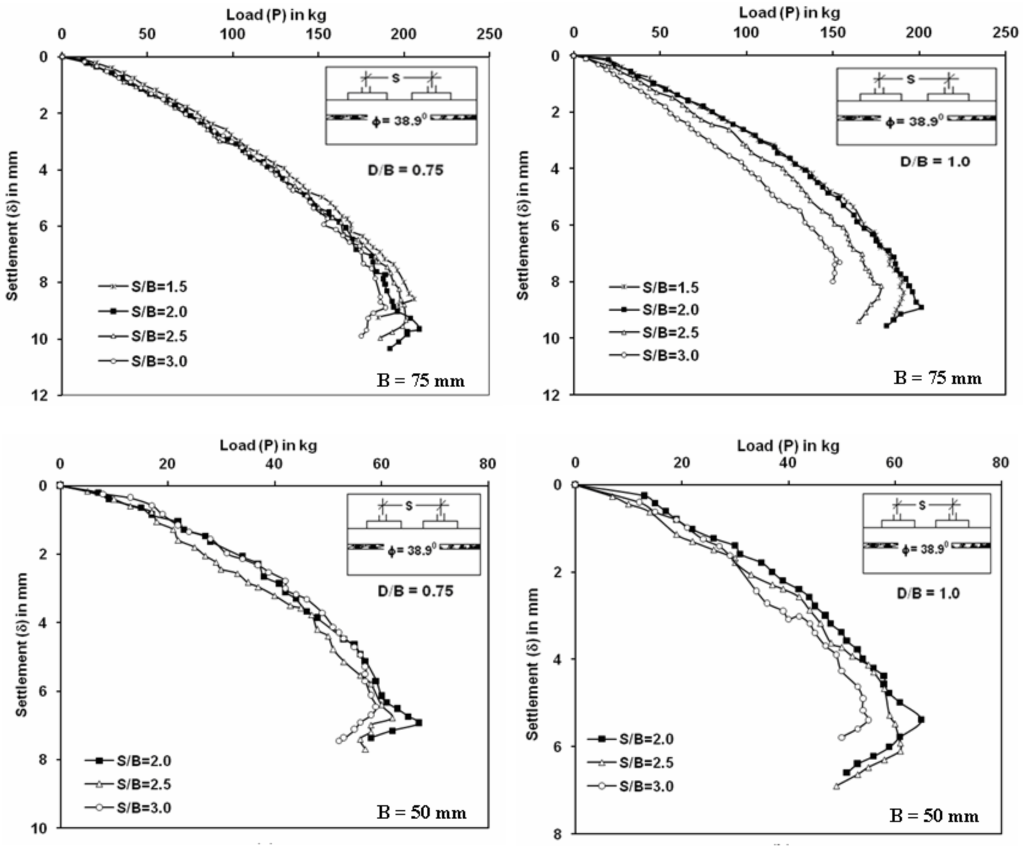
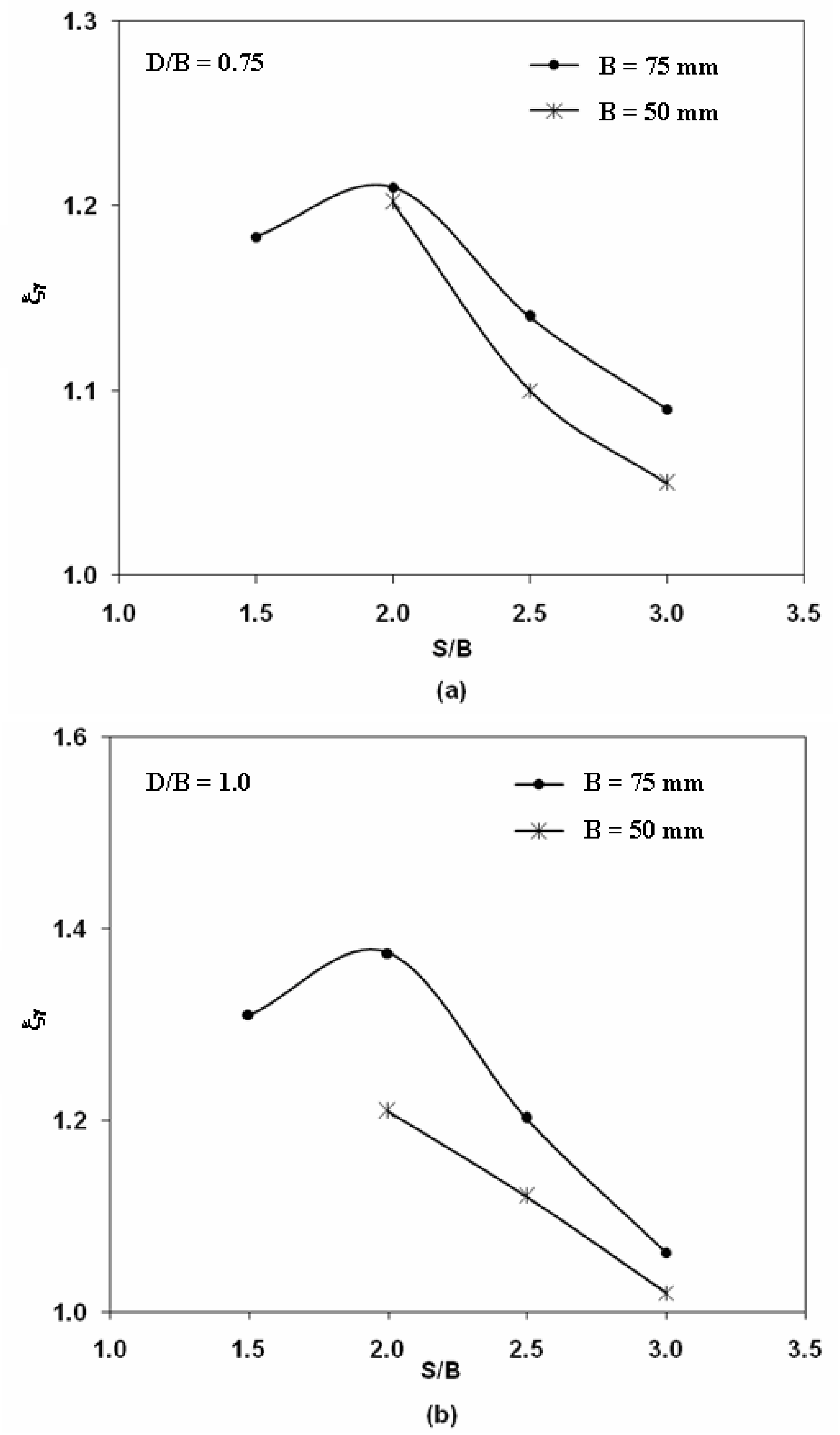


Figure 5: Variation of Load-settlement Curves for Footing Under Interference with Different *S/B* and *D/B*



(a)

(b)

Figure 6: Variation of ξ_γ with S/B for (a) $D/B = 0.75$, (b) $D/B = 1.0$

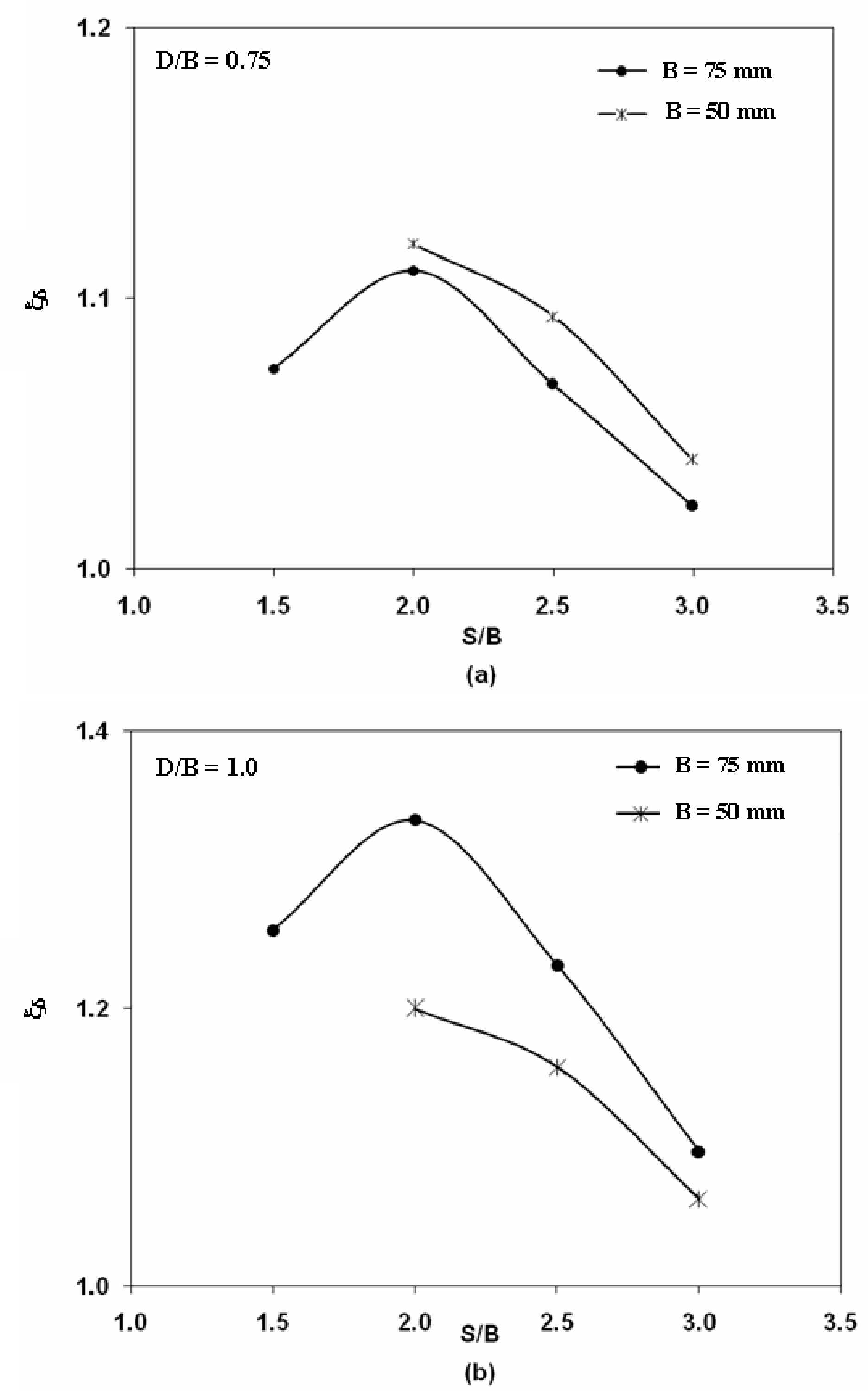
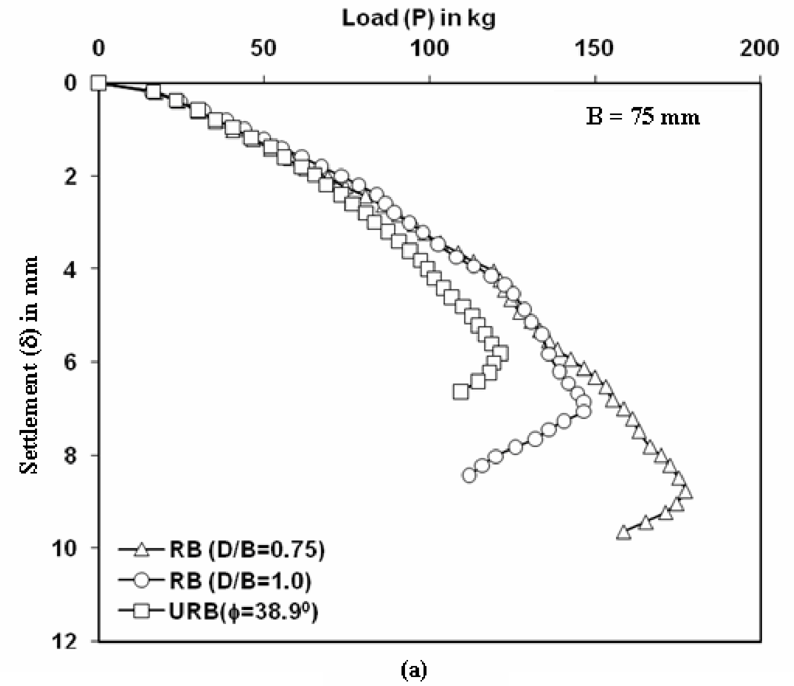


Figure 7: Variation of ξ_δ with S/B for (a) $D/B = 0.75$, (b) $D/B = 1.0$



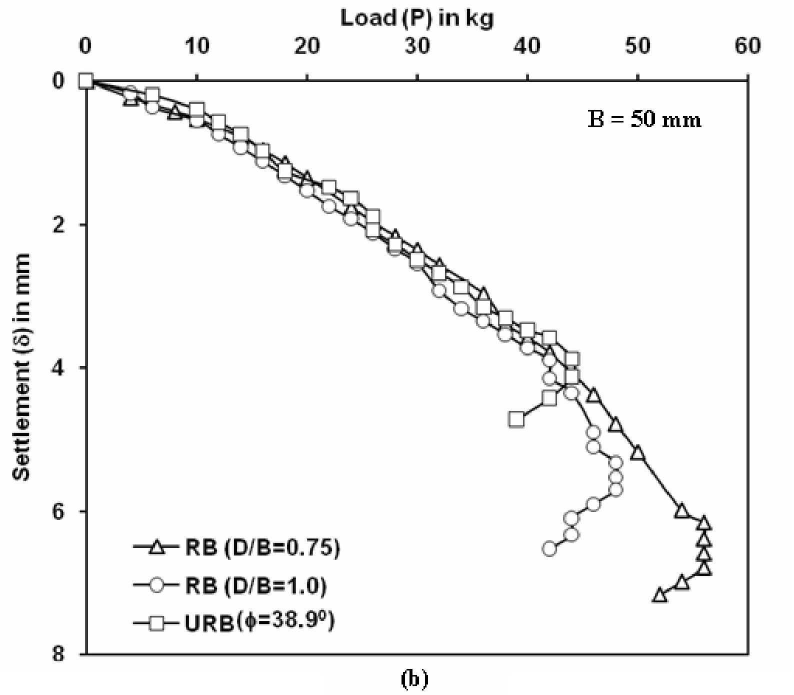


Figure 8: Comparison of Load-settlement Curves for Isolated Footing on Reinforced and Unreinforced Bed (a) $B = 75$ mm (b) $B = 50$ mm

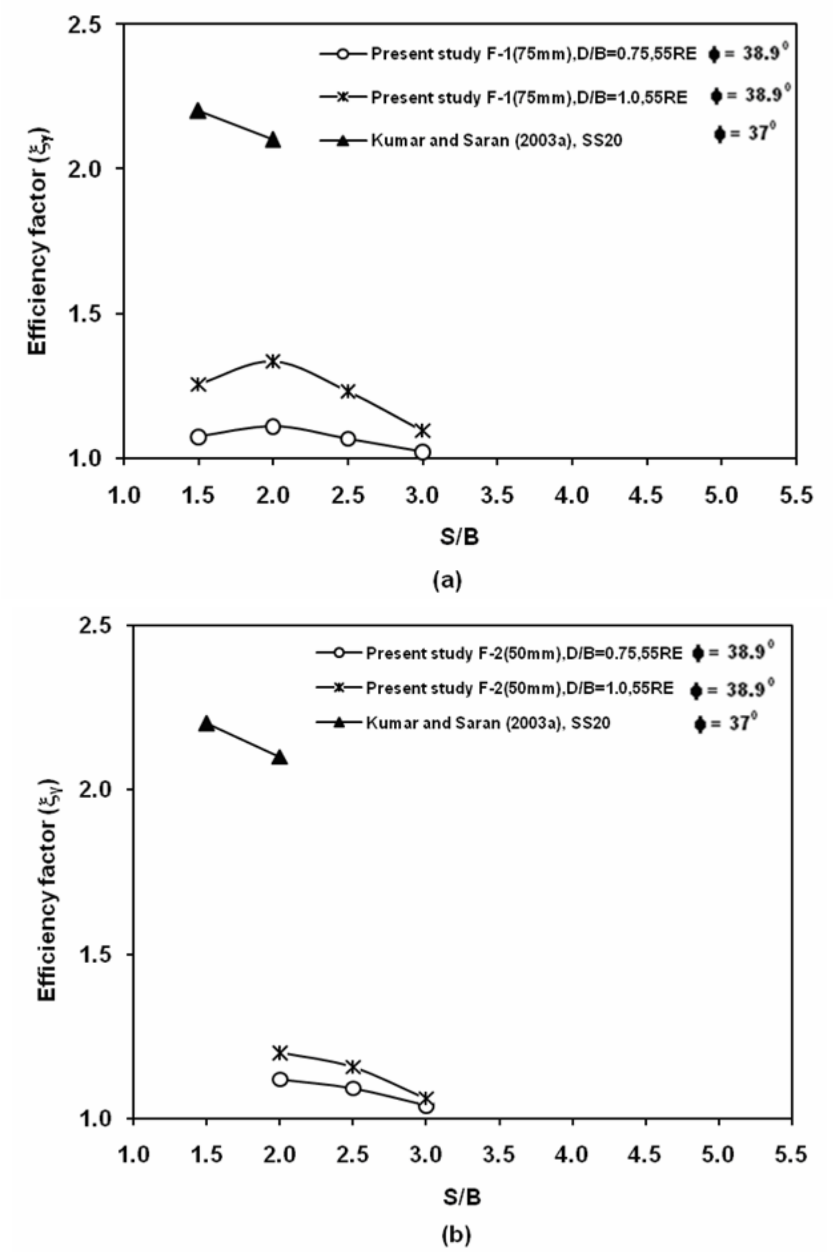


Figure 9: Comparison for ξ_γ with Different S/B on Reinforced Soil Bed for (a) $B = 75$ mm (F-1), (b) $B = 50$ mm (F-2)

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