Analysis of two closely spaced asymmetric strip footings embedded in cohesion-less soil medium

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ABSTRACT

The present study apprehends to finite element analysis of closely spaced asymmetric strip footings embedded in cohesion-less soil medium. Two rigid strip footings, the left and the right having width B_L and B_R, respectively are placed at a clearing spacing, S and both subjected to simultaneous loading. The footings are considered to be embedded at a depth, D_f from ground surface in homogeneous, isotropic and semi-infinite cohesion-less foundation soil medium having internal friction angle, ϕ. The analyses are carried out using finite element software ABAQUS, discretizing the domain with four node continuum plane strain elements, the foundation soil is modelled to follow Mohr-Coulomb failure criteria with non-associated flow rule. Parametric studies are performed by varying B_R, D_f, ϕ and S; the effect of interference on ultimate bearing capacity and settlement measured corresponding to bearing pressure at permissible limit are observed. It has been observed with increase in friction angle and depth of footing, the interference has a significant effect on both bearing capacity and settlement. Further, the effect is more prominent for the footings of smaller size than those of bigger size footing and the same is valid for settlement aspect.

Keywords: Interference; Asymmetric; Embedded Footings; Closely Spaced Footings

1 INTRODUCTION

In regard of rampant urbanization, lack of construction space, architectural requirements the footings are laid close to each other which further impacts the behavior of an isolated footing in respect to load-settlement behavior, failure mechanism. The failure zones below the adjacently placed footings combine, subsequently the shear zones getting denser and thus increasing the bearing pressure. The phenomenon was first reported by Stuart (1962) with his observations made through the theoretical studies on two symmetrical rigid strip footings resting on the surface of cohesion-less soil bed. In line, many researchers (Kumar and Bhoi 2009; Ghazavi and Lavasan 2008; Mabrouki et al. 2010; Nainegali et al. 2013, 2018; Noorzad and Manavirad 2014; Ghosh et al. 2017; Nainegali and Ekbote 2016) reported on different aspects of the phenomenon, using theoretical, numerical and experimental studies in concern to symmetric footings.

It may arise a condition that the closely spaced footings may not be symmetric; either the size of the footing or the loading conditions could be asymmetric. Nainegali et al. 2013, 2018 carried out the analysis of closely spaced asymmetric surface footings using finite element method considering the geometry and loading conditions. In line, Ghosh et al. 2017 carried out the analysis of interfering strip surface footings considering Pasternak model considering linear and nonlinear elastic behavior. The effect of interference needs to be considered in design and analysis of closely spaced footings. Moreover, review shows the studies on the behavior of embedded footings placed in close proximity are utmost/virtually nil and therefore the present case, elaborated under has been taken into account.

2 PROBLEM DEFINITION

The problem of two closely spaced asymmetric (with respect to footing width) strip footings having width, B_L and B_R (subscript L and R represents left and right footing, respectively) positioned at a clear spacing, S and embedded at a depth, D_f in the homogenous soil medium then loaded simultaneously with uniform pressure, q is considered for analyses. Fig. 1, illustrates the problem domain considered for the analyses. The parametric study have been carried out to assess the effect of interference on ultimate bearing capacity and settlement characteristics. The width of the left footing is kept constant and the width of right footing is varied; the mechanical properties of soil and range of varying parameters considered in the analysis are presented in Table 1, wherein γ, E, υ, c, ϕ and ψ are unit weight, Young's modulus, Poisson's ratio, cohesion, soil friction angle and dilation angle, respectively.

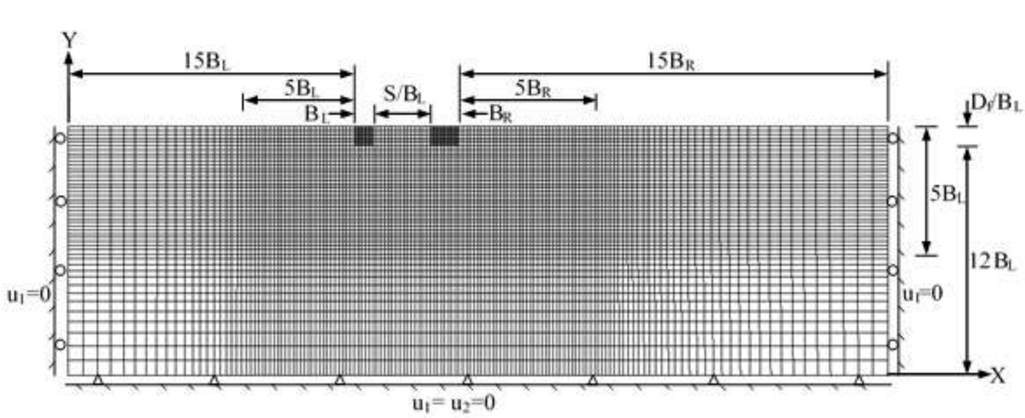


Fig. 1. Problem domain, finite element discretization and the boundary conditions

Table 1. Properties of soil and range of parameters varied.

Mechanical Properties of soil		
Parameters	Noorzad and Manavirad (2008)	Present study
γ (kg/m^3)	1500	1600
E (MPa)	2.0	32.0
υ	0.3	0.3
c (kPa)	2.0	2.0
ϕ	25°	25° – 40°
ψ	0°	½. ϕ
Range of varying parameters		
D_f/B_L	0.50, 1.0	
B_R/B_L	1.50, 2.0	
S/B_L	0.25, 0.50, 0.75, 1.0, 1.5, 2.0, 3.0, 4.0, 5.0	

3 NUMERICAL ANALYSIS

The present analyses have been executed using commercially available finite element software, ABAQUS considering the problem to be plane strain by assuming that the length of the footing long enough in comparison with the width of the footing,. The foundation soil medium was modelled using Mohr-Coulomb failure criterion following non-associated flow rule ($\phi \neq \psi$) and that the footing was modelled using linear elastic material having elastic properties, Young's modulus and Poisson's ratio of 25E3 MPa and 0.2, respectively. The problem domain was discretized using the 2D plane strain linear continuum elements (CPE4R) and the interaction between the footing and soil was provided using master–slave, surface to surface contact option available in ABAQUS by following tangential behavior which obeys Coulomb's friction law. The discretization scheme and appropriate boundary conditions are as depicted in the fig. 1. The displacement components u_1 (horizontal) and u_2 (vertical) were restricted for the bottom horizontal boundary whereas only u_1 (vertical) was restricted for the vertical edge boundaries.

As illustrated in fig. 1, the soil domain is discretized using four noded plane strain elements. A finer uniform mesh (0.2m) was adopted at the vicinity of the footings (5 times the width, from outer edge of the footing and 5 times the width below the footing) and a coarser mesh was adopted at the far end regions by using single bias (0.2m to 0.8m) technique available in ABAQUS. The mentioned size of the domain and the specified element size was implemented after sensitivity analysis carried out by series of trial and error analysis so that the far end boundaries should not affect the solution of the problem. However, due to space restriction, the detailed analysis is not presented.

Prior to the analysis of above defined problem the present finite element model is validated with the analytical solution provided by Meyerhof (1963) for single footing. The UBC (1606.84 kPa) estimated by finite element analysis for $D_f/B = 0.50$ for $\phi = 40°$ was approximately lesser by 3.47% in comparison to the analytical solution (1662.6 kPa) which can be considered fair approximation. Further, the validation was carried out with interfering footings reported by Noorzad and Manavirad (2012). Noorzad and Manavirad (2012) carried out the finite element analysis of closely spaced strip footings placed on the surface of unreinforced and reinforced soft clay soil using PLAXIS 2D. They carried out the analysis considering Mohr-Coulomb model and hardening soil model for different widths of the footings (1m and 2m), presenting the results in terms of non-dimensional interference factor, defined as the ratio of bearing capacity of interfering footings to that of bearing capacity of isolated footing of identical width. It is of note to mention here that the spacing considered by them is center to center spacing between the footings; fig .2, shows the comparison between present analysis and that reported by Noorzad and Manavirad (2012) for strip footing of width 1m considering Mohr-Coulomb soil properties.

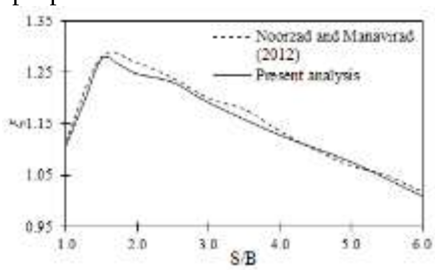
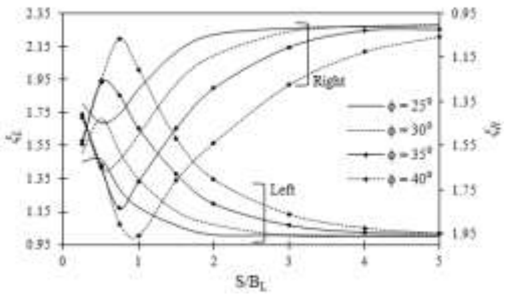


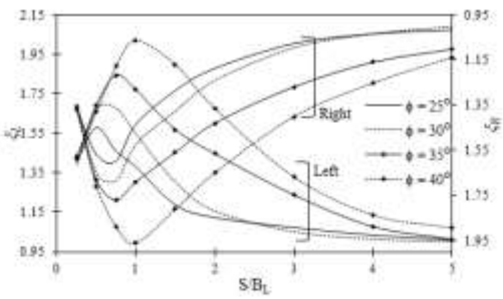
Fig. 2. Comparison of closely spaced strip footings

4 RESULTS AND DISCUSSION

The variation of ultimate bearing capacity and the settlement characteristics of closely spaced footings are evaluated and presented in terms of non-dimensional interference factors; ξ_L/ξ_R defined as the ratio of UBC of left/right footing in the presence of right/left footing to that of UBC of isolated footing and ζ_L/ζ_R defined as the ratio of settlement of left/right footing corresponding to allowable pressure of isolated footing to that of allowable settlement (50mm; as per IS 1904, 1986). Fig.3 and 4 represents the variation of ξ_L/ξ_R with S/B_L for D_f/B=0.5 and 1.0 for B_R=1.5 and 2.0, respectively considering different soil friction angle. It can be seen that there occurs significant interference at close spacing for all the cases and the bearing capacity increases with increase in spacing upto critical spacing to attain peak (ξ_L^{max}) and then onwards it decreases with increase in spacing until it reaches unity so as to behave as an isolated footing. From the fig. 3 and 4, it can be deduced that with increase in the depth of embedment (D_f/B) of the footing ξ_L^{max} for B_R/B_L=1.5 and 2.0, whereas ξ_R^{max} increase fairly for B_R/B_L=1.5 and decreases for B_R/B_L=2.0. The percentage decrease in ξ_L^{max} for B_R/B_L=1.5 between D_f/B 0.5 and 1.0 for ϕ = 25^0, 30^0, 35^0 and 40^0 is 6.8%, 2.4%, 4.6% and 8.6%, respectively. Similarly, the percentage decrease in ξ_L^{max} for B_R/B_L=2.0 between D_f/B 0.5 and 1.0 for ϕ = 25^0, 30^0, 35^0 and 40^0 is 6.6%, 1.75%, 4.1% and 0.5%, respectively. However, the percentage increase in ξ_R^{max} observed for B_R/B_L=1.5 between D_f/B 0.5 and 1.0 for ϕ = 25^0, 30^0, 35^0 and 40^0 is 11%, 1.82%, 3.4% and 0.5%, respectively and the percentage decrease in ξ_R^{max} observed for B_R/B_L=2.0 between D_f/B 0.5 and 1.0 for ϕ = 25^0, 30^0, 35^0 and 40^0 is 2.7%, 1.86%, 2.9% and 4.9%, respectively. Moreover, it can be witnessed that with increase in the width of the right footing the influence zone also increases hence the interaction factors increases and the spacing to attain the behavior similar to isolated footing also increases.

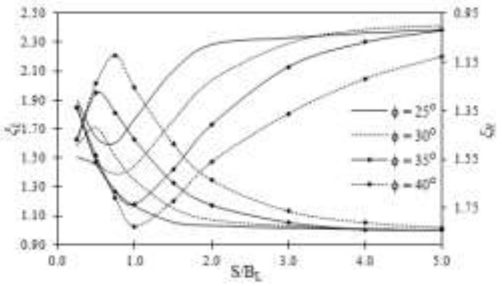


(a) Variation of ξ_L/ξ_R for D_f/B=0.5.



(b) Variation of ξ_L/ξ_R for D_f/B=1.0.

Fig. 3. Variation of UBC interaction factor with S/B_L for B_R=1.5B_L.



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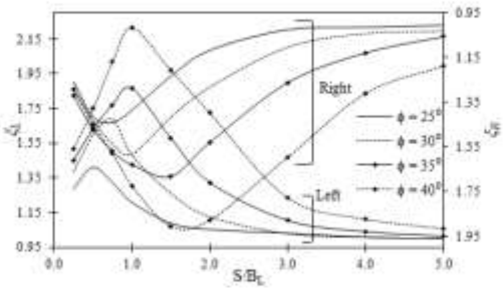
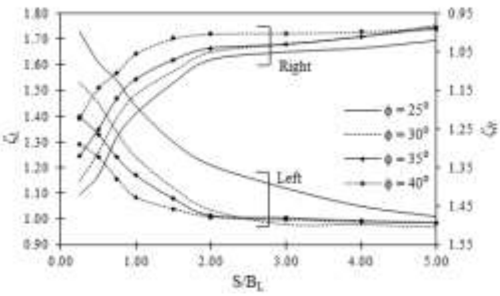


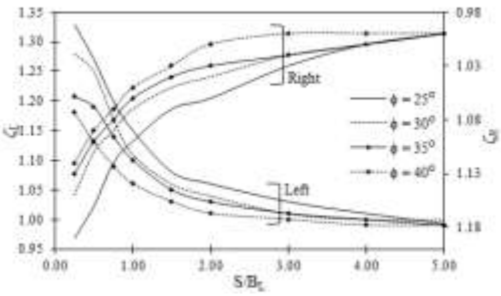
(b) Variation of ξ_L/ξ_R for D_f/B=1.0.

Fig. 4. Variation of UBC interaction factor with S/B_L for B_R=2.0B_L.

The analysis for settlement of interfering footings was carried out considering the settlement of isolated footing corresponding to bearing pressure at allowable settlement. From fig. 5 and 6, the inference can be made that with decrease in spacing the settlement increases gently. However, it can be noted that for the footing of bigger width, the interaction factor is lesser than that for footing of smaller width; that is the settlement corresponding to particular bearing pressure is lesser for the footing of bigger width than the smaller one. Moreover, the settlement is found to decrease with increase in embedment depth of the footing which can be accounted for the increased load carrying capacity due to increased shearing zone. The settlement is observed to be maximum at closed spacing, hence the peak settlement interaction factors (ζ_L^{max} and ζ_R^{max}) occurs at S/B_L=0.25. The observed percentage decrease in ζ_L^{max} observed for B_R/B_L=1.5 between D_f/B 0.5 and 1.0 for ϕ = 25^0, 30^0, 35^0 and 40^0 is 23.1%, 16.3%, 13.6% and 8.52%, respectively; similarly, the observed percentage decrease in ζ_R^{max} observed for B_R/B_L=1.5 between D_f/B 0.5 and 1.0 for ϕ = 25^0, 30^0, 35^0 and 40^0 is 16.2%, 17.2%, 14.4% and 8.2%, respectively.

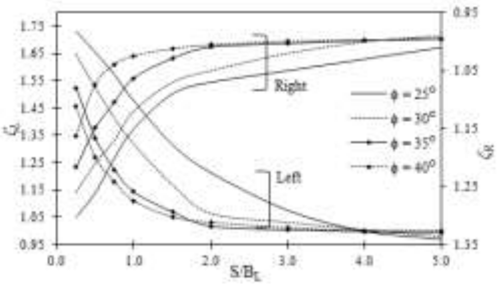


(a) Variation of ζ_L/ζ_R for D_f/B=0.5.

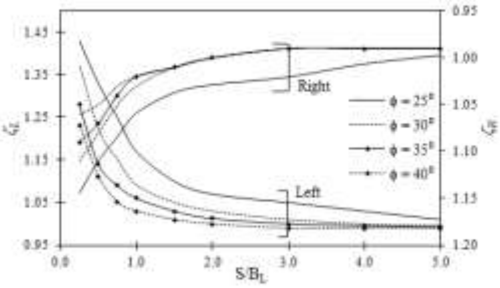


(b) Variation of ζ_L/ζ_R for D_f/B=1.0.

Fig. 5. Variation of settlement interaction factor with S/B_L for B_R=1.5B_L.



(a) Variation of ζ_L/ζ_R for D_f/B=0.5.



(b) Variation of ζ_L/ζ_R for D_f/B=1.0.

Fig. 6. Variation of settlement interaction factor with S/B_L for B_R=2.0B_L.

5 CONCLUSION

The study on the closely spaced asymmetric strip footings embedded in cohesion-less soil medium concludes that the significant effect of interference occurs at close spacing. The effect of interference is found to be more pronounced with respect to UBC on the small size footing than on large size footing. The spacing required for large size footing to behave identical as that of an isolated footing (same size and width) is greater than that compared to interfering footing of small size. Furthermore, UBC and the settlement interaction factors are found to be decreasing with increase in embedment depth of the footing. Hence, the closely spaced footing can be considered to be advantageous when the footings are embedded at depth, D_f/B from the surface of the ground.

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