Studies on Tilt of Closely Spaced Strip Footings on Unreinforced and Reinforced Sands

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Abstract. Two or more strip footings are quite often built close to each other, due to which there will be overlapping of stresses in zones or at points between the footings. There is a non-uniform pressure distribution in the foundation soil beneath the footings, in the space between the footings and beyond. There is also an increase in confining pressure of the soils between the footings. All these results in the tilt of the footings. This numerical study looks into the tilt of the already existing strip footings due to the construction of an adjacent new strip footing on the surface of cohesionless soils. A parametric study is conducted including the effect of geogrid reinforcement/s beneath the new footing. One of the footings representing an already existing foundation is loaded with half of the estimated failure load of a single strip footing, and adjacent new strip footing is loaded up to failure. The property boundary line is assumed to be midway between the two footings. Geogrid reinforcement layers beneath the new footing are considered to be extending equally beyond the footing on either side, up to the property line. Both unreinforced and reinforced sands are considered beneath the new footing for analyses. Tilts are observed to increase with the width of footing. At closer spacings, tilt was found to be more in case of loose sand**.** Results of this study indicate that there is a considerable increase in the tilt of the old footing in the presence of reinforcements beneath the new footing**.**

Keywords: Interference, Tilt, Strip footings, Reinforced new foundation, Existing foundation

1 Introduction

The primary function of the foundation of a structure is to safely transfer the loads from the superstructure to the soil beneath without occurrence of shear failure and excessive settlements. Due to rapid urbanisation, very often structures and their foundations are built close to each other. The closer spacing between the footings leads to interference effect, which may alter the bearing capacity, settlement, rotational characteristics and failure mechanisms of footings. Due to large stresses at points between the footings (due to the overlapping of stresses), there is a non-uniform pressure distribution beneath the footings in the gap between the footings and beyond. There is also an increase in the confining pressures of the soils between the footings. All these causes a tilt in the footings. This numerical study looks into the tilt of two adjacent strip footings on the surface of cohesionless soils. The presented numerical analyses are based on finite element software-PLAXIS 2D.

Interference effects of strip footings were first studied by Stuart [1]. Kumar and Saran [2] conducted laboratory-scale model tests to study interference effects, including tilts, of the closely spaced square and strip footings resting on geogrid-reinforced sand. According to Lavasan and Ghazavi [3] and Lavasan et al. [4], who performed laboratory tests, found interference to have a significant effect on the ultimate bearing capacities, settlements, tilts and the failure mechanisms of the footings. Experimental studies were made by Salampatoor et al. [5] on unequally loaded and sequentially constructed footings to study interference effect. Their study shows that settlement and tilting of old footing increases due to a new footing. It was reported that there would be an inward tilt of the two footings. Gupta and Sitharam [6] studied interference effects from the point of view of increased bearing capacities. They attributed interference to increase in confining pressure due to the interaction between the failure zones of interfering footings.

2 Problem definition

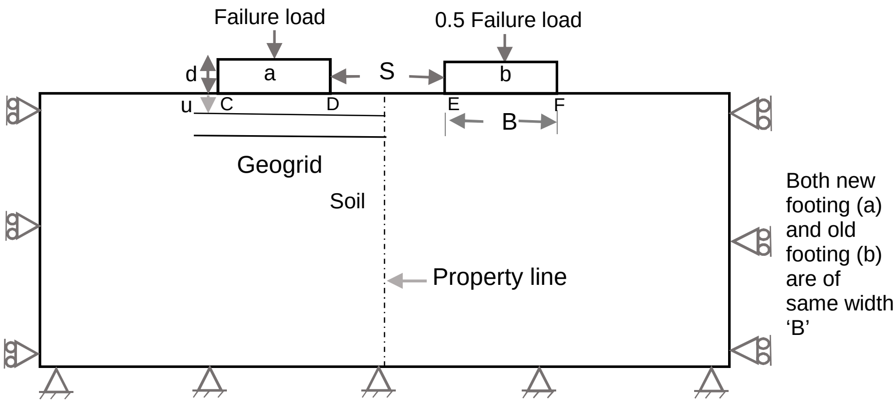


Fig.1. Problem definition

Two identical rough strip footings 0.75 m thick, spaced at clear spacing S, are assumed to be placed on the surface of the sand (Fig.1). One of the footings representing the existing/old foundation is loaded with half of the estimated failure load (Factor of safety 2) of isolated footing and adjacent footing loaded up to failure. The footings are loaded unequally and sequentially to simulate the mechanism of the new and old footing with different construction orders. The property boundary line is assumed to be midway between the two footings. Geogrid reinforcement layers beneath the new footing are also considered to be extending equally beyond the footing on either side, only up to the property line. Analyses are performed on reinforced soil with reinforcement placed in one layer and two layers. The reinforcements are placed at 0.3B depth from the top of the soil bed in case of one layer, at 0.3B, 0.5B depths in case of two layers. Both unreinforced and reinforced sands are considered beneath the new footing for analyses. The study is carried out by varying the spacing between the footings. The study is done for spacing ratio, S/B of 1.0, 1.5, 2.0, 2.5 and 3.0, where S is the clear spacing between the footings and B is the width of the footing. The footing width is varied as 1m, 2 m, and 3 m. The main objective is to study the tilt behaviour of old and new footings when the spacing between the footings is varied from 1.0 B to 3.0 B.

Plane strain condition and 15-noded triangular elements are used for the analyses. Both vertical displacement and horizontal displacements are restricted for the bottom horizontal boundary, whereas only horizontal displacements are restricted for the vertical boundaries. The Mohr-Coulomb failure criterion, which is an elastic, perfectly plastic model, is considered. The footing is simulated by using plate elements. Modulus of elasticity, E of concrete is taken as 25 x10^6 kN/m^2 and Poisson's ratio, υ is considered as 0.15. Geogrid is provided as reinforcement. The property assigned is flexural rigidity (EA), is taken as 500 kN/m. The soil parameters used for finite element analyses are shown in Table 1 [7].

Table 1. Properties of Soils [7]

Parameter	Cohesionless soils	
	Medium dense sand	Loose Sand
Unsaturated unit weight, γ (kN/m^3)	18.2	17.4
Saturated unit weight, γ_{sat} (kN/m^3)	21	20.9
Young's modulus, E (kN/m^2)	30000	15000
Poisson's ratio, υ	0.28	0.25
Cohesion, C (kN/m^2)	0	0
Angle of internal friction, Φ (^{0})	35	30

3 Results and discussions

Construction of a new footing adjacent to the old footing will alter the bearing capacity, settlement, rotational characteristics and failure mechanism of latter. In the present study, one of the footings representing an already existing foundation is loaded to half of the estimated failure load of a single strip footing and adjacent new strip footing is loaded up to failure.

3.1 Bearing Capacity of New Footings in the Presence of Existing Footing

Figure 2 presents the bearing pressure-settlement curves of new footing in the presence of existing footing placed at the different spacing ratio, S/B. The figure also shows bearing pressure-settlement curve of a single strip footing. It is seen that bearing capacity is increased due to the presence of the other footing, which can be attributed to the interference effect.

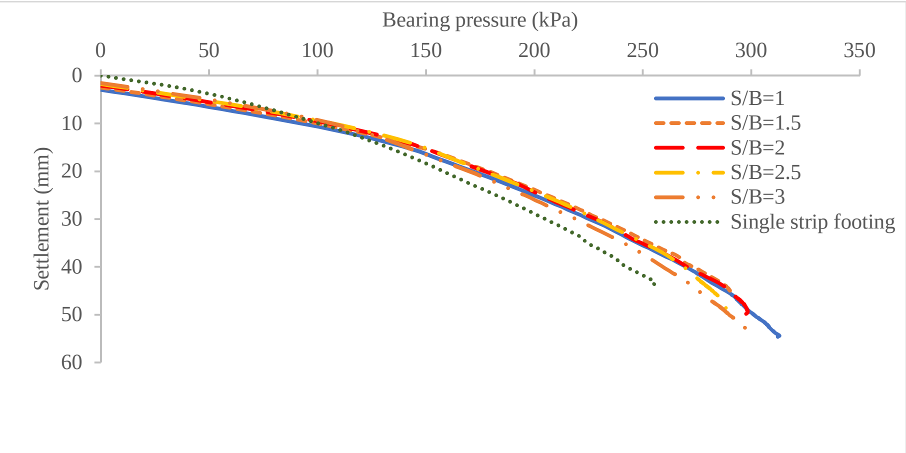


Fig.2. Bearing pressure versus settlement for new footing, when independent and in the presence of old footing of width 1m on medium dense sand on unreinforced soil condition.

To quantify the effect of old footing on the ultimate bearing capacity of new footing, the interference factor for new footing is determined. Interference factor for new footing $IF_{(new)}$ is defined in Equation 1.

$$IF_{(new)} = \frac{\text{Ultimate load carrying capacity of the new footing in the presence of old footing}}{\text{Ultimate load carrying capacity of single independent strip footing}} \quad (1)$$

The IF $_{(new)}$ versus spacing ratio S/B plotted in Fig.3 for both medium dense sand and loose sands. IF $_{(new)}$ is more when the spacing between the footings is less.

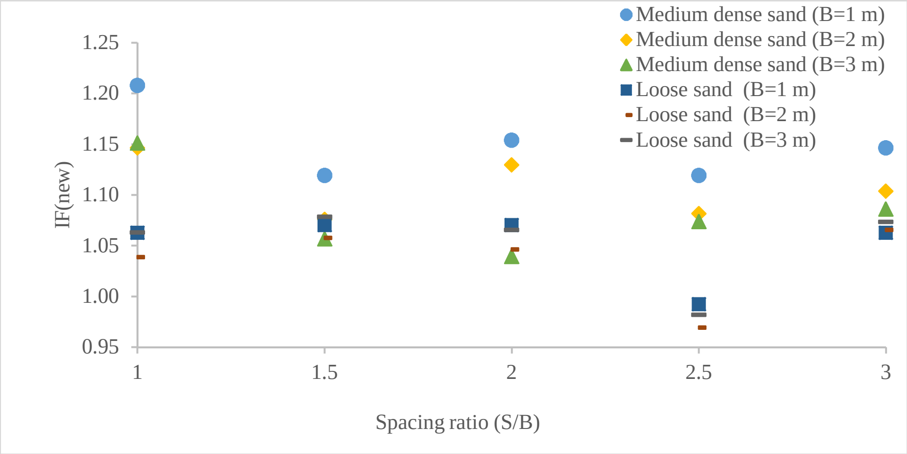


Fig.3. Interference factor of new footing adjacent to existing footing versus spacing ratio, S/B, for different footing widths on unreinforced soil.

3.2 Tilt of Existing Footing due to the New Footing

Tilt of existing footing due to the new footing on unreinforced soil

The tilt of existing footing due to the new footing is being studied. Tilt is expressed in terms of percentage. To study the effect of footing widths, tilt is plotted against spacing ratio for medium dense sand and loose sand for different widths (B=1m to B=3 m) (Fig. 4). Tilt is observed to increase with footing width and is found to be less for medium dense sand as compared to loose sand. Maximum differential settlement for a 3m wide strip footing on medium dense sand works out to be about 25 mm (for about 0.8% tilt) whereas in case of loose sand the differential settlement works out to be about 38 mm (for about 1.2% tilt). Discussion on the direction of tilt of both the existing and new footing on unreinforced soil is done in section 3.2.3.

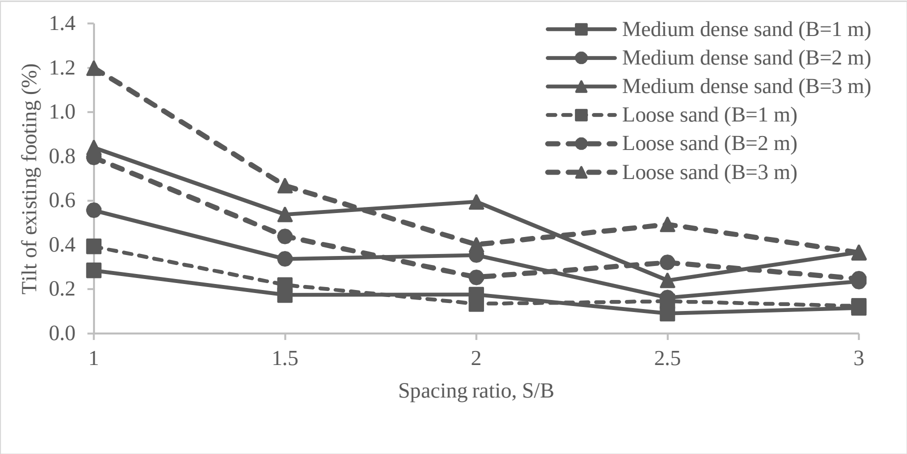


Fig. 4. Tilt of old footing due to new footing versus spacing ratio, S/B, for medium dense sand and loose sand on unreinforced soil conditions.

Tilt of existing footing due to the new footing on reinforced soil

To study the effect of reinforcement provided beneath new footing adjacent to the existing footing, on the tilt of existing footing, tilt is plotted against spacing ratio for both unreinforced and reinforced conditions for footing width B=1 m (Fig.5). In Fig.6

tilt is plotted against spacing ratio for both unreinforced and reinforced conditions for footing width B=3 m. In both cases, the tilt of existing/old footing due to the construction of the new adjacent footing is found to be more when there is reinforcement beneath the new footing. Discussion on tilts of existing and newly built strip footings, with the newly built strip footing supported on reinforced soil, is done in the next section (3.2.3).

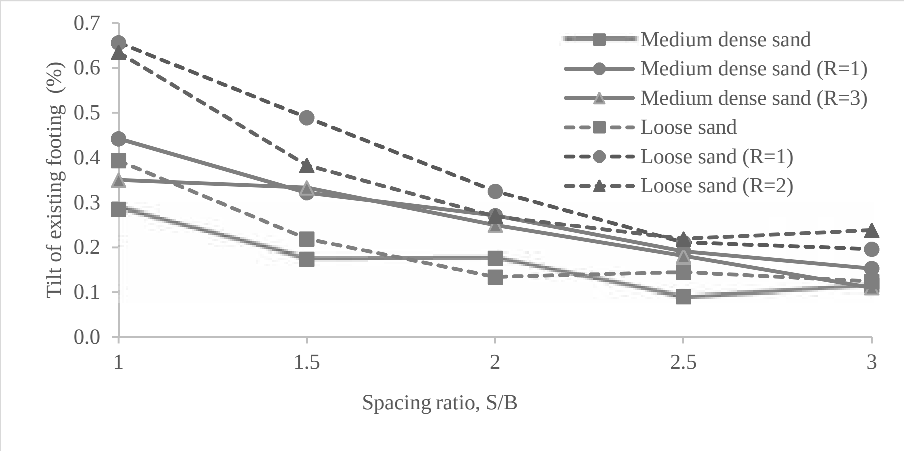


Fig. 5. Tilt of old footing due to new footing versus spacing ratio, S/B, for medium dense sand and loose sand on unreinforced and reinforced soil conditions (footing width 1m, R in bracket denotes the number of reinforcement layers beneath new footing).

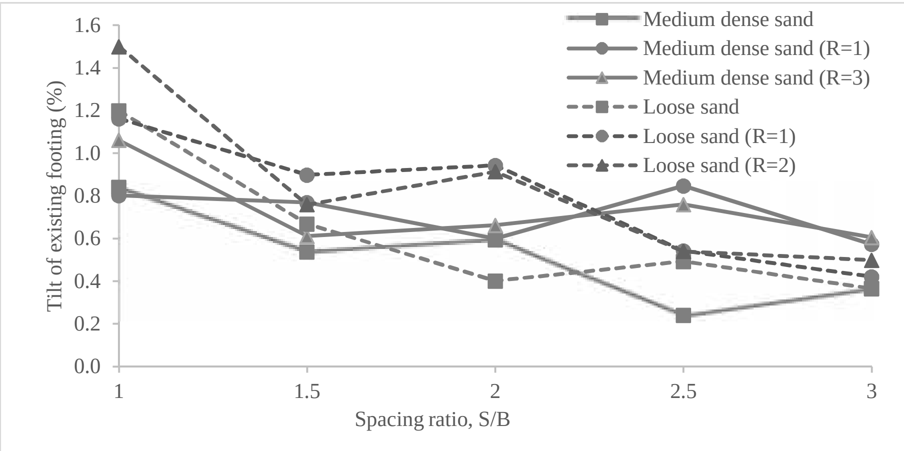
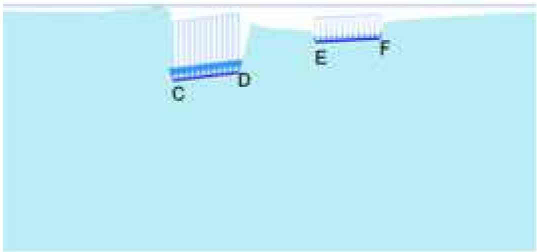


Fig. 6. Tilt of old footing due to new footing versus spacing ratio, S/B, for medium dense sand and loose sand on unreinforced and reinforced soil conditions (footing width 3m, R in bracket denotes the number of reinforcement layers beneath new footing).

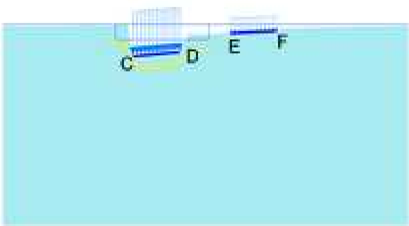
Direction of tilts of both existing and new footings

The direction of tilt is shown in Fig.7 (which is a computer output). CD represents new strip footing, and EF represents the old/already existing strip footing. In the present study, loading is done sequentially, i.e., the new footing is loaded after old footing is already in place. Also, differential loading is considered, old footing loaded to only 50% and new footing loaded to 100% of failure load of strip footings on sands. Both footings are tilting in the same anticlockwise direction as seen in Fig.7. It can be explained in the following way. For the old/existing footing, in the initial stages, increased stresses in the soil between the footings must have caused it to rotate anticlockwise or inward. But in case of the new footing, as it is gradually loaded, the soil between the footings gets more and more confined, and makes it hard for the inner edge (D) of the new footing to compress, whereas the outer edge which is having lesser confinement effect undergoes larger settlements-thus resulting in anticlockwise rotation or tilt. Thus, although there is an increase in stress in soil between the footings due to stress overlap, the confinement effect seems to dominate and dictate the direction of tilt.

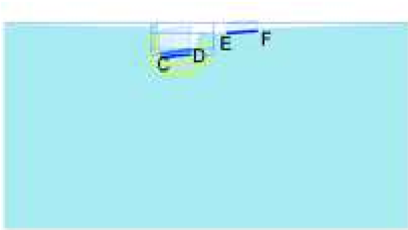
In the case of reinforcement beneath new strip footing, larger load and stiffer foundation soil must have made it undergo larger and uniform settlements (compared to already existing footing). This will cause larger rotation of the old strip footing when the new strip footing is on reinforced soil.



(a) S/B=1



(b) S/B=1 (R=1)

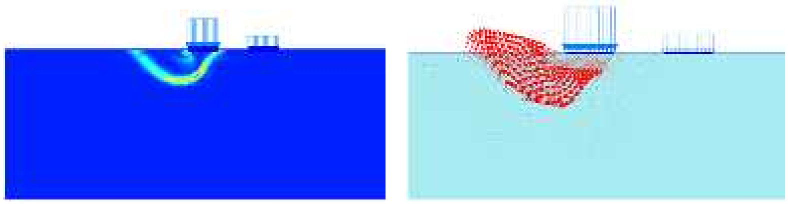


(c) S/B=1 (R=2)

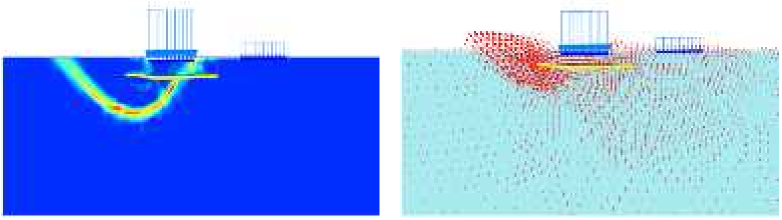
Fig.7. Computer output showing directions of tilt of old and new footings for spacing ratio, S/B=1, for medium dense sand for (a) unreinforced case (b & c) for reinforced cases with one and two layers of reinforcements beneath the new footing

3.3 Failure Zones of Interfering Footings

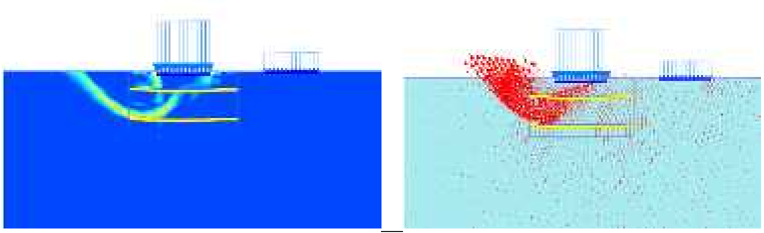
The elastic zones, as envisaged in Terzaghi's or Meyerhof's analyses, beneath old/already existing footings at all spacings on sands, is not very clear. It must be recollected here that only the new footing is loaded up to failure and the already existing old footing is considered to be loaded to 50% capacity. Therefore, it is to be expected that the failure surfaces are fully or better developed in the case of new footings but certainly influenced by the presence of the already existing and loaded (up to 50%) old footings. The variation of failure surface and incremental displacement pattern beneath the strip footings are shown in Fig.8. Maximum bearing capacity and tilt values are noted at spacing ratio 1. Therefore, the failure mechanisms at a spacing ratio of one are being studied. At unreinforced soil conditions, failure surface from beneath the new footing is developed fully (Fig.8a). When the new footing is provided with a single layer of reinforcement failure surface is seen to get wider and deeper Figs. (8b-8c).



(a) S/B=1



(b) S/B=1 (R=1)



(c) S/B=1 (R=2)

Fig.8. Shear strain contours and incremental displacement in case of footings on medium dense sand for footing width B=1m and (S/B=1) (R in bracket denotes the number of reinforcement layers)

4 Conclusions

The following conclusions are drawn from this study.

- In this study, the two strip footings (old and new on unreinforced and reinforced sands) are loaded sequentially and unequally. More load is considered on new strip footing. Both footings are tilting in the same direction.
- Large tilts are observed at a spacing ratio of one in both medium dense sand and loose sand. As expected, tilts were less for medium dense sand when compared to loose sand.
- Tilt increases with increase in footing width for sands.
- Providing reinforcement beneath the new footing and loading it to maximum, causes a somewhat larger tilt of already existing strip footings supporting lightly loaded structures.

References

1. Stuart, J. G.: Interference between foundations, with special reference to surface footings in sand. Geotechnique 12(1), 15-22 (1962). doi:10.1680/geot.1962.12.1.15.
2. Kumar, A., Saran, S.: Closely spaced footings on geogrid-reinforced sand. Journal of geotechnical and geoenvironmental engineering 129(7), 660-664 (2003). doi:10.1061/(ASCE)1090-0241(2003)129:7(660).
3. Lavasan, A. A., Ghazavi, M.: Behavior of closely spaced square and circular footings on reinforced sand. Soils and Foundations, 52(1), 160-167 (2012). doi: 10.1016/j.sandf.2012.01.006.
4. Lavasan, A. A., Ghazavi, M., Schanz, T.: Analysis of interfering circular footings on reinforced soil by physical and numerical approaches considering strain-dependent stiffness. International Journal of Geomechanics 17(11), 04017096 (2017). doi:10.1061/(ASCE)GM.1943-5622.0000992
5. Salamatpoor, S., Jafarian, Y., Hajiannia, A.: Bearing capacity and uneven settlement of consecutively constructed adjacent footings rested on saturated sand using model tests.International Journal of Civil Engineering 17(6), 1-13 (2018). doi:10.1007/s40999-018-0295-y.
6. Gupta, A., Sitharam, T. G.: Experimental and numerical investigations on interference of closely spaced square footings on sand. International Journal of Geotechnical Engineering, 1-9 (2018). doi.org/10.1080/19386362.2018.1454386.
7. Bowles L.E.: Foundation analysis and design. McGraw-hill (1996).