A NUMERICAL STUDY ON INTERFERENCE EFFECTS OF CLOSELY SPACED STRIP FOOTINGS ON SOILS

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ABSTRACT

Foundations of structures often need to be placed close to meet the architectural as well as the functional requirements. In such cases, the combined action of footings is different from a single footing. It causes interference of the stress zones. In the present study, the interference effects of two closely spaced strip footings on the surface of cohesive and cohesionless soils are being investigated. Parametric studies are done for two footings by varying the spacing between the footings and the width of the footings. The results are presented in terms of efficiency factors. In the first case, both the footings are loaded simultaneously up to failure. In the second case, one of the footings representing an already existing foundation is loaded with half of the estimated failure load of isolated footing and adjacent footing loaded up to failure. The effect of interference is observed to be particularly significant in terms of the settlement. Effect of shear keys placed beneath the footings, at different locations beneath the footing and the interference of such footings is also studied in case of stiff clay. It is found that the presence of shear keys has a significant effect on the interference between the footings, compared to without the shear keys, especially in reducing the tilt of foundations.

Key words: Interference, Strip Footing, Settlement, Bearing capacity and Shear Key.


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1. INTRODUCTION

In recent times, due to rapid developmental activities and scarcity of land, especially in the urban areas, demand for construction sites in good commercial areas are increasing at a rapid rate. Land prices are soaring sky high. Land which is categorised as nonsuitable for
construction also has to be utilised and made it suitable by any of the ground improvement methods. Several structures are built close to each other, and hence their closely spaced foundations often interfere with each other. The conventional methods of foundation design assume that the foundations are in an isolated condition. However, in actual practice, footings which are very close to each other are influencing and altering parameters such as settlement, bearing pressure, failure mechanisms and tilting, are known as interfering footings. Therefore, the study of the behaviour of closely spaced interacting footings is of paramount practical importance in the field of sub-structural engineering to achieve economical designs.

Recognising the effects of interference and designing the footing accordingly also ensures the safety of the structure. Newly constructed structures near to the old construction may change the settlement, pressure and tilt characteristics of the old one and could lead to its failure. Incorporating an additional element, such as shear key beneath the footing, reduces the effects of interference considerably.

Importance of the interference effect of shallow foundations was first noticed by Stuart [1]. Experimental and limit state method were used and an equation proposed for calculating bearing capacity with the interference effect by the inclusion of efficiency factors. Das and Larbi-Cherif [2] compared the model study results with previous studies and found out that efficiency factor magnitudes are lower when S/B less than 3. Graham et al. [3] considered three parallel strip footings and calculated efficiency factor as the ratio of failure load of the central interfering footing to the capacity of a similar isolated footing. Efficiencies are highest at close spacing and decreases until the footings act as independently. Kumar [4] studied the interaction of footings resting on reinforced earth slab. In this study, he found that in case of interfering footings resting on reinforced soil, the magnitude of settlement and tilt decreases for a given load intensity as compared to the same footings on unreinforced soil for the same load intensity. The tilt of the closely spaced foundation reinforced with geogrid was considered for the first time by Kumar and Saran [5]. Lavasan et al. [6] calculated efficiency factors of bearing capacity of interference footings for the practical range of friction angles. Many of the researchers done laboratory experimental studies on interference effects [7-16]. From the literature, it has been noted that most of the studies have been carried out for two or more interfering footings resting on the surface of cohesionless soil medium. Numerical analyses are carried out to understand the effects of interference of two closely spaced strip footings resting on both cohesionless soils and clay soils. Six different soil medium ranging from stiff clay, medium stiff clay, soft clay, dense sand, medium dense sand, and loose sand are considered. This detailed study of interference of six variety soils gives how much the soil properties affect the interference effects.

2. METHODOLOGY
Numerical investigations are carried out with various soils and mainly focused on bearing pressure, settlement and tilt characteristics. Strip footings are analysed in finite element 2D software PLAXIS. The soil parameters assigned are shown in Table 1. Widths of footings considered are 1m, 2m and 3m. Modulus of elasticity, E of concrete is taken as 25 x10^6 kN/m^2. The thickness of footing, d is taken as 0.75m and Poisson's ratio, ν is considered as 0.15. The geometry of interfering footings is shown in Figure 1.
Table 1 Material properties of soils [17]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Stiff clay</th>
<th>Medium stiff clay</th>
<th>Soft clay</th>
<th>Dense sand</th>
<th>Medium dense sand</th>
<th>Loose sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material model</td>
<td>Mohr-Coulomb</td>
<td>Mohr-Coulomb</td>
<td>Mohr-Coulomb</td>
<td>Mohr-Coulomb</td>
<td>Mohr-Coulomb</td>
<td>Mohr-Coulomb</td>
</tr>
<tr>
<td>Material type</td>
<td>Undrained</td>
<td>Undrained</td>
<td>Undrained</td>
<td>Drained</td>
<td>Drained</td>
<td>Drained</td>
</tr>
<tr>
<td>Unsaturated unit weight, $\gamma$ (kN/m$^3$)</td>
<td>18.4</td>
<td>17.2</td>
<td>16.0</td>
<td>19.1</td>
<td>18.2</td>
<td>17.4</td>
</tr>
<tr>
<td>Saturated unit weight, $\gamma_{sat}$ (kN/m$^3$)</td>
<td>22.0</td>
<td>21.0</td>
<td>20.3</td>
<td>21.1</td>
<td>21.0</td>
<td>20.9</td>
</tr>
<tr>
<td>Young’s modulus, $E$ (kN/m$^2$)</td>
<td>60000</td>
<td>30000</td>
<td>6000</td>
<td>50000</td>
<td>30000</td>
<td>15000</td>
</tr>
<tr>
<td>Poisson’s ratio, $\nu$</td>
<td>0.21</td>
<td>0.28</td>
<td>0.35</td>
<td>0.30</td>
<td>0.28</td>
<td>0.25</td>
</tr>
<tr>
<td>Cohesion, $C$ (kN/m$^2$)</td>
<td>80</td>
<td>50</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Angle of internal friction, $\phi$ (°)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>40</td>
<td>35</td>
<td>30</td>
</tr>
</tbody>
</table>

Figure 1. The geometry of interfering footings

Considering single isolated foundation, the far domain in horizontal, x and vertical downward, z directions are varied and the failure load compared with that calculated by IS code method [18] (Table 2). For each soil, the process carried out and the farthest domain in x and z directions have been obtained and are tabulated in Table 3.

Table 2 Comparison of ultimate bearing capacity ($q_u$) from PLAXIS 2D and IS code method [18] for various soils

<table>
<thead>
<tr>
<th>Soil</th>
<th>Width of footing (m)</th>
<th>Ultimate Bearing capacity ($q_u$) from IS code method [18] (kN/m$^2$)</th>
<th>Ultimate bearing capacity ($q_u$) from PLAXIS 2D (kN/m$^2$)</th>
<th>Percentage difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stiff clay</td>
<td>1</td>
<td>411.2</td>
<td>416</td>
<td>1.17</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>411.2</td>
<td>416</td>
<td>1.17</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>411.2</td>
<td>416</td>
<td>1.17</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>257.0</td>
<td>260</td>
<td>1.15</td>
</tr>
<tr>
<td>Medium stiff clay</td>
<td>2</td>
<td>257.0</td>
<td>260</td>
<td>1.15</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>257.0</td>
<td>260</td>
<td>1.15</td>
</tr>
<tr>
<td>Soft clay</td>
<td>1</td>
<td>102.8</td>
<td>104</td>
<td>1.15</td>
</tr>
</tbody>
</table>
Table 3 Selected domain for different soil types

<table>
<thead>
<tr>
<th>Soil</th>
<th>x</th>
<th>z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stiff clay</td>
<td>2B</td>
<td>2B</td>
</tr>
<tr>
<td>Medium stiff clay</td>
<td>2B</td>
<td>2B</td>
</tr>
<tr>
<td>Soft clay</td>
<td>2B</td>
<td>2B</td>
</tr>
<tr>
<td>Dense sand</td>
<td>15B</td>
<td>15B</td>
</tr>
<tr>
<td>Medium dense sand</td>
<td>12B</td>
<td>12B</td>
</tr>
<tr>
<td>Loose sand</td>
<td>15B</td>
<td>15B</td>
</tr>
</tbody>
</table>

The Mohr-Coulomb failure criterion which is an elastic, perfectly plastic model is selected for simplicity, practical importance and the availability of the parameters needed. Two equal rigid strip footings 0.75 m thick spaced at clear spacing ‘S’ are placed on top of the soil. In all analyses conducted in the present study, it is assumed that footings are located on the ground surface on the soil. The groundwater condition is not taken into account. Effect of widths of strip footings is studied by selecting three different widths of footings such as 1, 2 and 3m. Plane strain condition with 15 noded triangular elements are used in the modelling. Footings are modelled by plate elements. Horizontal and vertical displacements are restricted in the bottom boundary. Vertical boundaries are restricted only in the horizontal direction, and the top boundary is free in all the directions.

In the first case, both the footings are loaded simultaneously to failure at the same time. In the second case, one of the footings representing an already existing foundation is loaded with half of the failure load of isolated footing (Factor of safety is taken as 2) and adjacent footing loaded up to failure. Clear spacing between the footings ‘S’ is varied from 0.5B, 1B, 1.5B, 2B, 2.5B and 3B. Clear spacing divided by the width of the footings are mentioned as a spacing ratio, S/B. In this study, inner region midpoint between the two adjacent strip footings is considered to study the characteristics of the interference effect. Overlapping of stresses and tilts occur due to interference in the inner region. The settlement and stresses at points a, b, c, d, e, and f, as shown in Figure.2, which are at depths 0B, 0.25B, 0.5B, 1B, 1.5B and 2B respectively at the midway between the interfering footings are considered and analysed. In the third case footings are provided with shear keys. A shear key having depths (L) 0.25B, 0.5B and 1B beneath the footing and located at the inner edge and in the centre of the footing are considered in the case of stiff clay, and the changes in settlement of the footings are analysed for the points mentioned above (a, b, c, d, e, and f). The parameters relevant to the shear keys are shown in Table 4.
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Figure 2. Definition of problem

Table 4 Parameters of the shear key

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width of shear key, W (m)</td>
<td>0.75</td>
</tr>
<tr>
<td>Modulus of elasticity, E (kN/m²)</td>
<td>25x10⁶</td>
</tr>
<tr>
<td>Poisson’s ratio, ν</td>
<td>0.15</td>
</tr>
<tr>
<td>Depth of shear key, L (m)</td>
<td>0.25 B, 0.5B and 1B</td>
</tr>
</tbody>
</table>

3. RESULTS AND DISCUSSIONS

3.1. Both the Footings Loaded Simultaneously till Failure
Two parameters namely efficiency factor due to bearing pressure (\(\xi_\gamma\)) and efficiency factor due to settlement (\(\xi_\delta\)) are considered.

3.1.1. Efficiency factor due to bearing pressure (\(\xi_\gamma\))
In order to study the interference effect of two closely spaced strip footings, efficiency factors due to bearing pressure are determined from the load-settlement plots. Efficiency factor due to bearing pressure (\(\xi_\gamma\)) is expressed in Equation 1 [13].

\[
\xi_\gamma = \frac{\text{Ultimate bearing capacity of single footing in the presence of other footing}}{\text{Ultimate bearing capacity of the single isolated footing}}
\]  

The footings are modelled to rest on soils and loaded up to the failure. The load at failure is noted and compared regarding efficiency factor \(\xi_\gamma\). Figure 3 shows the variation of efficiency factor \(\xi_\gamma\) with spacing ratio S/B on various soils for footing width 1m, 2m and 3m respectively. Efficiency factor greater than one indicates, improvement of bearing pressure due to the adjacent footing, i.e., interference effect. The soil in between the footings is stiffened due to loading on the footings and due to confinement effect. Efficiency factor of one means that the footing bearing pressure is the same as that of isolated footing. Stiff clay, medium stiff clay and soft clay show that the ultimate bearing pressure of interfering footings compared to isolated footings is not very much different, and there is no significant improvement in bearing capacity. In cohesionless soils, the variation of efficiency factor shows the same trend for different footing widths. Maximum improvement regarding bearing pressure occurred in the medium dense sand at S/B=2 (20% improvement in case of footing width 1m, 15% in case of 2m wide footing and 11% in case of 3m wide footing respectively). The efficiency factor shows a value of less than 1 for the spacing ratio of 2.5 in cohesionless
soils except for medium dense sand. It shows the bearing pressure at a spacing ratio of 2.5 is less than that of isolated footing. The percentage of decrease is only in a range of about 7%.

**Figure 3.** Variation of $\xi_\gamma$ with S/B on soils for footing widths (a) $B=1m$ (b) $B=2m$ (c) $B=3m$

When the two footings are closely spaced ($S<2.5B$), the shear failure surfaces of each footing intersects the shear failure surface of the adjacent footing and strikes beneath the adjacent footing or strikes close to the adjacent footing. Therefore the footing requires larger load to cause failure than when the footings act independently (as seen in Figure 4(a) in case of medium stiff clay with S/B=1, in Figures 4(b) and 4(c) in case of stiff clay with S/B =0.5 and 1.0, Figure 4(d) in case of medium dense sand with S/B=0.5).

When the spacing is about 2 to 3B, the two shear failure surfaces emerge beyond the edges of the footing in the area in between the two footings. Thus there will be two failure surface emerging from the space in between. Therefore, there could be a reduction in the efficiency factor ($\xi_\gamma$) (as seen in Figure 4(e) in case of medium stiff clay with S/B=2, in Figure 4(f) in case of stiff clay with S/B=2 and Figures 4(g) and 4(h) in case of medium
dense sand with S/B=2.5 and 3 respectively). Since the soils in between footings are subject to lateral confining pressures (due to the vertical loads on the footings), they can sustain larger loads (or stresses) than the soils beneath a single independent footing. This is the reason for getting higher efficiency factors (ξγ) in the case of two footings adjacent to each other.

**Figure 4.** Incremental deviatoric strain contours (a) medium stiff clay (S/B=2) (b) stiff clay (S/B=0.5) (c) stiff clay (S/B=1) (d) medium dense sand (S/B=0.5) (e) medium stiff clay (S/B=2) (f) stiff clay (S/B=2) (g) medium dense sand (S/B=2.5) (h) medium dense sand (S/B=3)
3.1.2. Efficiency factor due to settlement ($\xi_{\delta}$)

In order to study the interference effect of closely spaced strip footings, efficiency factors due to the settlement are determined from the load-settlement plots; where the efficiency factor due to settlement ($\xi_{\delta}$) is expressed in Equation 2.

$$\xi_{\delta} = \frac{\text{Settlement at the point considered when two footings are loaded till failure}}{\text{Settlement at the point considered when only one footing is present}}$$ (2)

For the first loading case, i.e., both the footings are loaded simultaneously till failure, the efficiency factors are determined and compared. The points considered in the analysis of settlement are at the midway between the footings (Figure 2). For the second loading case, i.e., the first footing is loaded with half the estimated failure load of isolated footing and the second is loaded till failure. It can be seen that the efficiency factor ($\xi_{\delta}$) is greater than 1 (signifying settlement of interfering footing is greater than the isolated footing) in most of the cases. The efficiency factor is recorded the highest values at the surface point ‘a’ in most of the spacing ratios. Figures 5-10 show the variation of the efficiency factor due to settlement ($\xi_{\delta}$) with respect to the spacing ratio for various footings widths with all the six soils. Generally, the efficiency factor is highest in clays at S/B=1.5, except in the cases of medium stiff clay and soft clay with footing width of 3 m and 1 m respectively. The stresses are maximum at the centre, in between the two footings, because of the overlapping of stress zones when the S/B ratio is 1.5 in the case of clays. Efficiency factor of sands is recorded the highest value at S/B=0.5, and a decreasing trend can be seen as spacing ratio increases.

**Figure 5.** Variation of efficiency factor ($\xi_{\delta}$) with S/B for stiff clay (a) B=1 m (b) B=2 m (c) B=3 m
Figure 6. Variation of efficiency factor ($\xi_\delta$) with S/B for medium stiff clay (a) B=1m (b) B=2m (c) B=3m

Figure 7. Variation of efficiency factor ($\xi_\delta$) with S/B for soft clay (a) B=1m (b) B=2m (c) B=3m
Figure 8. Variation of efficiency factor ($\xi_\delta$) with S/B for dense sand (a) B=1m (b) B=2m (c) B=3m

Figure 9. Variation of efficiency factor ($\xi_\delta$) with S/B for medium dense sand (a) B=1m (b) B=2m (c) B=3m
3.1.3. Tilt of footings

Due to large stresses at any point between the footings (due to overlapping of stresses), there is a non-uniform pressure distribution beneath the footings (Figures 12 to 14). There is an increase in stresses from the outer edge of the footing to the inner edge. This causes an inward tilt in the footings. The settlement also will not be uniform. The tilt of footing is expressed in percentage for left footing is being analysed. Variation of tilt, in percentage, with respect to the spacing ratio is plotted for various footing widths (Figure 11). In all the six soils, soft clay provides maximum tilt for footing widths of 1m, 2m, and 3m. 7% in footing width 1m, 12% in 2m and 14% in 3m. It can be observed that the maximum tilt of footing occurs at a spacing ratio of 1.5 in clays and loose sand. It is also observed that maximum tilt at left, as well as right footing, occurs at a spacing ratio of 2 in the case of dense sand and medium dense sand. (1.6%, 3.2% and 4.8% of dense sand at spacing ratio 2 for footing width 1m, 2m, and 3m). It is noted that the magnitude of the tilt is proportional to the footing width.
3.1.4. Variation of settlement on a horizontal plane

Variation of settlement is studied on a horizontal plane. The study is done up to a distance 2B from the outer end of footings on the horizontal plane. The study is carried out at different horizontal levels like at the surface, 1B below the surface and 2B below the surface. Maximum interference effect is observed at the surface.

Figure 12 shows the variation of settlement on a horizontal plane at the ground level for footing width 1m on stiff clay. It is clear that the settlement shows the maximum value at a spacing ratio of 1.5. Other footing widths (2m and 3m) also show a similar trend to that of 1m. The similar trend is seen in the case of medium stiff clay. Figure 13 shows the variation of settlement in a horizontal plane at the ground level for footing width 1m on dense sand. The settlement shows the maximum value at the spacing ratio of 0.5. Medium dense sand and loose sand also follow a similar trend.

3.1.5. Variation of effective stress on a horizontal plane

Effective stresses on a horizontal plane for soils are significant on a horizontal plane 2B depth from the ground surface. For all the six soils effective stresses are maximum noted for the spacing ratio of 0.5 (Figures 14 and 15).
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**Figure 12.** Variations of settlement on a horizontal plane at the ground level for B=1m on stiff clay

**Figure 13.** Variations of settlement in a horizontal direction at the ground level for B=1m on dense sand

**Figure 14.** Variation of effective normal stress on a horizontal plane at the depth 2B below the ground surface for B=3 m in stiff clay
3.2. One Footing Loaded With Half of the Estimated Failure Load of Isolated and Adjacent Footing Loaded to Failure

3.2.1. Efficiency factor due to bearing pressure

Efficiency factor, $\xi$, is the ratio of failure load of the new footing to the failure load of isolated footing. In this case, the old footing is loaded half of the failure load of isolated footing. Variation of efficiency factor with spacing ratio plotted for various soils. Significant variations of bearing pressure are not seen for clays. Maximum improvement is noted for dense sand, medium dense sand and loose sand at the spacing ratio 1.5, 1 and 1.5 respectively. Various efficiency factor with the spacing ratio for various footing widths is plotted in Figure 16.

3.2.2. Variation of settlement

The settlement shows the highest values at the surface point (a) in most of the spacing ratios for clay soils. The maximum settlement is observed for spacing ratio 1.5 for stiff, medium stiff and soft clays. The settlement shows the highest values around 1B below the surface for dense sand and around 0.5 B for medium dense sand and loose sand. Maximum settlement obtained at the closer spacing for sand, i.e., spacing ratio 0.5.

3.2.3. Tilt of the footings

In cohesive soils, the tilt of existing/old footing adjacent to newly constructed footing is negligible. In cohesionless soils, the maximum tilt value is observed at spacing ratio 0.5, where footings are very close to each other (Figure 17).

3.2.4. Variation of settlement on a horizontal plane

Variation of settlement is determined on a horizontal plane. Interference effect in terms of the settlement is maximum at the surface. Figure 18 shows the variation of settlement on a horizontal plane at the ground level for footing width 1m on stiff clay. The maximum settlement is recorded at the spacing ratio 2.5 for clay soils. Figure 19 shows the variation of settlement in a horizontal direction at the ground level for footing width 1m on dense sand. From this Figure 19, the settlement shows a slightly higher value at a spacing ratio of 1.5. Other footing widths (2m and 3m) also show the similar trend as that of 1m. Moreover the settlement in case 2 are not symmetric about the midpoint between the two footings unlike case 1 where the settlement were somewhat symmetric.
Figure 16. Variations of efficiency factor ($\xi$) with the spacing ratio for footing widths (a) $B=1\,\text{m}$ (b) $B=2\,\text{m}$ (c) $B=3\,\text{m}$
Figure 17. Variations of tilt of old footing in the presence of newly constructed footing with S/B on soils with footing width (a) B=1m (b) B=2m (c) B=3m

Figure 18. Variations of settlement on a horizontal plane at the ground level for B=1m on stiff clay
3.3. Effect of shear key on interference

Shear keys are protrusions provided beneath the footings (Figure 20), generally provided to give additional sliding resistance (especially to lateral loads). In the present study, shear keys are contributed to be provided beneath footings to see if they made any difference to the interference effects between the adjacent strip footings subjected to vertical loads. The interference effects studied include those due to bearing pressure, due to settlement and on tilts. Shear keys are considered to be provided with at the inner edge of footings and also at the centre of the footings. A parametric study is carried out by varying the L/B ratio of the shear key, where L is the depth of shear key and B is the width of the footing.

The effect of the shear key on the interference of footing is not significant regarding bearing pressure. Figure 21 shows the variation of the settlement of footing when the shear key is added to the footings for footings on stiff clay having B=1m, 2m, and 3m respectively for a spacing ratio of 1.5. From the study, it is found that the settlement becomes less when the shear key placed at the centre of the interfering footings at an L/B ratio of 0.25 irrespective of the footing width. For B=1m the settlement becomes 15% of the settlement of footings without a shear key at the ground surface. In the case of B=2m and B=3m settlement becomes almost 25% of footings without a shear key. The tilt of footing decreases drastically when shear key included in the footing. The reduction in the tilt of footing is more than 90% of the tilt of footing without a shear key (Table 5).

Figure 19. Variations of settlement in a horizontal direction at the ground level for B=1m on dense sand

Figure 20. Footings with the shear key at the centre
Figure 21. Variation of the settlement of footing with (placed at edge and centre of footing) and without shear key on stiff clay for a spacing ratio of 1.5 with footing width (a) B=1 m (b) B=2m (c) B=3m
Table 5 Variation of tilt with and without the shear key on footings for footings resting on stiff clay

<table>
<thead>
<tr>
<th>Footing width</th>
<th>Tilt (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Footings without shear key</td>
</tr>
<tr>
<td>1</td>
<td>5.304</td>
</tr>
<tr>
<td>2</td>
<td>2.515</td>
</tr>
<tr>
<td>3</td>
<td>2.585</td>
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</tbody>
</table>

4. CONCLUSIONS
Finite element analysis is carried out on two adjacent strip footings on clays and sands, by varying parameters, to study the interference effects. Interference effects are studied in terms of bearing pressure, in terms of the settlement and finally tilt of footings. Two loading cases are considered such as (i) both footings loaded simultaneously (ii) first footing (an existing/old footing) is loaded with half estimated failure load and then the second (new) footing is loaded up to failure. In the case of footings on stiff clay, the effect of providing shear keys beneath footings is also studied. The analysis yield the following results:

- The effect of interference, regarding the efficiency factor for bearing pressure, in the case of clays is negligible.
- The frictional soil between the footings is subjected to confinement due to the loading on the footings and makes the soil in between stiffer and stronger. This is reflected in case of sands with efficiency factor for bearing ($\xi$) greater than one in almost all cases studied.
- Stresses in the area between the two footings will be large due to the overlapping effect. Stresses on the inner edge of footing will be larger than outer edge resulting in an inward tilt of the footings. Efficiency factor of settlement attains a clear peak value when the spacing ratio is 1.5 for clays, whereas in the case of sands the peak value of efficiency factor is when the spacing ratio is about 0.5.
- Maximum tilt in clays occurs when the spacing ratio is 1.5. In clays the tilt of old footing (loading case ii) is negligible. Maximum tilt in sands occurs at a spacing ratio of about 0.5.
- The effect of the shear key on footings resting on stiff clay seems to be maximised when the shear key is placed at the centre of the footing having an L/B ratio of 0.25.
- The settlement decreases drastically, compared to the interfered footings without a shear key for the same conditions. Moreover, the reduction in the settlement is in the range of 75%.
- The tilt of footing on stiff clay reduces by the addition of shear key on footings. The reduction is in a range of 90%.

REFERENCES


