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# LOAD SETTLEMENT CHARACTERISTICS OF STRIP FOOTING PLACED ON THE PILED SANDY SLOPE IN PLAXIS 3D

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**Abstract -** *This paper consists of analysis of numerical modelling of strip footing over sandy slope supported with number of piles to improve its bearing capacity. For this investigation, the FEM-based PLAXIS-3D version 2013 programme was adopted. The footing width was assumed to be 0.8m. The sand slope was taken 3:2 (H:V). Piles were the only reinforcements used in the sandy slope. BCI was reviewed for both piled and non-piled case to evaluate which was the most efficient case. The variables were pile diameter, pile spacing, pile length, pile row positioning and footing position with respect to the slope crest. The findings show that stabilizing the soil slope with piles has major influence on the BC of strip base footing. The enhancement in BCI develops when pile spacing is reduced and simultaneously further improvement rises as pile diameter along with pile length increases. As a result, reducing pile spacing improves BCI by approximately 67% and reducing crest distance of pile improves BCI by approximately 47%. The effective increment in BCI in piled cases can be seen up to 2B, but in non-piled cases it is up to 3B. $R^2$ = 0.75 and $R^2$ = 0.79 is obtained from regression analysis for piled and non-piled case respectively via excel. Regression analysis-based settlement equations is likely to be beneficial for researchers for rapid calculation as a part of the design considerations for similar conditions.*

***Key Words***: FEM, PLAXIS, piled, non-piled, sandy slope, BCI, regression analysis.

***Abbreviations:*** *FEA = Finite Element Analysis, FEM = Finite Element Method, BC = Bearing Capacity, BCI = Bearing Capacity Improvement, BCR = Bearing Capacity Ratio, CoV = Coefficient of Variation.*

## 1. INTRODUCTION

Footings are built on sloping surfaces or near to a slope crest in a variety of scenarios. When a footing is placed on sloping terrain, the BC of a footing may be drastically reduced, depending on where the footing is placed in relation to the slope. As a result, using a foundation system may be impossible, and adopting uneconomic foundation types such as piles or caissons, becomes the only viable choice. As a result, throughout the time, the issue of soil slope stabilisation has become one of the most attractive fields of scientific research and attracting a great deal of attention.

Slope stability can be improved by changing the slope surface geometry, utilising soil reinforcement, or adding continuous or discontinuous retaining barriers like as walls or piles or sheet piles. The stability of such foundations over slope is a hard subject in geotechnical engineering since both overall stability and BC must be considered.

In the present research, the study on piled and non-piled slopes was conducted, and PLAXIS-3D was adopted to explore the BC enhancement of footings lying on piled and non-piled slopes.

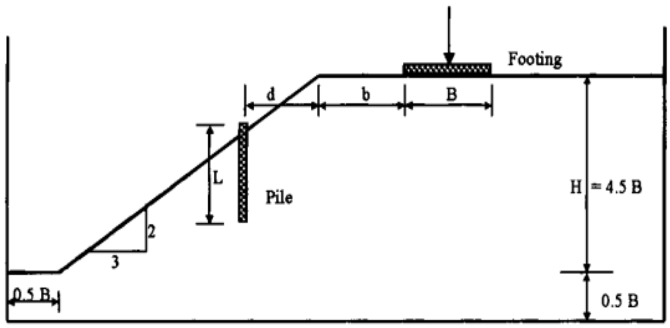



**Figure-1**: Sketch of the model

Where;

B = width of footing,

b = distance of footing from the crest of slope,

D = diameter of pile,

d = distance of piles from the crest of slope,

L = length of piles, x = spacing between piles,

N = number of piles.

## 2. OBJECTIVES

Following were the objectives of current research:

1. To analyse the effect of the varying crest distance of the footing on the load bearing capacity of slope in PLAXIS 3D.
2. To study the effect on load carrying capacity of strip footing due to different spacing and size of piles in PLAXIS 3D.
3. To study the effect of varying crest distance of pile and evaluating the optimal location of row of piles in slope in PLAXIS 3D.
4. To develop regression models to determine the settlement of strip footing in PLAXIS 3D for piled and non-piled slope.

## 3. METHODOLOGY

In the present research, the study on piled and non-piled slopes was conducted, and PLAXIS-3D was adopted to explore the BC enhancement of strip footing. Total 156 models were constructed and evaluated to fulfil the objectives. First three objectives were fulfilled by analysing 60 models and 96 models were required for the fulfilment of last objective. For extreme accuracy, the mesh is generated via fine meshing. The details of model parameters are tabulated below –

**Table-1**: Parameters for model evaluation

| Series | Constant Parameters | Variable Parameters | No. of models |
|---|---|---|---|
| 1. | D/B=0.075, d/B=0.0, L/B=1.00 | x/B=0.5,1.00, 1.25,2.5 | 4 |
| 2. | D/B=0.075, d/B=0.0, L/B=1.25 | x/B=0.5,1.00, 1.25,2.5 | 4 |
| 3. | D/B=0.075, d/B=0.0, L/B=2.00 | x/B=0.5,1.00, 1.25,2.5 | 4 |
| 4. | D/B=0.075, d/B=0.0, L/B=3.00 | x/B=0.5,1.00, 1.25,2.5 | 4 |
| 5. | D/B=0.10, d/B=0.0, L/B=1.00 | x/B=0.5,1.00, 1.25,2.5 | 4 |
| 6. | D/B=0.10, d/B=0.0, L/B=1.25 | x/B=0.5,1.00, 1.25,2.5 | 4 |
| 7. | D/B=0.10, d/B=0.0, L/B=2.00 | x/B=0.5,1.00, 1.25,2.5 | 4 |
| 8. | D/B=0.10, d/B=0.0, L/B=3.00 | x/B=0.5,1.00, 1.25,2.5 | 4 |
| 9. | D/B=0.15, d/B=0.0, L/B=1.00 | x/B=0.5,1.00, 1.25,2.5 | 4 |
| 10. | D/B=0.15, d/B=0.0, L/B=1.25 | x/B=0.5,1.00, 1.25,2.5 | 4 |
| 11. | D/B=0.15, d/B=0.0, L/B=2.00 | x/B=0.5,1.00, 1.25,2.5 | 4 |
| 12. | D/B=0.15, d/B=0.0, L/B=3.00 | x/B=0.5,1.00, 1.25,2.5 | 4 |
| 13. | D/B=0.075, x/B=0.5, L/B=2.00 | d/B=1.0,1.5,2.0,2.5 | 4 |
| 14. | D/B=0.10, x/B=0.5, L/B=2.00 | d/B=1.0,1.5,2.0,2.5 | 4 |
| 15. | D/B=0.15, x/B=0.5, L/B=2.00 | d/B=1.0,1.5,2.0,2.5 | 4 |

Total number of proposed models were 60.

Where B = width of footing, b = distance of footing from the crest of slope, D = diameter of pile, d = distance of piles from the crest of slope, L = length of piles, x = spacing between piles, N = number of piles.

**Table-2**: Material criteria used in PLAXIS 3D for the current work

| Parameter | Sand | Footing | Piles |
|---|---|---|---|
| Material Model | Mohr-Coulomb | Linear Elastic | Embedded Piles |
| Drainage Type | Drained | Non-porous | - |
| Dry Unit Weight (γ) | 18.94 $kN/m^3$ | 25 $kN/m^3$ | 25 $kN/m^3$ |
| Young's Modulus (E) | 20000 $kN/m^2$ | $3 * 10^7$ $kN/m^2$ | $3 * 10^7$ $kN/m^2$ |
| Poisson's Ratio (ν) | 0.3 | 0.1 | - |
| Cohesion (C) | 0 $kN/m^2$ | - | - |
| Internal friction angle (ϕ) | 42° | - | - |

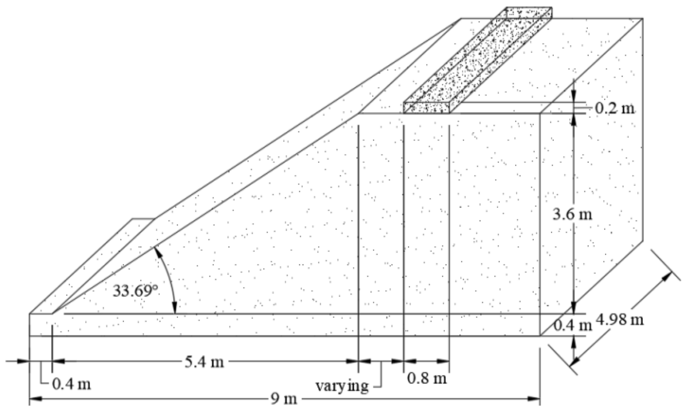



**Figure-2**: Dimensions of model constructed in PLAXIS-3D

The varying parameters were-

- **Distance of footing from crest of slope (b):** 0B (0m), 0.5B (0.4m), 1B (0.8m), 2B (1.6m), 3B (2.4m), 4B (3.2m).
- **Distance of pile from crest of slope (d):** 2.5B (2m), 2B (1.6m), 1.5B (1.2m), 1B (0.8m), 0B (0m).
- **Diameter of piles (D):** 0.075B (0.06m), 0.10B (0.08m), 0.15B (0.12m).
- **Length of piles (L):** 1B (0.8m), 1.25B (1m), 2B (1.6m), 3B (2.4m).
- **Spacing between piles (x):** 2.5B (2m), 1.25B (1m), 1B (0.8m), 0.5B (0.4m).

Strip footing dimensions were assumed to be constants such as Width of footing (B) = 0.8m and thickness of strip footing = 0.2m. Piles inserted in slope were taken as circular piles. The 96 models were tested to carry out the regression analysis to obtain the load settlement equations, out of which 48 models were for non-piled case and 48 were of piled slope case. This analysis was carried out for the corresponding load at 50mm allowable settlement and factor of safety of 0.5 and 1.5, which results in the load values of 1300kN, 650kN and 1950kN respectively.

**Table-3:** Mean value, Co-efficient of Variation, Standard deviation of soil parameters

| Soil Parameters | Mean (μ) | CoV (%) | Standard Deviation (σ) |
|---|---|---|---|
| C | 0 | 0 | 0 |
| γ | 18.94 | 7 | 1.3258 |
| ϕ | $42^0$ | 5 | 2.1 |
| E | 20000 | 10 | 2000 |
| ν | 0.3 | 13 | 0.039 |

Where,

C = Cohesion of sand (kN/m$^2$),

E = Young's Modulus of sand (kN/m$^2$),

ϕ = Angle of friction of sand ($^0$),

γ = Unit weight of unsaturated sand (kN/m$^3$),

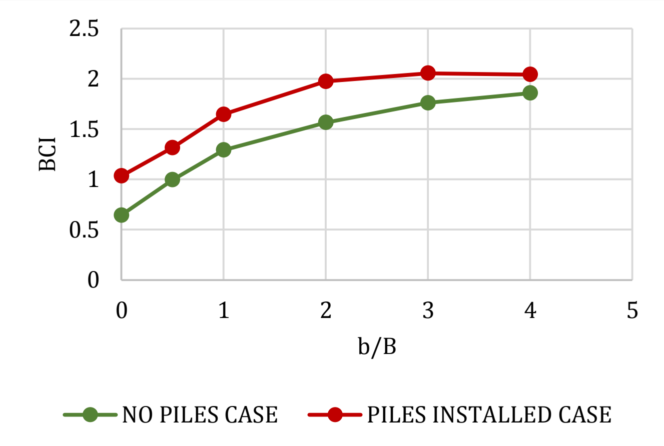
ν = Poisson's ratio of sand.

## 4.RESULTS

Representing all the results of model tests which were conducted for the fulfilment of objectives. The influence on pile load bearing capacity and pile count on both piled and non-piled slope scenarios was discussed.

### 4.1 Effect of varying crest distance of footing:

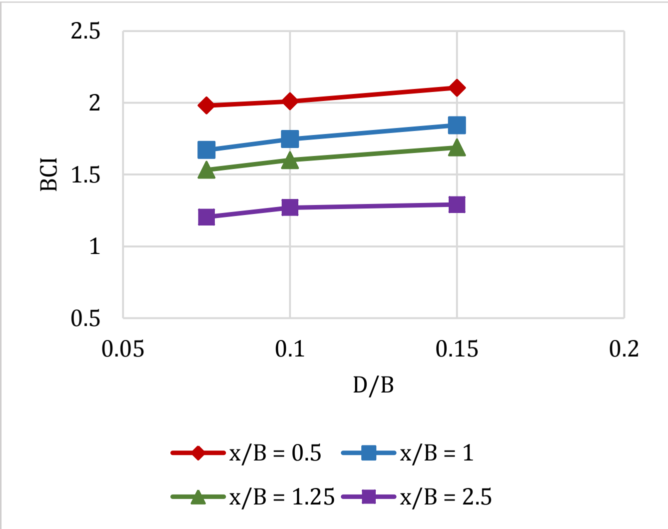
Two sets of modelling were done in both piled and non-piled situation to investigate the influence of the edge distance (b) on sand slope. Curves clearly indicates the footing moves away from the edge of the slope, the load bearing capacity improves considerably in both piled and non-piled cases. The influence of piling on BC tends to grow. The footing's maximum load carrying capacity increases as the edge distance (b/B) gets larger on both piled and non-piled slopes, but the slope's origin appears to have little effect on the footing's load carrying capacity when the crest distances rises more than 3B.




**Graph-1:** Variation of BCI with and without piles for varying crest distance of footing (b)

### 4.2 Effect of varying of pile diameter:

A series of experiments were carried out to analyse the effects of pile diameter using a row of piles placed at the slope peak with same pile length (L/B=3) and pile dimensions (D) of 0.06, 0.08, and 0.12 m.

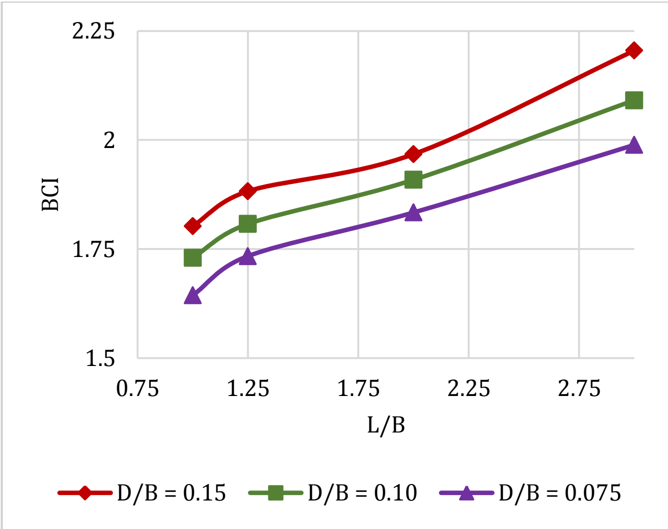



**Graph-2:** Variation of BCI with pile diameter (D/B) for different pile spacing (b/B=0, L/B=3.0)

The graph clearly shows that even as pile diameter grows, so does footing performance. An improvement of up to 210% is obtained for a pile diameter (D/B=0.15) as compared to that without piles. This demonstrates that as the pile diameter grows, so does its rigidity and resistance to deformation of soil beneath the footing, and thus the BCR. Enhancing the pile diameter reduces the spacing between piles when there are an equal number of piles in a row. As a result, will enable less soil mass movement between piles, resulting in better pile row performance.

### 4.3 Effect of varying pile length:

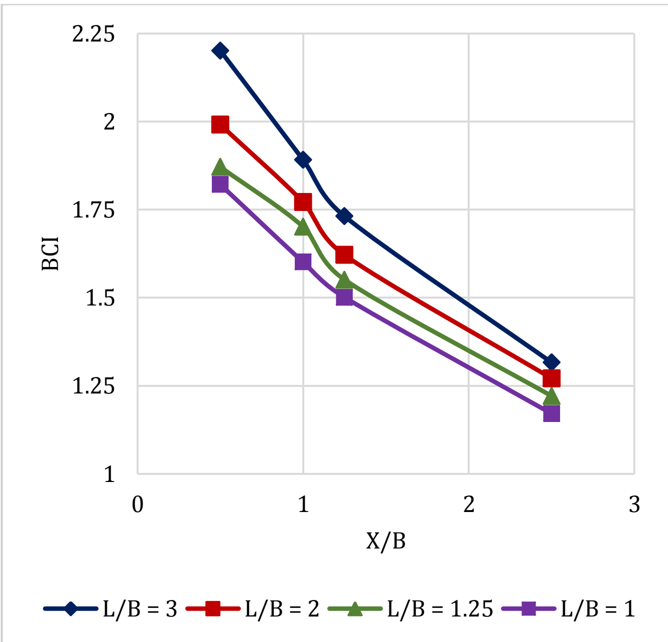
The graph shows how the BCI factor varies with length (L/B) for a footing close the slope crest (b/B=0) and for a row of piles positioned at the slope crest. The three curves show a similar trend of footing response for the numerous pile diameters. The greater the overall increase in performance in bearing capacity, the longer the pile. BC is improved by 22% when a row of piles placed to x/B=0.5 and D/B=0.15 and a regular pile length of L/B=3. The rise in bearing capacity is obtained with increase in pile length. Increasing the pile length increases the pile's embedded portion in the stable soil beneath, resulting in improved pile stability below the footing.




**Graph-3:** Variation of BCI with pile length (L/B) for different pile diameters (d/B=0 and x/B=0.5)

### 4.4 Effect of varying pile spacing:

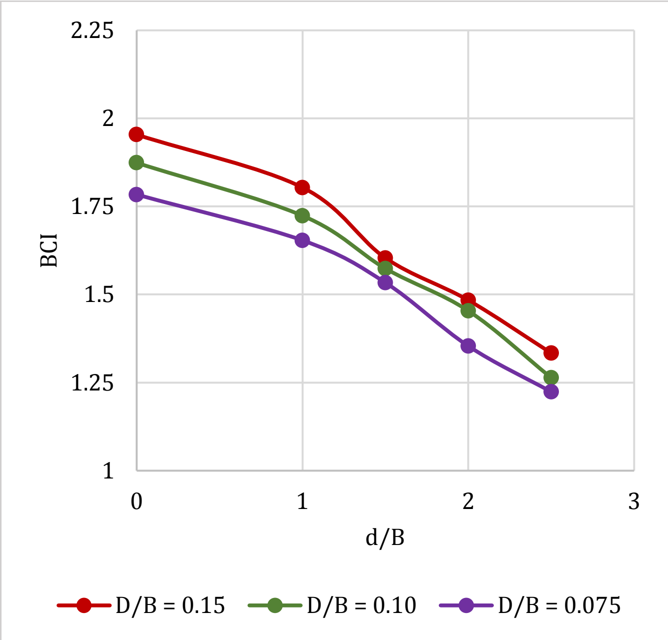
The graph depicts the fluctuations in BCI with pile spacing (x/B) for various lengths. With a decrease in pile spacing (x/B), the BC of the model footing increases significantly. x/B=0.5 and pile length L/B=3 might result in 2.20 times increase in bearing capacity over that without slope stabilisation. However, the improvement in bearing capacity is only 1.32 times for with pile spacing x/B=2.5. As a result, reducing pile spacing from x/B=2.5 to x/B=0.5 improves BCI by approximately 67%.




**Graph-4:** Variation of BCI with pile spacing (x/B) for different pile lengths (d/B=0 and D/B=0.15)

### 4.5 Effect of varying crest distance of row of piles and evaluating its optimal location in slope:

For various pile diameters, the chart depicts the variation in BCI with pile row place (d/B). It is clear that the BC increases as the pile row gets closer to the slope crest. Modelling with different pile diameters reveals a similar pattern. As a result, the most suitable pile location in aspects of footing maximum load is near the slope crest.




**Graph-5:** Variation of BCI with pile row location (d/B) for different pile diameters (x/B=0.5 and L/B=2.0)

Researchers are unsure of the best position for pile rows to provide the best slope stability and safety factor. A most effective pile location for improved footing BC is at the slope crest. Other pile locations have enhanced the slope's overall stability but these piles did not intersect with the failure plane, these cannot prevent lateral soil deformations beneath the footing and near the slope. As a result of decreasing the pile's crest distance from d/B=2.5 to d/B=0, the BCI increases from 1.33 to 1.95, indicating a 47% improvement.

### 4.6 Regression analysis of strip footing placed on the sandy slope without and with piles intallation:

The regression analysis was performed via excel after obtaining the settlement values of 96 models for both piled and non-piled cases. Following equations produced –

**CASE 1: Regression analysis-based equation for non-piled slope-**

$\delta = 20.268 + 0.985\gamma + 1.225\phi - 0.00182*E - 60.315\nu$……….(i)

**CASE 2: Regression analysis-based equation for piled slope-**

$\delta = -9.209 + 1.179\gamma + 1.368\phi - 0.00137E - 54.479\nu$……….(ii)

Where,

$\delta$ = Settlement of footing in slope (mm),

E = Young's Modulus of sand (kN/m$^2$),

$\phi$ = Angle of friction of sand ($^0$),

$\gamma$ = Unit weight of unsaturated sand (kN/m$^3$),

$\nu$ = Poisson's ratio of sand.

For non-piled situation, R=0.89 while $R^2$=0.79 was found to be dependent variable as coefficient of determination in the regression analysis. Similarly, for piled situation, R=0.87 and $R^2$=0.75 was found to be dependent variable known as coefficient of determination in the regression analysis. Based on these coefficients, the model may be assumed to predict the dependent variable quite good. Both the regression analysis settlement equations are valid for non-piled and piled slope beneath strip footing of similar shapes and dimensions evaluated in this study and is likely to be beneficial for researchers for rapid and appropriate estimation as a part of the design considerations respectively.

## 5. CONCLUSIONS

Suitable dimensions and location improve the BC of a strip footing supported on granular soil significantly. The final conclusion may be formed based on the findings of current study are:

1. BCI increases rapidly with the increase in distance of footing from crest of slope in both cases. Effective increase in BCI in piled case can be seen up to 2B whereas in non-piled case up to 3B and from this onwards rise in BCI is less significant.

2. The BCI improves the most when pile spacing is kept to a least and pile length is managed to keep to a maximum. Enhancing the pile diameter improves the BC performance of the footing even more. However, pile spacing has a much larger impact on BCI than pile length or diameter. As can be seen, decreasing pile spacing from x/B=2.5 to x/B=0.5 increases BC by approximately 67%.

3. Reducing crest distance of pile up to zero, improves BCI by approximately 47%. Thus, the best position of a row of piles is at the slope crest, considering BCI rather than the overall stability of the slope.

4. For non-piled situation, $R^2$=0.79 and for piled situation, $R^2$=0.75 was found to be dependent variable known as coefficient of determination in the regression analysis. Obtained regression analysis settlement equations are valid for non-piled and piled slope beneath strip footing of similar cases is beneficial for rapid and appropriate calculation.

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