Effect of size and depth on capacities of strip footings in limiting settlement approach

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ABSTRACT. Structural and geotechnical engineers very often seek different options while deciding foundation sizes for buildings. In this research, the effect of different sizes and depths of strip footings below existing ground are studied based on the load bearing capacity using Geo5 spread footing software. Only vertical loadings were taken into account for this study. Four different strip footing widths (1.0m, 1.5m, 2.0m and 2.5m) were modeled under three different loads, 260kN, 600kN and 1000kN. The ground profile considered in this work was having a 2.0m thick weak layer at 6.0m below the existing ground level. Results showed that as the depth of footing increases, the depth of influence underneath the footing and settlement decreases. Also, it was noticed that as the footing width increases, the influence zone’s depth below the footing that passing the weak layer increases.

Keywords: Zone of influence, settlement, bearing capacity, Standard Penetration Test, GEO5

1. INTRODUCTION

Soil parameters are usually seen with considerable variation over space. In general, variations in horizontal direction are neglected because it is not practical to investigate ground strata with large number of boreholes especially when the differences are not very significant. At large, foundation settlements were proven to be detrimental for structures majorly made with concrete being rigid material. Hence, it is required to check both immediate and long-term settlements as part of the foundation design. Soil stress-strain relation is mostly non-linear even at small strains and therefore design procedures based on linear elasticity cannot be recommended in order to predict soil deformations. In order to predict soil deformations, design procedures based on linearelasticity cannot be used [1]. Settlement can be obtained more close to reality but load tests are undoubtedly expensive from affordability point of view.

In a study, it was proven that when safety factor is more than 2.5, consideration of bearing capacity is more important than the settlement [2]. Many empirical equations were suggested by several researchers that correlates N-value from standard penetration test with elastic modulus of soil. Also, ample number of scientists proven that resistance of cone in cone penetration test (CPT) is highly beneficial in indirectly determining the stiffness of soil [3]. In another analytical study conducted using Geo5 software, it was shown that results obtained from software and manual calculations were very close in which the soil profile dominated by clay [4]. In another study, elastic moduli obtained from correlations were used for understanding the soil deformations and was noticed that vertical stress and settlement are not dependent on each other [5]. Usage of empirical relationship for estimating key parameters may yield realistic result in some case, but not in all practical situations and field conditions [6]. A widespread study [7] for few decades aimed at calculating approximately the elastic settlement of shallow foundations resting over coarse grained soils shown that while comparing the settlement prediction methods, reliability and
accuracy are the prime criteria. Although several researches were carried out earlier to estimate settlement and bearing capacity, practical challenges are inevitable mainly because of naturally variable ground conditions from one place to another.

The current study comprises of a soil profile from a project in Abu Dhabi with intermittent 2.0m thick weak clayey sand encountered at 6.0m below the existing ground that could pose potential challenges in footing design. The aim of this research was primarily to understand the effect of weak layer presence on settlement of foundation. However, the extent of this current research was limited to strip (continuous) footings of various sizes founded at different depths with 12mm limiting settlement. Details pertaining to soil profile, various variables used in study as well as results obtained were discussed in the forthcoming sections.

2. STRATIGRAPHY OF SITE

The soil strata was obtained from one of the sites in Abu Dhabi. A total of fourteen (14) boreholes down to 20m were drilled on site. Standard Penetration Tests (SPT) were carried out from ground level in 0.5m interval till 3.0m depth and at every 1.0m depth thereafter till rock head was confirmed. After the confirmation of rock head through SPT refusal, cording was done till the end of borehole. Soil and rock parameters were obtained by conducting field and laboratory tests [8]. Any required parameters not obtained directly from tests were calculated using standard empirical correlations [9]. The site stratigraphy is shown in Table 1.

| Type of Soil | Depth (m) | SPT N-value | Relative Density (%) | Dry Density (kN/m³) | Elastic Modulus (MPa) | Cohesion (kN/m²) | Friction Angle (Degree) |
|--------------|-----------|-------------|----------------------|---------------------|----------------------|------------------|-----------------------|
| Silty Sand   | 0.0-6.0   | 23          | 56.70                | 17.63               | 9                    | 0                | 34                    |
| Clayey Sand  | 6.0-8.0   | 4           | 17.43                | 14.38               | 6                    | 5                | 30                    |
| Silty Sand   | 8.0-15.0  | 27          | 63.03                | 18.22               | 10                   | 0                | 35                    |
| Clay         | 15.0-17.5 | 43          | 81.66                | 20.27               | 20                   | 50               | 27                    |
| Mudstone     | 17.5-20.0 | -           | NA                   | 16.10               | 371                  | 56               | 38                    |

3. ANALYTICAL METHODOLOGY

Geo5 software was used for this current research while analyzing strip footings with limiting settlement of 12mm as per U.A.E standards. Four different widths (1.0m, 1.5m, 2.0m and 2.5m) of footings were analyzed at different foundation depths (1.0m, 1.5m, 2.0m, 2.5m, 3.0m and 3.5m) below existing ground level. These footings were tested under three different loads 260kN, 600kN, and 1000kN per meter run of the footing.

Bearing capacities were analyzed using Brinch-Hansen’s method with a factor of safety 1.5. Foundation settlements were calculated with oedometric modulus using equation (1).

\[
E_{oed} = \frac{E_{def}}{\beta}
\]

Where

\[
\beta = 1 - 2v^2
\]
$1 - \nu$

$\nu$ = Poisson’s ratio

$E_{def}$ = Modulus of deformation estimated using SPT N-Value

The depth of influence zone was limited to $1/10^\text{th}$ of the stress due to load applied on the footing. Samples of foundation analysis, bearing capacity (footing of 1.0 m wide at 1.0 m depth below ground level) and settlement with depth of influence zone can be seen in Figs. 1, 2 and 3 respectively.

**Figure 1.** Sample (footing width = 1.0m, footing depth = 1.0m) result of bearing capacity analysis

**Figure 2.** Sample result of bearing capacity analysis (1.0m wide strip footing at 1.0m depth)
4. DISCUSSIONS ON ANALYTICAL RESULTS

After performing the analytical calculations, results obtained were systematically shown in different graphs and can be understood from sections below.

4.1 Effect of depth of footing on settlement of foundation

It is evident that (see Fig. 4) for an applied load of 1000kN, with increase in depth of footing, the settlement decreases for all tested footing sizes. This is possibly due to higher magnitude of stress being transmitted to the stronger layers as footing depth increases. Identical patterns were observed for 600kN and 260kN as seen in Fig.5. However, it shall be emphasized from Fig. 5 that for all the footing widths, maximum settlement was found to be 12mm when applied load was 260kN.

![Figure 3. Sample (footing width =1.0m, footing depth = 1.0m) result of settlement analysis](image1)

![Figure 4. Settlement of foundation versus footing depth (1000 kN load on strip footing)](image2)
4.2 Effect of depth of footing on extent of influence zone

From Fig. 6, it is clear that with increase in footing depth, the depth of influence zone decreases. The influence zone is usually in trapezoid shape that extends sideward as well as downward away from outer edges of foundation to a distance equal to double the foundation width. Thus, it is obvious that with increase in footing depth, the deepness of zone of influence reduces. Identical form of results were noticed for 600kN and 260kN load cases (Fig.7). In addition, it is also clear from Fig.7 that with reduction in applied load on footing, a reduction on deepness of zone of influence was seen.
4.3 Effect of depth of footing on highest vertical load under limiting settlement

From Fig. 8 it is evident for all sizes of footings that with increase in depth of footing and at limiting settlement (12 mm) criteria, the highest vertical load increases. However, the rate at which it increases with footing depth is not uniform but reduces with increase in footing depth. This is primarily ascribed to the zone of influence zone being approaching close to the weaker layer (existing from 6.0 m to 8.0 m below ground level) that leads to increase in settlement.
Furthermore, an effort has been made to know the extent of zone of influence below ground level for all sizes of footings at which stress caused due to the load applied at 12 mm limiting settlement crosses the very weak clayey sand layer (i.e. depth of influence zone + depth of footing ≥ 6m). As shown in Table-2, it is clear that as depth of footing increases, the depth of stress influence zone at which it passes the weak clayey sand layer decreases. Also, it shall be noted that with increase in footing width, influence zone’s depth for limiting settlement criteria increases. This could be attributed to lesser stress level developed for a given loaded with increase in area of footing.

| Footing Depth (m) | 1.0m wide | 1.5m wide | 2 m wide | 2.5m wide |
|-------------------|-----------|-----------|----------|-----------|
| 1.0               | 4.56      | 4.73      | 4.88     | 5.06*     |
| 1.5               | 4.40      | 4.59*     | 4.76*    | 4.90*     |
| 2.0               | 4.26*     | 4.40*     | 4.59*    | 4.74*     |
| 2.5               | 4.07*     | 4.24*     | 4.38*    | 4.54*     |
| 3.0               | 3.87*     | 4.04*     | 4.21*    | 4.35*     |
| 3.5               | 3.71*     | 3.84*     | 4.00*    | 4.17*     |

* Influence zone depth of each size of footing passing the strata of weak clayey sand

5. CONCLUSIONS

Following are the key conclusions obtained as part of analytical calculations made in this research work:

1. As the footing depth increases from the existing ground level, foundation settlement reduces gradually.
2. As footing depth increases, the depth of influence zone was observed to be reduced.
3. For any given depth, the depth of zone of influence under the footing reduces with reduction in load on the footing.
4. Within the criteria of limiting settlement, the highest load that could be applied was found to be increasing with increase in depth of footing.
5. For all the analyzed footing sizes and depths, the footing depth at which zone of influence passing very weak layer reduces with increase in footing size, but was to be increasing with increase in footing width.

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