Relationship between shallow foundation shape and contact area, and the settlement in granular soils

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Abstract

The aim of this investigation is to discover the effects of foundation shape and contact area on foundation settlement. There is little research at the current time which relates the increase in size or scale effects to the settlement, with current research in the subject area being much more focused on bearnig capacity, [1], [2]. This is carried out using Oasys [3], a geotechnical software that predicts the settlement of foundations when a pressure load is applied to a foundation. The results showed a clear relationship between area of foundation and maximum settlement. As expected, as area increases so does the settlement, however, it is seen that there are clear differences between the effects from different shapes of foundations in terms of settlement values. It was discovered that the data shows similar patterns between different shapes, however the values for each shape do vary .

Key words: foundation shape and size; settlement; Oasys;

1. Introduction

The aim of this paper is to determine the relationship between an increase in the size of a shallow foundation and the settlement of that foundation. In this case the increase in size means an increase in area of the shallow foundation. This will also be compared to a change in the shape of the shallow foundation. This paper will explore this effect across 5 different shapes: square, circular, and 3 rectangles. The three rectangles analysed have the following length to width ratios: 1:1.5, 1:2, 1:5. This research was carried out using the computer software Oasys Pdisp [3], a geotechnical package used to analyse settlement and consolidation, and the soil considered under the foundation was granular.

The objectives of this paper are to produce the maximum settlement values from several different foundation shapes on a granular material, and to compare between different foundation shape effects. This will be with regard to comparing between different sizes, how a square performs with regard to settlement as size increases, and also comparing between different shapes, how a square foundation compares to a circular foundation.

2. Problem Description

Original principles set out by Terzaghi [4] are still relevant today, however, comparisons between different foundation shapes have never been fully established or researched.

There have been some research that demonstrates how an increase in size of shallow foundations can have an effect on the bearing capacity of a soil and how scale / size factors. Work done by Bolton and lau [1] is a great example of the research into scaling effects on the bearing capacity of soils. This paper shows that as the size of a footing increases the bearing capacity functions, that is N_y, N_c, N_q, decrease linearly. The aim of this research is often to allow for the interpolation of laboratory results obtained to larger scale projects which would be seen in real world applications.

One of the papers that researched settlement in a similar vein to this investigation was presented by Nareeman [5] where similar foundation shapes to the ones produced in this paper were researched. The results produced by Nareeman [5] were aimed at comparing when only at testing/ laboratory sizes. The largest size analysed by Nareeman [5] was a 20cmx20cm square foundation. In [5] The diference in settlement as the size of the foundation increased seemed to be a linear relationship. Expanding from this work, results presented here will also allow the comparison between different shapes, and help understand whether this relationship will be present throughout the different shapes.

3. Numerical results

Firstly, it is required to establish some values, the soil profile has already been established, using a Young's modulus of 50000 kN/m^2 and a Poisson's ratio of 0.2, shape ratios remain the same for each data set throughout, as does the depth of the soil medium which is roughly 10m. A load of 100kN/m^2 is applied as a pressure on each of the foundations and remains constant throughout the research.

The modelling for the following data is carried out using Oasys [3]. Oasys is a finite element program that analyses the non-linear response of materials[6]. In this case it was ideal to use, as finite element methods can help to produce the most accurate representations for circular models, one of the models analysed in this paper.

Oasys uses the boussinesq method in order to determine the settlement of each foundation. The boussinesq method uses elasticity in order to calculate the vertical stress underneath a point load in a homogeneous soil. [7] presents a detailed outline of the Boussinesq method and its assumptions. One assumption is that the stress distribution underneath the foundation are similar to those previously researched. It is acceptable to hold this assumption to be true due to the fact that a vast amount of research has been aimed towards stress distributions.

Also from [7], the conclusions seen were that results produced were compared to experimental results produced in laboratory conditions and that they were more similar to the Westergaard theory before the ultimate bearing capacity of the soil was reached. After the ultimate bearing capacity was reached, it was seent that the Boussinesq method produces more accurate results. While the conclusions were that the Westergaard theory does produce more accurate results, the differences in these results were quite minor, and therefore, not relevant for the results presented here. This is not relevant because our approach is much more of a comparative analysis of the results, therefore the differences should effectively cancel out and comparisons should still be accurate.

Table 1 Maximum settlement of foundation shapes at different sizes

	Maximum Settlement (mm)				
Area (m^2)	Square	Circular	Rectangle (1:1.5)	Rectangle (1:2)	Rectangle (1:5)
0.01	0.02828	0.00393	0.00399	0.00399	0.00399
0.04	0.11134	0.01600	0.01596	0.01595	0.01594
0.25	0.62708	0.09931	0.09947	0.09925	0.09867
1	1.87631	0.38684	0.39172	0.39060	0.38184
4	4.04298	1.49409	1.48338	1.46792	1.35596
25	8.47602	6.94225	6.73923	6.47935	5.05419

Table 1 shows the maximum deflection for each of the foundation shapes and each of the foundation sizes. For all of the shapes and sizes the maximum deflection was found to be in the centre of the shape. This is what would be expected and predicted. We also see that each of the rectangles settlement was the same at the smallest area. The reason for this is likely to be due to inaccuracies in the measurement and calculation or simply the fact that at that size the values cannot truly be differentiated at this accuracy.

When considering the rectangular and square shapes we see that as the l/b ratio increases, the settlement decreases, the largest difference is the jump from square to rectangular, but not by much as the difference between 1:2 is comparable from square to 1:1.5. the lowest settlements produced consistently throughtout the experiment are produced by the rectangle with ratio 1:5. One reason for this could potentially be due to the fact that this shape is much closer to a strip footing, which means it could be unfair to compare these to the other foundations. What is expected is that the average settlement would be quite similar to the other shapes for each area but that the maximum overall settlement would be lower.

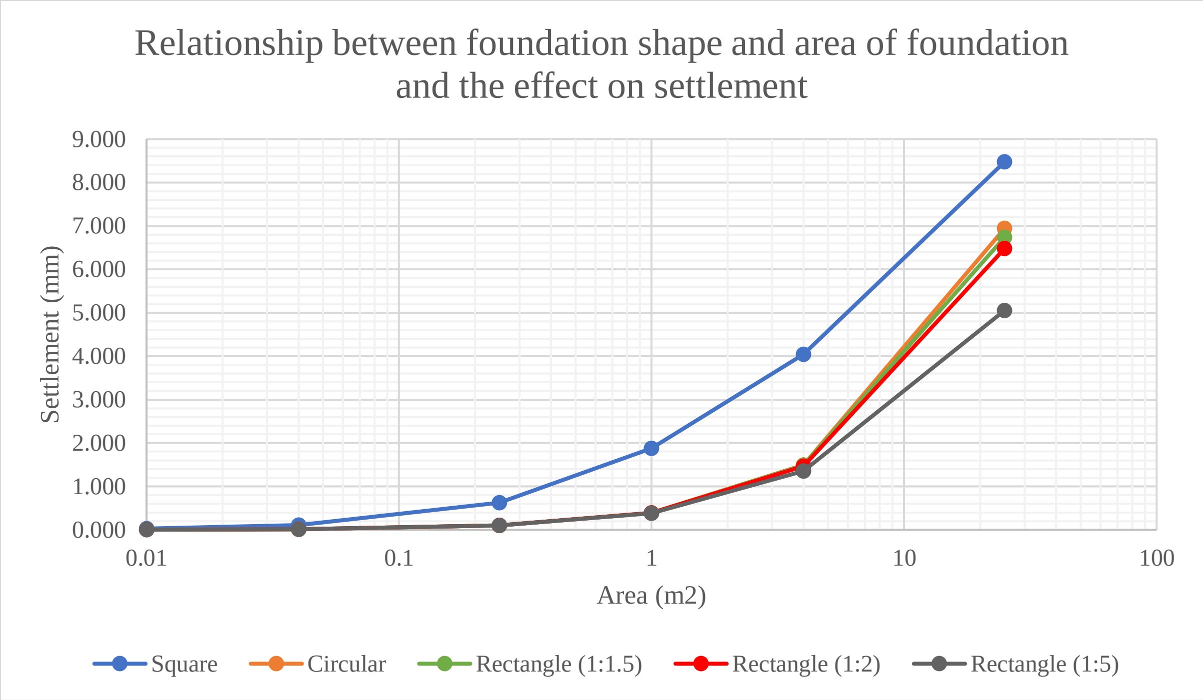

Figure 1 Graph of relationship between foundation shape and area of foundation and the effect on settlement

The graph in figure 1 shows very interesting patterns. It is important to understand that this graph is plotted on a logarithmic X axis. The reason for this is so that the smaller areas can also be represented and analysed, as on a linear scale, the values would be bunched up towards the origin. What this means for the data is that a line that looks like an exponential is in fact a linear relationship, which happens to be true for all of the different shapes.

Therefore, it can be stated that, for all of the shapes presented in this paper, there is a linear relationship between area and settlement of the foundation. And that as area increases so too does settlement.

If we compare the loading results on the graph we can see that the foundation shape that results in the highest settlement is square, at 25m^2 it produces more than 1.5mm larger settlement than the next highest, which is circular. Furthermore, we see that as length to width ratio increases for rectangles, settlement decreases. The Values for square begin to separate quite clearly even from the smallest area of 0.01m^2, as square is roughly 7x higher than the next highest values. This difference continues but does slowly close. It would be interesting to see if this relationship continues where square produces the clear largest settlement, or whether the relative difference continues to close until square eventually performs better.

So, despite the fact that square foundations are some of the most commonly used foundations they can produce the highes settlement of all the shapes presented here. One reason for that may be due to the stress buildup. It can be assumed that where there is the highest stress we would likely see the largest settlement. We can also assume that the largest stress buildups occur at the corners of shapes. Therefore, a square foundation could produce the highest stress buildups as the high stresses at the corner converge in the centre of the shape to produce the highest stress. Whilst this does help to explain why square produces the highest settlement, it also helps to explain why the largest magnitude of settlement is produced in the centre.

Considering circular foundations, this can be explained in a similar way, as despite the fact that we wouldn’t see the same stress buildups at corners, it should be evenly distributed around the edge of the shape, and because there is a constant radius the soil stresses would accumulate in the centre. This is also why we find that the maximum settlement is located in the centre of the foundation.

As l/b ratio increases, that is 1:1.5, 1:2, 1:5 in ascending order it is seen that the maximum settlement decreases across all different areas, at $25m^2$ this difference is quite substantial, with almost a 1.5mm difference and almost a 3mm difference between 1:5 and the square.

4. Conclusions

To conclude, the results presented in this paper are very interesting and show how the difference in shape of foundations can have quite substantial effects on the settlement of a foundation. We see that the "worst performing" shape is square, while the best performing is rectangular with l/b ratio of 1:5. The theory proposed in this paper is that the reason for this is due to the build-up of stresses at the corners and how these accumulate at the centre of a shape.

Regardless of which shape produces the highest settlement, we see that all of the shapes produce a linear relationship, and that as area increases so too does settlement. The relationship also seems to be incredibly similar between the different shapes, therefore while the values of settlement vary between different shapes, the relationship is incredibly similar.

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