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CRITICAL APPRAISAL ON FOOTING SUBJECTED TO MOMENT

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Abstract - *Foundations for overhead catenary systems carrying electrical power in railway networks, transmission towers, and for large road and railway hoardings and other elevated commercial signs have to be designed mainly to resist large moments and relatively small vertical and horizontal forces. A widely used type of foundation for these structures is the rigid pier. Such foundations rely heavily for their stability on the mobilization of passive soil resistance and are consequently often referred to as side-bearing foundations. In the past, the design of laterally loaded rigid pile and pier foundations has been based upon empirical information mainly from full-scale tests or conventional model studies in the laboratory. This paper highlights the work done in the area of moment capacity of foundations, laboratory experimentation and numerical modelling.*

***Key Words*: Moment, Pier, Laterally loaded rigid pile, Load eccentricity, Load inclination angle**

1. INTRODUCTION

Foundations for overhead catenary systems carrying electrical power in railway networks, transmission towers, and for large road and railway hoardings and other elevated commercial signs have to be designed mainly to resist large moments and relatively small vertical and horizontal forces. Forces acting on overhead catenary system support are shown in Fig.1. Moments on the foundation base are mainly caused by horizontal forces acting on the structure. Horizontal forces are the resultant of earth pressure, wind pressure, seismic force, and water hydrostatic pressure etc. Short bored pile or pier foundations are widely used in situations where moment-carrying capacity is the dominant design requirement. Such foundations rely heavily for their stability on the mobilization of passive soil resistance and are often referred to as side-bearing foundations. The techniques for the analyses of these foundations are not as advanced or as well understood as those for foundations subjected to vertical compressive loads, although the closely related problem of the laterally loaded pile has received considerable attention.

This paper highlights the work done in the area of moment capacity of foundations, laboratory experimentation and numerical modelling.

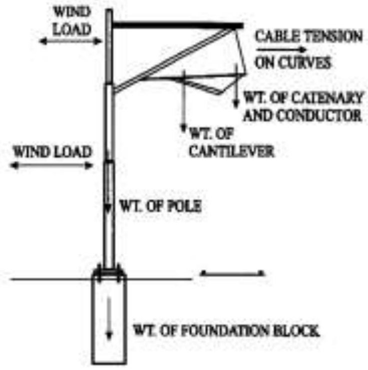

Fig -1 Forces acting on overhead catenary system support

Centrifuge and conventional model studies in short pile foundations in cohesionless soil were subjected to large overturning moments are reported [1]. Soil packing, pulling height, pile geometry, and ground surface profile are shown to influence moment carrying capacity significantly. Centrifuge tests were also carried out on embedded walls to establish empirical shape factors for potential use in conjunction with two-dimensional theoretical analyses. These shape factors were found to increase significantly with pile embedment ratio. Prototype moment limits derived from the centrifuge results compare reasonably well with predictions from the design methods of Broms, McCorkle, and UIC/ORE.

The moment response of rectangular piers in cohesionless soil was investigated numerically [2] and [5] using a three-dimensional, non-linear finite element program PIER3DNL, and by centrifuge modelling. In general numerical modelling behaviour matches observation well. Moment capacity increases almost linearly with pier length and depth and simple expressions are derived. Dimensionless moment factors increase with soil packing but decrease significantly with pier length for aspect ratios less than 1.33. Soil packing also affects moment-carrying capacity markedly. The resistance of a pier in loose sand is approximately one third of that in dense sand. Numerical analyses, incorporating parameters derived from triaxial and plane strain compression tests, yield results which closely match those from centrifuge model tests when the value of the coefficient of earth pressure at rest, K_0, is assumed to be 1.0 and 0.45 for piers in dense and loose sand, respectively.

The experimental investigation and numerical predictions into the moment carrying capacity of short rigid pier foundations in saturated clay is described [3] and [4]. The results show that the relationships between moment and rotation are nonlinear but do not exhibit any peak values, and that moment limits, defined by limiting angular rotations, increase with increases in pier depth and breadth. The results from linear three-dimensional program are shown to provide satisfactory agreement with the moment-rotation behaviour and working limits observed in the centrifuge model tests. It is shown that the axi-symmetric program yields significantly higher rotations per unit moment than the linear three-dimensional program and that, using both of these programs, elastic analyses of the conventional and centrifuge models and of the prototype yield very similar results.

Laboratory work and numerical analysis were performed [6] and [7] to study the behaviour of one sided skirted strip footing subjected to eccentric and inclined load. Various load inclination angles, load eccentricities and skirt lengths were investigated. Increasing the length of the skirt improve the load-settlement behaviour. The rate of improvement increases with the increase of both load eccentricity and load inclination angle and reached its maximum value at skirt length equal to half the footing width. Increasing the skirt inclination angle increases the ultimate bearing capacity and decreases the corresponding settlement. The skirt enhanced the footing behaviour supported by loose and medium sands. However, in the dense state the skirt had no effect in the elastic state of loading. For skirted footing, PLAXIS 7.1 was a good tool in understanding the soil behaviour under different loading conditions. Although it generally gave higher values than the experimental results, it was capable of predicting the load–settlement relationship with enough accuracy, except at high load eccentricities.

Piled raft foundation has been widely recognized as a rational and economical foundation system with the combined effects of raft and piles. However, the behavior of laterally loaded piled raft foundation has not been well understood due to the complicated interaction of raft–ground–piles. A series of static horizontal loading tests were carried out [8] on three types of foundation models, i.e., piled raft, pile group and raft alone models, on sand using a geotechnical centrifuge. In this paper, the influences of relatively large moment load and rotation on the overall performance of laterally loaded piled raft foundation as shown in Fig.2 were examined. From the centrifuge model tests, it is found that the vertical displacement due to horizontal loads is different between piled raft and pile group foundation, and this vertical displacement has significant influences on the performance of laterally loaded piled raft foundation. The horizontal resistance of the pile part in the piled raft foundation is higher than those observed in the pile group foundation due to raft base contact pressure. The vertical displacement of the foundation due to the horizontal loads affects the vertical resistances of piles, which results in the different mobilization of moment resistances between the piled raft and pile group foundations.

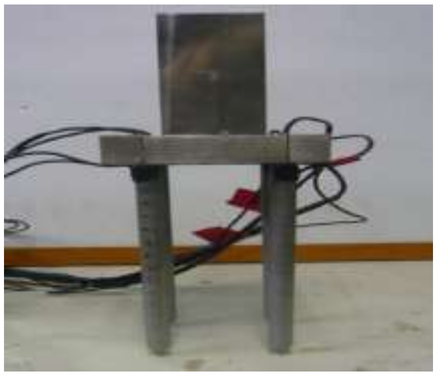

Fig -2 Pile raft model

The paper presents [9] the results of three-dimensional finite-element analyses of circular foundations on the surface of homogeneous, purely cohesive soil. The foundations were assumed to adhere fully to the soil, and compressive, tensile and shear stresses may develop at the interface between the footing and the soil. The predicted ultimate response of the foundations to combined vertical, moment and horizontal loading was compared with other available theoretical predictions. A three-dimensional failure locus is presented for these foundations, based on the numerical predictions. An equation that approximates the shape of the failure locus is also suggested, and this provides a convenient means of calculating the bearing capacity of circular foundations on uniform clay and subjected to combined loading.

Published literatures show that more research is done in deep foundation. For small scale works, these foundations are costly. Published literatures are scarce in shallow foundation. It is essential to study the deformation behaviour of shallow foundation subjected to moments.

2. EXPERIMENTAL STUDIES

The load tests are conducted in a combined test bed and loading frame assembly. The test beds are prepared in a tank of internal dimension 1000 mm length x 750 mm width x 750 mm depth. The model circular footing has a diameter of 100 mm, thickness 20 mm and is fabricated with mild steel. The clayey soil is filled in the test tank to the required level with compaction done in layers of 50 mm thickness. The water content of the clayey soil is maintained at 18%. The clay was compacted by ramming. The loading tests are carried out in a loading frame fabricated with ISMB 300. The vertical load is applied using a hand operated- mechanical jack of capacity 50 kN. The applied vertical load is measured using a proving ring of capacity 100 kN. Moment is applied by eccentric loading on the footing in addition to the vertical load. The eccentricity in all the tests is 245mm. Eccentric load is measured using an additional proving ring of capacity 50 kN. The tilt of the model footing is measured using two dial gauges of 0.01 mm sensitivity kept diametrically opposite to each other 350 mm apart. Locally available clay is used as foundation soil. The properties of clay are listed in Table 1.

Table -1: Properties of clayey soil

Sl No	Properties	Values
1	Specific gravity	2.68
2	Optimum Moisture Content (%)	18
3	Maximum Dry Density (kN/m^3)	15.61
4	Liquid Limit (%)	58
5	Plastic Limit (%)	22
6	Plasticity Index (%)	36
7	IS Classification	CH
8	Unconfined Compressive Strength, q_c (kN/m^2)	140.08

The diameter and depth of circular footing are 'B' and 'D' respectively. Diameter of the footing is 100 mm. Depth to diameter ratio (D/B) is taken as 0.5. Distance between two dial gauges is fixed as 350 mm. Vertical load (P1) is taken as 90 N. Eccentric load (P2) is increased at regular intervals. The eccentric distance of eccentric load P2 is fixed as e = 245 mm. The experimental setup is shown in the Figure 3.

Fig -3 Experimental Setup

3. RESULT AND DISCUSSION

Moment versus rotation curve for vertical load P1=90 N and D/B=0.5 is presented in Chart 1.

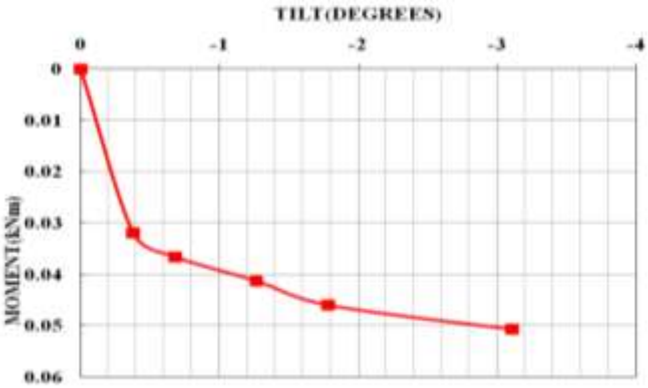

Chart -1: Moment versus rotation curve

When the eccentric load increases, the moment acting on the footing increases. As the moment increases, the tilting of the footing increases.

4. CONCLUSIONS

The following conclusions are deduced from this study:

- When the eccentric load increases, the moment acting on the footing increases.
- As the moment increases, the tilting of the footing increases.

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