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The use of flexible flaps in improving the settlement resistent behaviour of raft foundations

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Abstract: Today shallow foundation construction in soft soils faces many problems due to low bearing capacity of soft soil. Although deep foundations can be used as an alternative, considering the costs and the time involved, the approach is proven to be uneconomical. This has led many researchers to design innovative shallow foundation systems for construction on soft soils, with adequate bearing capacity, while minimizing the settlement. Two such foundations are the "Cakar Ayam foundation" and "Akar foundation", which are currently used in construction industry in countries like Malaysia.

Two vertical flexible flaps attached to the underneath of a raft were used as a modified foundation model in this project to see it the foundation is capable of reducing the settlement when built on soft soil. The physical models of the modified foundation were built by varying the flap length and tested under different loads. Further, the models were analysed using finite element package, PLAXIS. The results obtained from physical modelling and finite element analysis showed that the foundation can be used to reduce excessive settlement on soft soil. The settlement reduces with the increase of flap length. Finally, the results verified that the modified foundation can be used as a temporary foundation to build a working platform for construction vehicles to pass through the working site.

Keywords: Settlement, Flexible, Foundations, Raft, Flap

1. INTRODUCTION

Good quality soils are always preferred in civil engineering projects, where the bearing capacity of the grounds is sufficiently high and the resulting settlement is non-excessive. However, these sites may not be readily available with the increase in world population and land use, making it inevitable to construct on less favourable soils [3].The common solution adopted in such difficult cases is to construct deep foundations such as pile foundations. Although the piles serve the purpose well by transferring the load to a firm stratum deep down in the subsoil, the scale of machinery, materials, labour, costs and time involved are inevitably high. Thus, the approach may prove to be uneconomical and even unwise with over-designs to counter the poor soil quality.

Countries like Malaysia have extensive deposits of peat and organic soils which makes development on such areas a challenging task for civil engineers. This has led many researchers to design innovative shallow foundation systems on soft soils which have adequate bearing capacity while minimizing the settlement. Two such foundations are the "Cakar Ayam foundation" [1],[4] and "Akar foundation"[2]. Dr. Ir. Sedyatmo (1961) from Indonesia, proposed the use of the locally termed "Cakar Ayam" or "Chicken Feet" [4] foundation system that consisted of a reinforced concrete slab resting on a number of reinforced concrete pipes. The passive soil pressure creates a stiff condition of slab-pipe system, enabling the thin concrete slab to float on the supporting soils with the pipes kept in vertical positions. The foundation system, termed the "Akar Foundation", literally translates as "Root Foundation". It is a lightweight platform supported by a group of pipes. This foundation mainly serves dual functions; to collectively exert a stronger grip of the soft soils hence giving higher bearing capacity, and to spread the imposed structural load evenly into the subsoil thus avoiding excessive and non-uniform settlements. Research conducted has shown the effectiveness of both foundations depending on several parameters such as compatibility of the pipe spacing, individual pipe lengths, raft dimensions and the load applied. In a promising light, the reduced settlement of both foundations when compared to a raft foundation, has

illustrated the potential of the "Akar foundation" [2] and "Cakar Ayam foundation" [1]as economical and effective foundation systems in soft soils.
In this study, the ability of a shallow foundation; which is made of a rigid raft, underneath to which two flexible vertical flaps are attached, to reduce the settlement was identified as the modified foundation system. The objectives was to investigate the model behaviour of the modified foundation in a soft soil and to compare the observed behaviour of the proposed foundation with that predicted by the finite element analysis. The study was limited to identifying only the influence of the flap length and to the behaviour of the foundation, while keeping all the other parameters such as raft dimensions constant and connectivity between flaps and the raft fixed. The finite element analysis of the foundation was carried out using only finite element software, PLAXIS and only a 2D model of the foundation was analysed.

2. MATERIALS & METHODS

2.1 Selection of a location for soil sample collection and soil testing

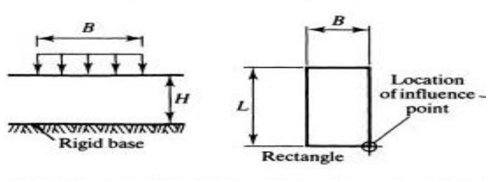
First task of the project was to identify a location with soft soil with suitable soil parameters and collect samples of that soil for physical model testing. For this task, four locations in Panideniya town, Kandy were identified. Vane shear tests were then carried out in those four locations to find the in-situ shear strength of the soil at depths 0.5m and 1m from the ground level. The location with the least shear strength was identified as the most suitable location and soil samples were obtained at a depth of 0.5m from the surface. The collected soil samples were protected and preserved with wax at the laboratory, to find soil properties of the selected soil. Finally laboratory tests were carried out to identify required soil parameters (Table 2.1).

Table 2.1: Properties of the soil

Property	Value
Natural moisture content	51%
Liquid limit	45%
Plastic limit	24%
Plasticity index	20 %
Organic content	6.8%
Specific gravity	2.58
Undrained shear strength	14 KPa
Young's modulus	1800 KPa

2.2.Theoretical calculations

According to the theory of elastic settlement of foundations by Steinbrenner in 1934, elastic settlement, $S_i = C_s\ q\ b\ (\frac{1-v2}{Es})$ [7], [6]. Using above equation elastic settlement of the raft was calculated for further verifications.



Since L/B = 75/4 = 1.875 and H/B = 200/4 = 5, from figure 3.7, C_S= 0.50.
Substituting the data, Es = 1800 KPa, v= 0.495, C_S= 0.50 and q= 17.5 KPa (Elastic failure under raft foundation – found from Plaxis) for the equation,

$$S_I = C_S\ Q\ B\ (\frac{1-v2}{Es})$$
$$= 0.50 * 17.5 * 0.08*(\frac{1-0.4952}{1800})$$
$$= 294*10^{-6}\ m$$

Therefore, elastic settlement at the mid span of the raft is 0.294mm.

2.3 Dimensions of the model

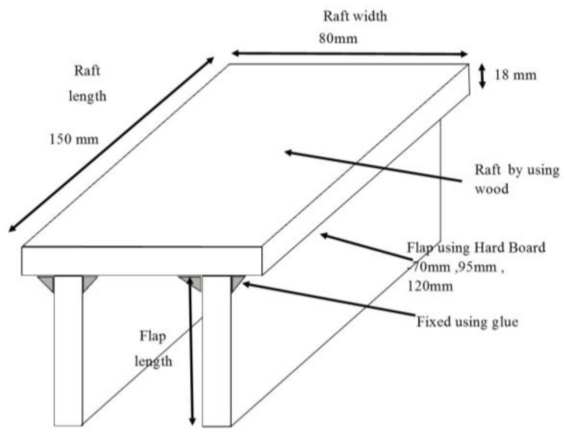


Figure 2.1: Proposed model

Selected dimensions for the foundation,
Raft – 18*80*150 mm
Flap depths – 70, 95, 120 mm
Flap thickness, length – 3mm, 150mm

2.4 Finite element model analysis using Plaxis

The Plaxis analysis was performed for 2-D model of the proposed foundation using Mohr-Coulomb model under plane strain conditions. The boundary was the dimensions of the soil box and the boundary conditions were fixed[5]. 15 node triangular elements were used in developing the mesh. The input parameters for the soil such as Young's modulus, unit weight, cohesion used in the Plaxis analysis were the results from the soil tests. The Poisson's ratio of the soil was used as 0.495 assuming incompressibility of soil. The rigid material was assigned with the material properties of wood and the flexible material were assigned with material properties of hardboard.
The Plaxis analysis was carried out for the foundation model by varying the length of the flaps. A rigid raft was used as the control model to find the effectiveness of the proposed foundation.

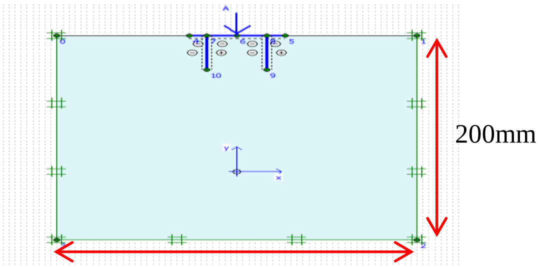


Figure 2.2: the foundation model used in the analysis

The length of the flap was varied in the model as 70mm, 95mm and 120mm and the variation of the vertical mid-point deflection of the raft with the flap length was determined. In each case, the behaviour of the raft and the flap was analysed individually.

2.5 Physical model testing

The rigid raft- flexible flap combination was the only foundation model that was used for physical testing, since it was the main aim of the project. Thus prepared physical models were tested under different loads to identify the settlement behaviour of this foundation on soft soil. The results obtained from physical testing were compared with the finite element analysis results obtained on the same models.

2.5.1 Model Preparation

Four models were prepared which included three physical models of the proposed foundation (rigid raft to which two flexible flaps are attached underneath) with flap lengths 70mm, 95mm, 120mm and the control model (a rigid raft). Hardboard was used for the flap and wood was used for the raft. The two flaps and the raft were joined together with glue. The experimental model is shown in Figure 2.3.

Figure 2.3: The experimental model

The loading from a triaxial apparatus was used to apply the load to the physical model when conducting the experiment. Since the loading applied through the tri-axial apparatus was through one point, a loading arrangement that would provide a distributed loading was required.
Figure 2.4 shows the loading arrangement that was designed and made with steel to suit this purpose.

Figure 2.4: The loading arrangement

2.5.2 Test procedure

First, the experimental model was placed in the soil sample such that the raft was seated on the top soil surface and the two flaps were inserted into the soil, but the vertical edges visible through the glass box as shown in Figure 2.5. In order to ensure the visibility of these vertical edges of the flaps, they were painted with white paint prior to inserting into the soil. The horizontal bar of the loading arrangement was placed along the groove made along the center line of the raft, while the vertical bar was connected to the tri-axial apparatus. A dial gauge with a least count of 0.002mm was placed on the horizontal bar of the loading arrangement, to measure the mid span vertical deflection of the raft. Then, the load was applied at a rate of 0.05mm/min to the model, until the ultimate load of 5.76 kN/m was achieved. The consequent load applied to the model was measured using a 250lb proving ring connected to the loading frame of the tri-axial apparatus. At the end of the test, the deflected shapes of the flaps were marked on the Perspex wall before withdrawing it from the soil sample. The same procedure was repeated for all the other models.

Figure 2.5: The physical model testing

3 RESULTS AND DISCUSSION

3.1 Physical model testing

Variation of the mid-point vertical displacement of the raft with the load applied for the rigid raft-flexible flap model with different flap depths and the rigid raft are shown in Figure 3.1.

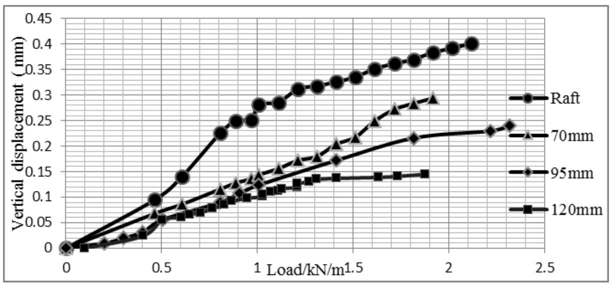


Figure 3.1: Variation of mid-point deflection of the raft with the load applied for the rigid raft-flexible flap model with different flap length and the rigid raft

The variation between the mid-point deflection of the raft and the load applied was obtained for rigid raft-flexible flap foundation model through physical model testing as depicted in Figure 2.5. It is clear from the results obtained, that when the flap length increases, the mid span deflection of the raft reduces.

3.2 Plaxis analysis results

The mid-point vertical displacement of the raft of rigid raft - flexible flap model with different flap lengths 50mm, 95mm, 120mm, 175mm and 225mm, at different loads applied (1kN, 2kN, 3kN,4kN, 5kN and 5.6kN) were obtained as follows. The model had a fixed spacing between the two flaps of 50mm. The behaviour of the raft was only analysed here.

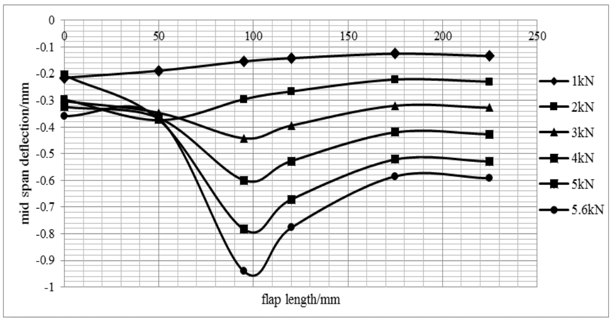


Figure 3.2: Variation of the mid span deflection with the flap length for different applied loads

When considering the above results, it is clear that with the increase in the applied loads, the mid-span deflection of the raft increases in the models with the flap length up to 100mm. But in the models with the flap length more than 100mm, the mid span deflection of the raft starts to reduce gradually.

Therefore, it is evident that the models with flap length less than 100mm exhibits a rigid behaviour by punching into the soil continuously with the application of loads and the models with flap length more than 100mm exhibits a flexible behaviour by bending the flaps.

When the lateral deflection and the bending moments of only the flaps were analysed, some of the flaps showed behaviour similar to that of a short or rigid pile, while some other flaps exhibited behaviour similar to a long elastic pile. This is illustrated in Figure 3.3 and Figure 3.4.

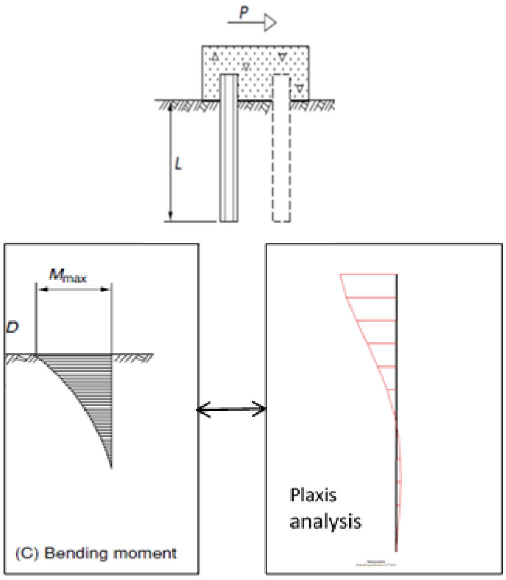


Figure 3.3. The similarity in the bending behaviour of short piles to that of the bending behaviour of 50mm flap

For a pile to behave as a short or rigid pile, the ratio between the length of the pile and relative stiffness coefficients in clay should be less than or equal to two. From calculations, the ratio obtained for 50mm flap was 1.82 which proves that theoretically the flap behaves as a rigid pile. The limiting length value of a flap length to raft width is 0.33 in order to behave as a short pile.

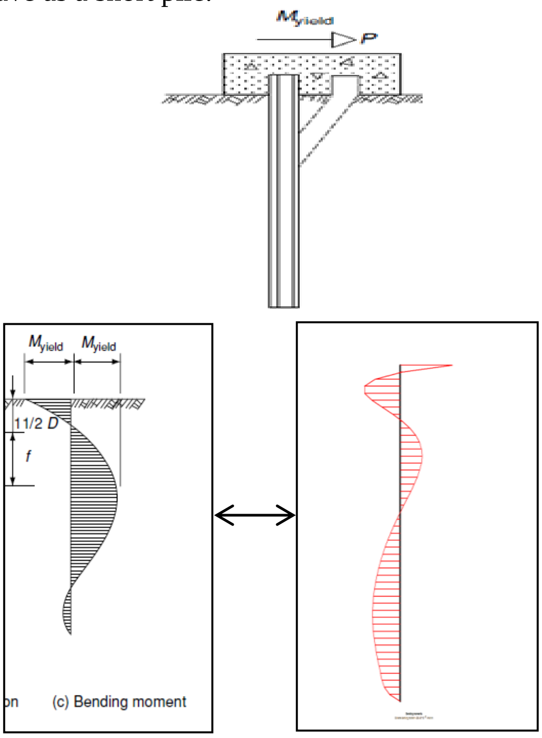


Figure 3.4. The similarity in the bending behaviour of short piles to that of the bending behaviour of 175mm flap

For a pile to behave as a long or elastic pile, the ratio between the length of the pile and relative stiffness coefficients in clay should be greater than 4.5. The value of this ratio obtained for the 175mm flap was 6.4, which is well above 4.5 . Thus this flap behaves similar to a long pile. The limiting value of flap length to raft width 0.83 is required to behave as a long piles.

So any flap length to raft width ratio between 0.33 and 0.83 behaves as an intermediate pile.

3.3 behaviour of the raft

Figures 3.5,3.6,3.7,3.8 indicate the individual comparison between physical test results and Plaxis analysis result for rigid raft- flexible models with flap lengths 70mm,95mm,120mm) and rigid raft.

1. Rigid raft

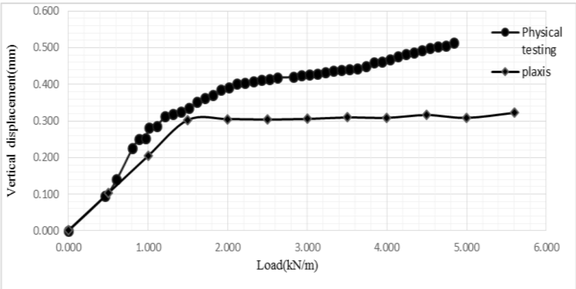


Figure 3.5: Variation of the vertical displacement of the mid-point of the raft with the load applied for the rigid raft

2. Rigid raft-flexible flap model with flap length 70mm

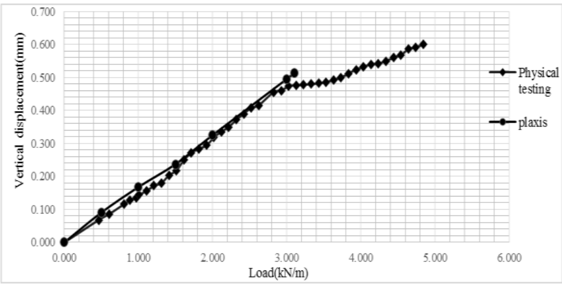


Figure 3.6: Variation of the vertical displacement of the mid-point of the raft with the load applied for the rigid raft-flexible flap model with flap length 70mm

3. Rigid raft-flexible flap model with flap length 95mm

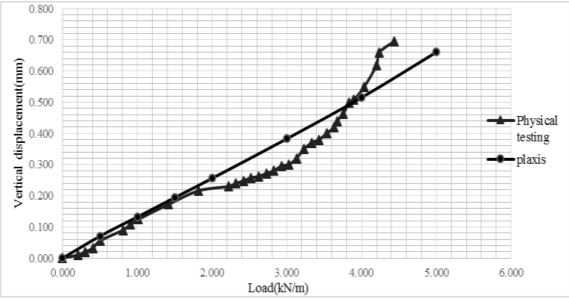


Figure 3.7: Variation of the vertical displacement of the mid-point of the raft with the load applied for the rigid raft-flexible flap model with flap length 95mm

4. Rigid raft-flexible flap model with flap length 120mm

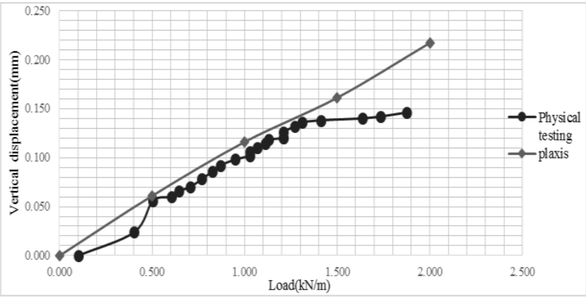


Figure 3.8: Variation of the vertical displacement of the mid-point of the raft with the load applied for the rigid raft-flexible flap model with flap length 120mm

Although the values obtained for the vertical displacement of the raft at a specific load applied, is nearly equal in both physical testing and Plaxis analysis, there are deviations between the physical testing and Plaxis analysis results. These variations may be due to, errors in carrying out the physical testing, initial disturbance to the soil sample when obtaining it and inserting the model, errors in the instruments used and absorption of moisture in the soil by the hardboard.

3.4 Behaviour of the flap

Figure 3.9: Behaviour of flap in physical testing for the rigid raft-flexible flap model with flap length 70mm

The similarity in the behaviour of the flap in physical testing and Plaxis analysis is shown in Figure 3.9 and Figure 3.10 for the model with 70mm flap length. Other models 90mm and 120mm flap length models also showed a similar pattern.

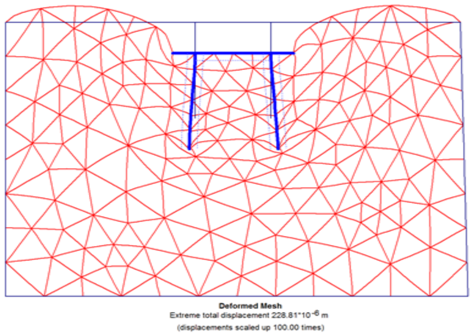


Figure 3.10: Behaviour of flap in Plaxis analysis forthe rigid raft-flexible flap model with flap length 70mm

3.5 Behaviour of the soil

During the physical model testing, the soil on either side of the raft exhibited a bulging behaviour outwards, with the increase in the load application. This behaviour is clearly shown in Figure 3.11.

Figure 3.11: The bulging behaviour exhibited by the rigid raft-flexible flap foundation model under applied loads

The same behaviour is shown by the model analysed using Plaxis and thus can be explained using plaxis. Figure 3.12 shows the total displacement of the soil in the model. According to this figure, the soil underneath the raft moves vertically downwards. This movement causes the soil near to the flap to move laterally and ultimately vertically upward, away from the raft this results in the soil bulging.

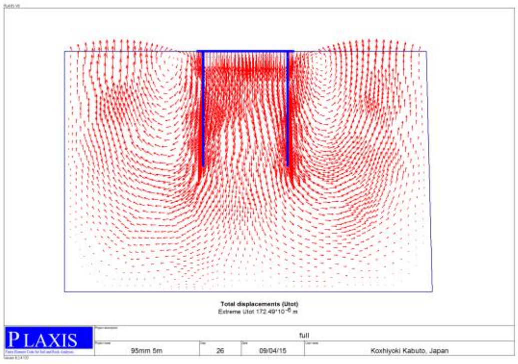


Figure 3.12: The bulging behaviour exhibited by the rigid raft-flexible flap foundation model under applied loads

4. CONCLUSIONS

In this project, the settlement behaviour of the physical model and the finite element Plaxis model which was made of a rigid raft, underneath to which two flexible vertical flaps were attached was analysed and the following conclusions can be summarized by observing the results.

(1) The improvement of the settlement resistant behaviour is remarkably increased in both physical model and finite element Plaxis model with the increase of the flap length. The vertical displacement pattern of the raft in both physical model and finite element model are similar.

(2) A decrease in the vertical displacement of the raft is seen with the increase of the flap lengths and also a reduction in the horizontal displacement of the flaps occur with the increase of flap length.

(3) The vertical displacement undergone by all the points on the raft are all most similar in value in rigid raft model, which is similar to a punching behaviour.

(4) When the soil underneath the raft undergoes a vertical movement due to the applied load, in order to keep the total strain constant, a quantity of soil has to move in the lateral direction resulting in a horizontal deflection of the flaps connected to the raft. Thus, the flap and the raft mutually influence each other's deflection behaviour.

(5) The same soil bulging behaviour shown by the model when analysed using Plaxis was shown when conducting physical testing. Thus it can be explained using the total dispalcement behaviour of soil in Plaxis. When the soil underneath the raft moves vertically downwards the soil near to the flap try to move laterally and ultimately vertically upward, away from the raft resulting in the soil bulging.

(6) The percentage reduction in settlement is highly depended on the flap length of the two flaps.

(7) When comparing with laterally loaded pile behaviour, the flap lengths to raft width ratio lesser than 0.33 behave similar to the short piles, and flap lengths to raft width ratio more than 0.83 behaves similar to long piles.

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