

Equivalent pier theory for piled raft design

Équivalence de la théorie de la jetée pour la conception de radeau empilé

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ABSTRACT: The objective of generating an economical and safe foundation system reducing the settlement rather than eliminating has led to the change in the design philosophy recognising the fact that most structures can tolerate a certain amount of settlement. The piled raft analyses and design is three dimensional interaction problems, wherein, the applied load is transferred by a complicated interaction process between the piles and the raft.. The necessity to have a relatively simple design procedure so that the preliminary design can give adequate but reasonably accurate data for the final analyses is explained. The paper presents such a simple design process in the form of equivalent pier approach by establishing its applicability by applying it to two cases. Also the study has brought out the effect of deep compressible deposit sandwiched between two dense layers.

RÉSUMÉ : L'objectif de créer un système de fondation économique et fiable, par la réduction des affaissements plutôt que de leur éradication, a entraîné un changement dans la philosophie de conception, admettant le fait que la plupart des structures sont capables de tolérer un certain nombre d'affaissements. Les analyses et la conception du radier sur pieux comportent des problèmes d'interaction tri dimensionnels, où la charge appliquée est transférée par un processus d'interaction complexe entre les pieux et le pilier. Il est expliqué la nécessité de disposer d'une procédure de conception relativement simple, de manière à ce que la conception préliminaire puisse apporter des données appropriées suffisamment précises pour les analyses finales. L'article présente un processus de conception aussi simple, sous forme d'approche de pilier équivalent, en prouvant sa faisabilité par son application dans deux cas. L'étude a également révélé les effets du dépôt fortement compressible coincé entre deux couches épaisses.

KEYWORDS: Piled raft, Pier, Peat.

1. INTRODUCTION

The design of foundation system for structures that cannot tolerate settlements, the aspect of balancing the performance and cost, had always been a challenge for the foundation designers. Due to the complexity involved in the soil structure interaction analyses, required for an optimum design, designers have so far been resorting to the traditionally designed pile foundations system permitting very small limiting settlements. Even though this approach produces a safe design, the economics of the design becomes questionable. The objective of generating an economical and safe foundation system reducing the settlement rather than eliminating, has led to the change in the design philosophy. Keeping the above objective in mind researchers like Burland (1995) and subsequently Polous (2001) had brought out the use of piles with the raft to reduce the settlement of the raft. This had led the advent of the combined piled raft foundation system, which provides a skilful geotechnical concept to design the foundation for structures which are sensitive to large settlements. The piled raft analyses is a three dimensional interaction problems, wherein, the load transfer mechanism is a complicated interaction process by which the load is shared. The interactive process between the Various procedures based on observational study (Katzenbach et al., 2000a) small scale model studies such as centrifuge models (Horikoshi 1995) 1g model studies (Balakumar, 2008) and the resulting interactive process with the numerical modeling (Clancy 1993; Russo, 1998;) supported by the development of new geotechnical computational facilities (Polous and Small 2007) has led to the the piled raft foundation system being

extensively used to support tall and heavily loaded structures in a successful manner permitting larger settlements close to the permissible value (Polous, 2008; Yamashita et al., 2010).

2. DESIGN PROCESS

The satisfactory performances of piled raft largely depend upon the performance of the pile group of piled raft in providing the initial stiffness and then allow the raft to have a higher capacity by functioning as settlement reducer. Hence after ascertaining the feasibility of the piled raft to support the structure, a preliminary analyses has to be done to finalize the computational details of the constituent elements. Primarily the number, length of the piles, the load shared by the pile group are the essential parameters in addition to the properties of the supporting soil layers. In the case of the piled raft the pile group capacity and the overall capacity of the piled raft play an important role. The second stage of analyses has to produce these data in a reliable manner such that when used in the final analyses, the analyses will produce a design which need not be subjected to any iteration process. This requirement makes the procedure to be more realistic and simple enough such that the computational efforts are minimum and economical. Even though the existing methods can provide a design approach, these involve a very detailed computational efforts, not really warranted for the second stage of design, from the commercial design organisation point of view.. Therefore it is essential to have a relatively simple design procedure so that the second stage of work can give adequate but reasonably accurate data for the final analyses.

5. RESULTS, ANALYSES, AND DISCUSSION.

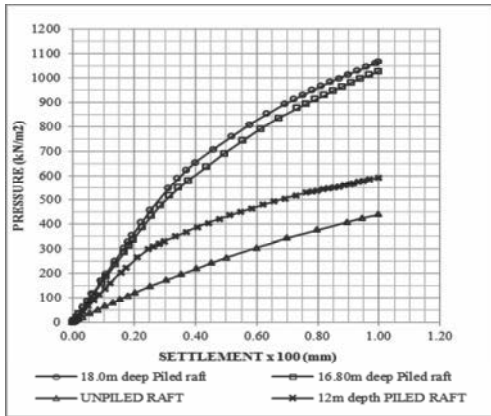


Figure 4 Load settlement response

The results obtained from the model 1 are plotted in the form of load settlement response curves and presented in Figure 4. The load settlement response of 12m pier is presented separately in figure 5.

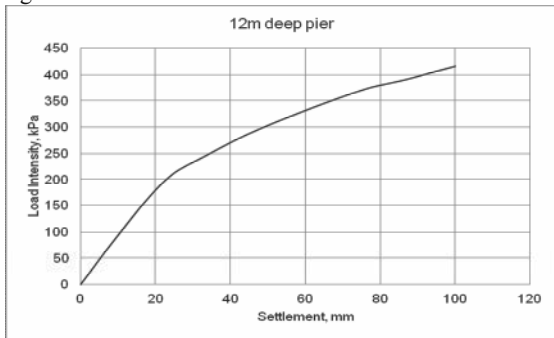


Figure 5. Load settlement response 12m pier

For the pier lengths of 12m, 16.8m, and 18mm. At any stage of settlement, it was found that the load taken by the piled raft was far higher than the load taken by the unpiled raft for the corresponding settlement. The results are studied independently for the three cases analysed, and then they are compared. From the load settlement response of the unpiled raft and the piled raft, the load shared by the pier (pile group) is computed at different settlement levels namely 12mm, 25mm, 50mm, 80mm and 100mm and has been presented in Table 1.

Table 1 Load Sharing Ratio At Various Settlement Levels

Pier length	Settlement				
	12m m	20mm	50mm	80m m	100mm
12.0m	0.54	0.53	0.37	0.30	0.25
16.8m	0.64	0.65	0.60	0.58	0.56
18.0m	0.61	0.56	0.64	0.59	0.59

In the case of load settlement response of all the three cases, in the initial stages upto a settlement level of 25mm, the piled raft exhibits a higher stiffness, with the very small rate of change in the stiffness. As seen from the table 1, the loads shared by the pier in the initial stages are higher and then gradually reduces with settlement. This indicates that the major part of the applied load is taken by the pile group or the pier. Beyond this level the rate of fall in the stiffness increases rapidly indicating that the full friction has been mobilised and the raft starts taking a higher load. This stage exists upto a settlement level of

75mm. Beyond this level the rate of fall of stiffness further increases rapidly even for a small increment in the load. In the case of piled raft with 16.8m deep pier the load corresponding to 25mm settlement is higher than the previous case by 100% indicating that the pier mobilises a higher friction in the linear elastic stage. At 75mm settlement level the increase in the load taken by the 16.8 m deep pier is higher by 60%, indicating that the load shared by the pier reduces gradually. and in the case of 18m deep pier this increase is only 15% when compared to 16.8m deep pier.

6. EFFECT OF PEAT LAYER

The study of the Table 1 and the Figure 6 which presents the shaft stress distribution with the depth indicates that the load sharing ratio and the shaft stress indicate an increase and then a fall. The shaft stress increase commences at a level of 13m and extends upto 16m level; and then it reduces. In the case of load sharing ratio the increase takes place at a settlement level of 20mm in the case of 16.8m deep pier and 50mm level in the case of 18m deep pier. This trend is absent in the case of 12 m deep pier which is above the peat layer.

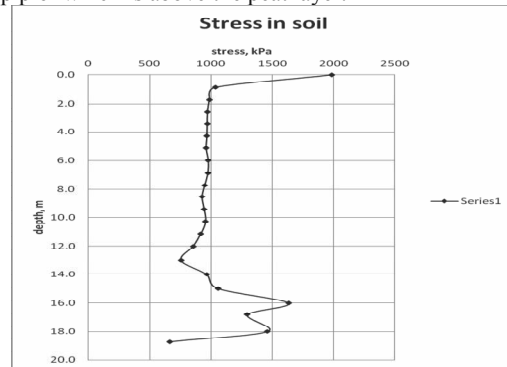


Figure 6 Shaft stress mobilisation (18m deep pile)

The most probable reason for this behavior is that at a higher load the peat layer generates a negative skin friction causing a higher load on the pile group. This results in the sudden increase in the shaft stress and the load sharing ratio value. Figure 6 presents the mobilisation of shaft friction with depth. It is seen that the shaft friction increases and then falls down rapidly with depth confirming the ductile behaviour in the sense that major part of the load is transferred by friction.

7. HYPERBOLIC BEHAVIOUR

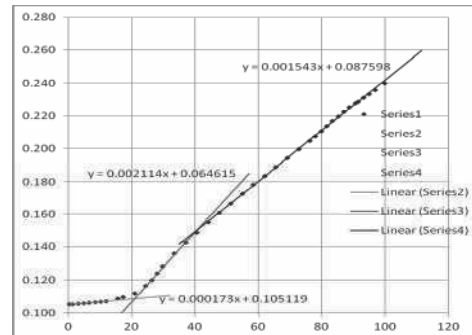


Figure 7 Chin's graph (12m pier)

The curve relating to the 12m deep pier exhibits in a distinct manner a three phase behaviour; namely OA, which is a linear elastic stage AB a visco- plastic stage and BC the plastic stage. In the other two cases the third stage is has not reached mainly because the piled raft was still capable of taking higher load. Typically the piled raft with 12 m pier depth had exhibited a hyperbolic behaviour and it has been loaded close to failure

has exhibited a hyperbolic behaviour. It has been established that the hyperbolic behaviour can be expressed in terms of Chin-Kondner type functions, when the inverse of the stiffness is plotted against settlement, a linear plot can be obtained. In that case the inverse of the slope gives the asymptotic ultimate capacity of the pier. Accordingly as atypical case the load settlement response of the piled raft with 12m pier was plotted as Chin's graph. Figure 7

The asymptotic ultimate capacity was found to be of the order of 750kN, indicating that the asymptotic ultimate capacity is three times the capacity at the elastic limit and 1.5 times the load corresponding to the elasto plastic stage. This would mean that the capacity has to be limited to the load corresponding to the elasto plastic stage. Therefore the limiting capacity of the piled raft can be the capacity at a settlement level of 10% of the pile diameter when the pile can be seated in the non-compressible layer and when the pile has to pass through a compressible layer, and then the negative friction has to be accounted for.

8. OBSERVATIONAL STUDY MODEL

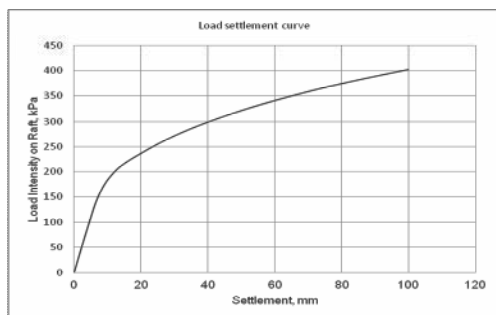


Figure 8 Load settlement response pier

Figure 8 presents the load settlement response of the pier representing the pile group and the raft which forms a part of the piled raft supporting the structure. Here it is seen that the elastic stage is seen upto a load level of 200kN per sq.m.

However in the analyses the pressure was applied continuously whereas during construction the load was applied in gradual manner over a period of time.

However the settlement shown by the equivalent pier analyses is 12 mm as against the observed value of 14mm reported in the referred publication, The load sharing behaviour and the shaft stress mobilisation exhibited a similar trend as in the case of earlier model and as observed in the observational study. In this case the load level was found to be well with in the elastic limits. The settlement observed from the observational study was 14mm and from the pier analyses the settlement obtained was 12mm indicating a very close agreement indicating that the equivalent pier concept can fill the need of a simple design procedure.

9. CONCLUSIONS

The extensive study carried out on the two independent cases adopting the equivalent pier theory has established that the equivalent pier theory, although involves numerical approximation, the performance of the piled raft in both the cases predicted by equivalent pier theory is in conformity with the earlier works by Oh et al.,(2008) and Balakumar (2008)The study has further pointed out that in the case of piled rafts with the pile group passing through seams of compressible layer the behaviour is affected by the mobilisation of negative skin friction and the equivalent pier concept is able to predict this effectively.The compressible layer generates negative skin friction and increases the load on the pile as shown by the increase in the load sharing ratio and then allows the pile group

behaviour to be ductile. In short the equivalent pier theory is an ideal theory for the piled raft analyses.

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