FINITE ELEMENT ANALYSIS OF PILED RAFT FOUNDATION IN CLAY AND SAND

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Abstract. Piled raft foundations provide an economical foundation option for areas where the performance of the raft alone cannot satisfy the design requirements. Under these situations, the addition of a limited number of piles to support Raft may improve the ultimate load capacity, the settlement and differential settlement performance, and the required thickness of the raft. In this study, an attempt has been made to describe the various approaches of modeling the soil–structure–foundation system for piled raft foundation and a three-dimensional finite-element model of a piled raft foundation is proposed to simulate the case of a piled raft foundation through PLAXIS 3D software which accounts for pile-to-pile, raft-to-pile, pile-to-soil, and raft-to-soil interactions. The model will be used to examine the effect of the key parameters influencing the performance of piled raft foundation during uniform loading and building column reactions on Piled Raft in case of clayey and Sandy soil. A parametric study is also conducted to show the effect of various geometrical parameters on the performance of Piled Raft Foundation. The results of this study could be used as guidelines for achieving economical design for piled raft foundations and to lead to additional research in this area.

Keywords: Piled raft foundation; Foundation design; PLAXIS 3D; SSI.

1 Introduction

Foundations are structural members that are responsible for providing the contact between soil and structure. The main requirement of the foundations is to transmit the structural loads to the soil media under required safety conditions. In the earlier researches of the foundation design, it is generally suitable to start with the shallow foundation options like, raft foundations, spread footings and combined footings as these are significantly economical and can be constructed easily. If the load-bearing capacity and settlement criterion of the foundations are not full filled, then the foundation is needed to redesign the foundation. In this situation, deep foundation options like piles, etc. are considered. The main philosophy of the designing pile foundation is transmitting the structural loads to soil layers that have appropriate engineering properties.

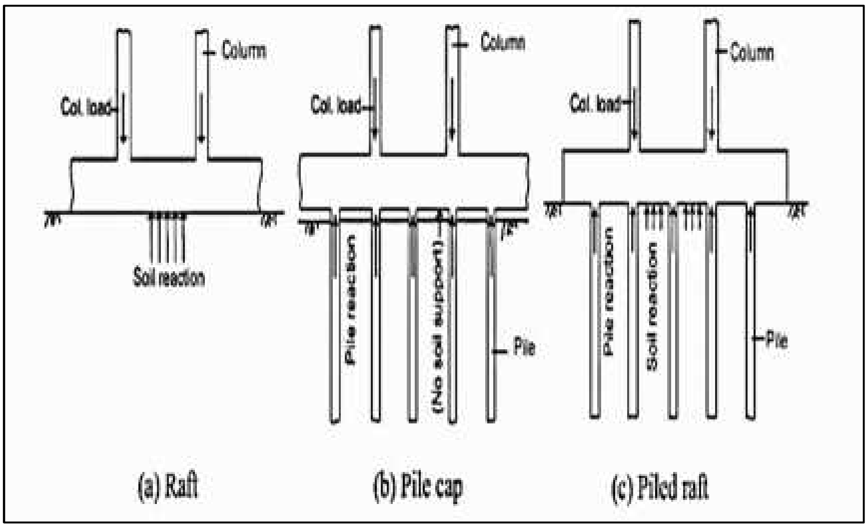


Fig. 1. Behavior of different foundation under loading condition

In the pile foundation approach, the entire structural loads are carried by the piles and the load-carrying contribution of the soil and pile cap (raft) is ignored. Conventional pile foundation approach results in highly conservative and non-economic designs. However, it is observed that the design of foundations considering only the pile or raft is not a feasible solution because of the load sharing mechanism of the pile-raft-soil. Therefore, the combination of two separate systems, namely "Piled Raft Foundations" has been developed Clancy and Randolph [1] .

Piled raft foundations provide an economical foundation option for areas where the performance of the raft alone cannot satisfy the design requirements. Under these situations, the addition of a limited number of piles may improve the ultimate load capacity, the settlement and differential settlement performance, and the required thickness of the raft. In piled Raft system, it becomes the combination of a shallow foundation such as the raft and a deep foundation such as the pile, both sharing in the process of load transfer to the soil. Fig 1 attempts to express this picture. Hence in theoretical terms, there are following ways of interaction between the raft, the piles and the soil which makes it a complex problem for any rigorous analysis. To resolve the problem best method would be numerical analysis like the 'finite element method'. In the conventional design approach, it can be assumed that loads to be carried only by the piles or raft. However, in the design of piled raft foundations, the load sharing between piles and the raft is taken into account [2].

This sharing of load improves the underestimated load capacity of the foundation comparing with the conventional approach, considering the properties of the piles and the raft remain unchanged. Also, the piles may be used to control the settlement rather than carry the entire load in the piled rafts. Tan and Chow [5] illustrated the usage benefit of piles and raft together in the design of foundations in Fig 2.

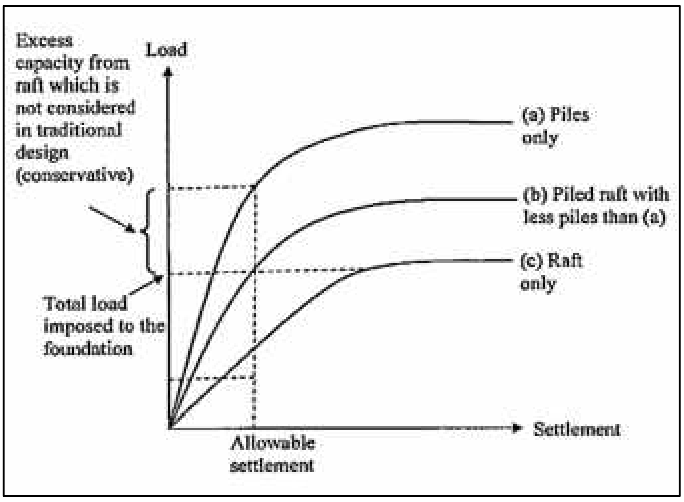


Fig. 2. Concept of piled raft [5]

Advantages of Piled Raft Foundation

1. Piled raft foundations use piled support for control of total and differential settlements in which piles are providing most of the stiffness at serviceability loads while the raft element providing additional capacity at ultimate loading. Simultaneously, the required number of piles can be reduced when the raft provides this additional capacity to the foundation. So by proper geotechnical assessment, it could be very helpful to increase not only the capacity of the pile elements and the raft elements, but also in combined capacity and interaction under serviceability loading. Hence the required limits for differential settlements and settlements can be satisfied.
2. The pressure applied from the raft on to the soil will increases the lateral stress between the underlying piles and the soil. Hence it can increase the ultimate load capacity of a pile as compared to free-standing piles in conventional pile design system. it can also reduce the number of piles as compared to conventional piled foundation because in piled raft it considers the bearing effect of raft which was ignored in conventional pile design.
3. If eccentric loading or difficult subsoil conditions arise there will be a risk of foundation tilting which can be decreased by piled raft foundation because in piled raft foundation a centralization of actions and resistances occurs for the cases of large eccentricities.
4. There will be a reduction of the bending stress for the raft foundation. If some regions of the foundation are subjected to different loads, this system will minimize the differential settlement also.

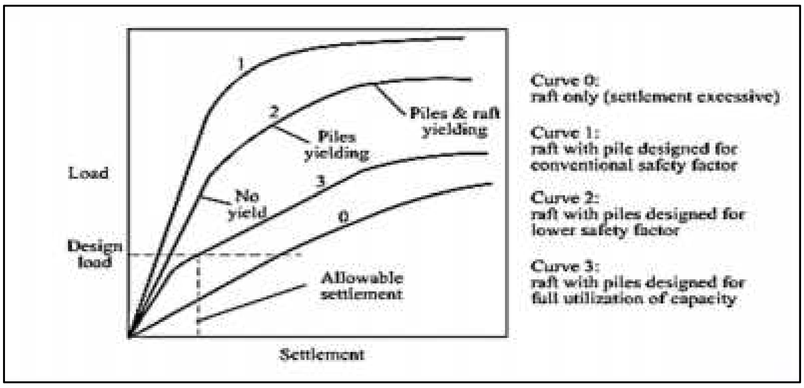


Fig. 3. Load settlement curves for piled rafts according to various design philosophies [3]

5. It provides an economical foundation where structural loads are carried partly by piles and partly by raft contact stresses hence it works as a cost optimizer for the whole foundation.

2 Validation of PLAXIS MODEL

The model prepared in PLAXIS 3D with the same parameters as Sinha and Hanna's [4] . Sinha and Hanna's [4] model includes the layer of Clay soil modeled under piled raft on ABAQUS 3D. The results obtained are compared which are found to be nearly equal as shown in fig. 4.

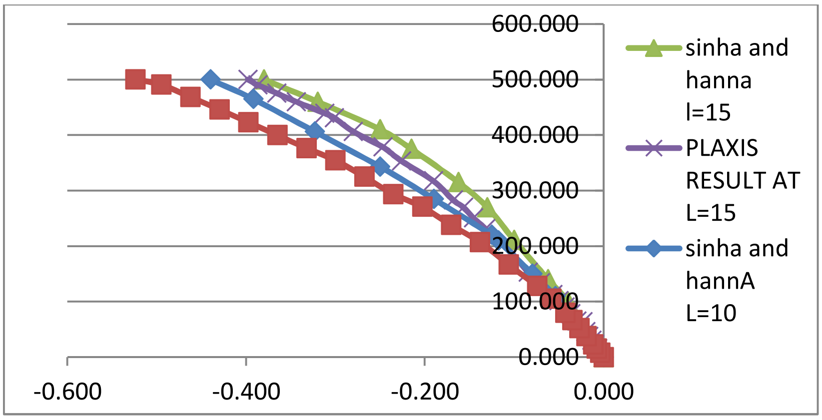


Fig. 4. Validation curve between displacement and applied load

3 METHODOLOGY AND MATERIALS

Finite Element Analysis is a general method to solve boundary value problems in an approximate and discretized way. It is often used for deformation and stress analysis. In the Finite Element Method, the division of geometry into finite element mesh occurs. For the analysis of Piled raft foundation PLAXIS 3D software is used here.

3.1 Project properties.

For the analysis, basic soil elements of the 3D finite element mesh (size 170×170×50m) of 10-node tetrahedral elements are used. The pile-soil interaction is governed by relative movements between the (newly generated) pile nodes and the (existing) soil nodes.

3.2 Material Models

Modeling of soil, raft, and solid piles is done with the help of the Mohr-Coulomb and Linear elastic model.

3.3 Soil properties

To define soil properties for the model, boreholes will be located in the drawing area at (0 0 0) which defines the information regarding soil layers and the water table. Soil parameters of medium dense sand and medium-stiff clay are selected for the study of Piled Raft foundation. Following properties of sand and clay will be used for study:

Table 1. SOIL PROPERTIES

Parameters	Identi-fication	Unit	Parametric study		Building analysis	
			Clay	Sand	Clay	Sand
Drainage type	Type	-	Drained	Drained	Drained	Drained
Unsaturated Unit weight	γ_unsat	kN/m³	9	17	15	15
Saturated Unit weight	γ_sat	kN/m³	19	20	20	18
Young's modulus	E	kN/m²	5.4X104	3.0X104	10000	6000
Poisson's ratio	ν (nu)		0.15	0.3	0.35	0.3
Cohesion (constant)	c	kN/m²	20	0	18	0
Friction angle	φ (phi)	°	20	36	0	25

3.4 Proposed structural elements

The structural data for piles, raft is taken from the research paper of Sinha and Hanna (2016) in which Piled raft foundation designs on ABAQUS. Raft of 24m×24 m×2m size, 16 piles of different diameter and length will be used with for parametric study and building analysis.

Table 2. MATERIAL PROPERTIES OF STRUCTURAL ELEMENTS

Parameters	Identification	Unit	Pile	Raft
Drainage type	Type		Non-porous	Non-porous
Unsaturated Unit weight	γ_unsat	kN/m³	25	25
Saturated Unit weight	γ_sat	kN/m³	25	25
Young's modulus	E	kN/m²	2.5X107	3.4X107
Poisson's ratio	ν (nu)		0.2	0.2

3.5 Analysis of the Piled raft under asymmetric multistory building

An multistory building (G+10) is designed under STAAD-PRO Vi8 considering various dead load, live load and earthquake loads as IS 1893 for seismic zone III. The column loads and moments in analysis as shown in fig. 5 and fig. 6 are transferred to the raft for the analysis of the behavior of Raft and piled raft foundation.

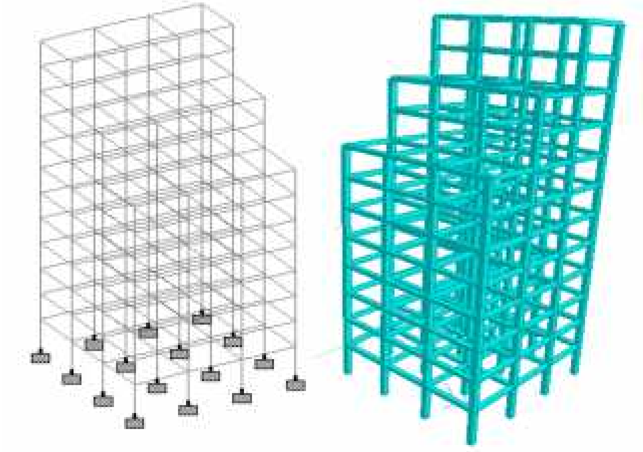


Fig. 5. Multi- story G+11 Building model in STAD PRO Vi8

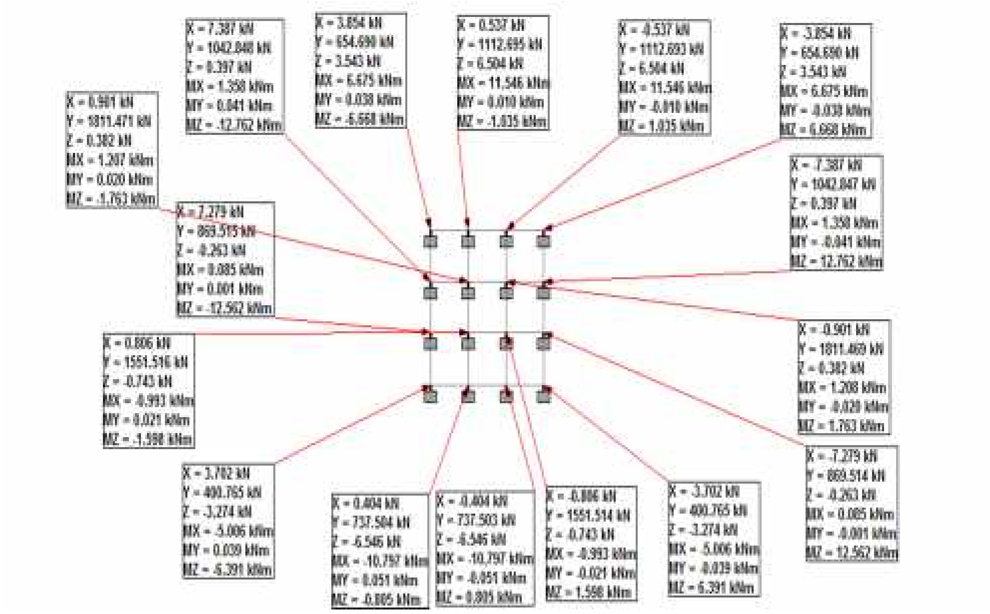
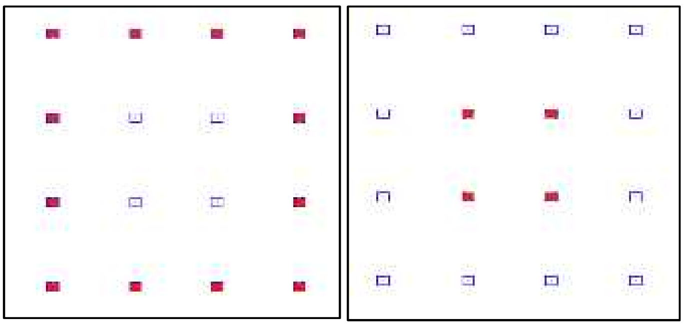


Fig. 6. Multi- story G+11 Building model in STAD PRO Vi8

4 RESULT AND DISCUSSION

4.1 BUILDING ANALYSIS

Piled Raft with different pile patterns are modeled under loading as shown in fig.6 with 24x24x2.5 m raft and 4x4 array of piles having 1m diameter. Material properties used were as shown in Table 1 and Table 2.



(a) Model I Pattern (b) Model II Pattern

Fig.7**.** Pile patterns use for Foundation

Clay.
In the case of clay, When piles of equal length that is 10m and 5m in all raw and column is used for model then the observed average settlement was 37mm and 44mm respectively. After this, two models were prepared in which, Model-I has 10m length piles in outermost raw while 5m pile length in central matrix while Model-II has 5m length piles in outermost raw and 10 m pile length in central matrix. From these two models, it was found that Model-I gives 39mm settlement while Model-II gives 45mm settlement. Here it could be seen that the settlement of Model-I is nearly equal to the model having equal piles of 10m which is more economical and efficient.

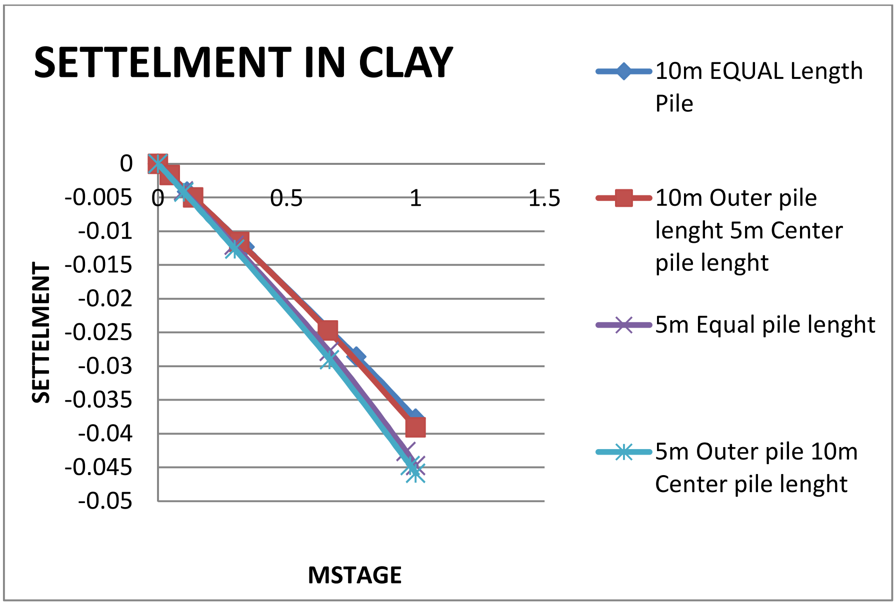


Fig. 8 . M-Stage graph with Displacement for Clay

Sand.
In the case of sand, When piles of equal length that is 10m and 5m in all raw and column is used for model then the observed average settlement was 59mm and 72mm respectively. After this, two models were prepared in which, Model-I has 10m length piles in outer most raw while 5m pile length in central matrix while Model-II has 5m length piles in outer raw and 10 m pile length in central matrix. From these two models, it was found that Model-I gives 39mm settlement while Model-II gives 45mm settlement. Here it could be seen that the settlement of Model-I is nearly equal to the model having equal piles of 10m which is more economical and efficient.

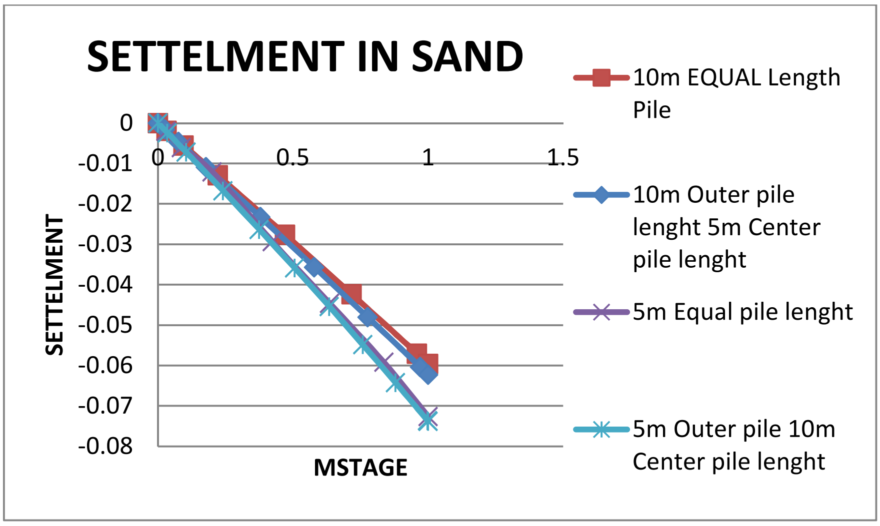


Fig. 9. M-Stage graph with Displacement for Sand

4.2 PARAMETRIC STUDY

The role of the foundation geometry including pile diameters, pile lengths and pile patterns in Clay and Sandy soils for Piled -Raft foundation with uniform distributed load of 500kn is conduct on 24x24 Raft with material properties as described in Table 1 and 2.

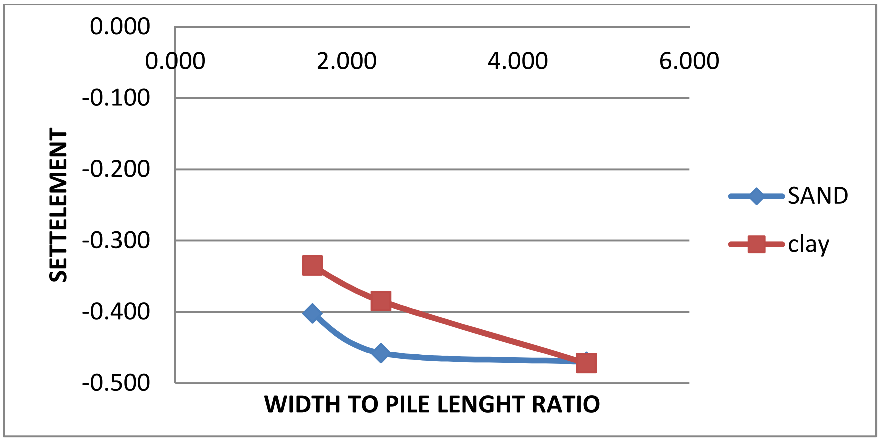


Fig. 10. Settlement graph with Width to Pile Length Ratio

From fig 10 and 11, it is seen that as the width to pile length ratio is increased from 1 to 5 a significant settlement increase is observed. Also, a similar trend can be seen for an increase in with to diameter ratio. As, the width to diameter ratio is increased the settlement has been increased. Figure 12 compares the results attained for different soil types, and it can be observed that, for the present given soil conditions clayey soil has relatively less settlement than compared to sandy soils. Also, the results shows the effect of center to corner pile length ratio, which implies Use of longer piles in the outer edge of pile matrix and relatively smaller length piles in inner matrix can reduce settlement in more economical way. Following results obtained from the parametric study;

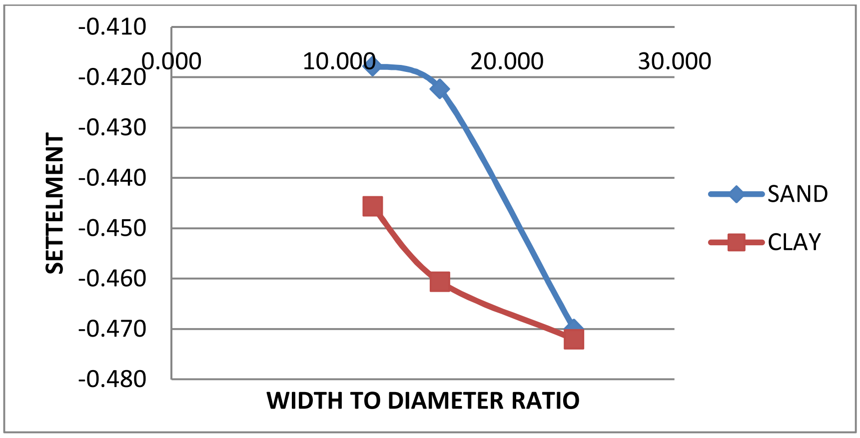


Fig. 11. Settlement graph with Width to diameter Ratio

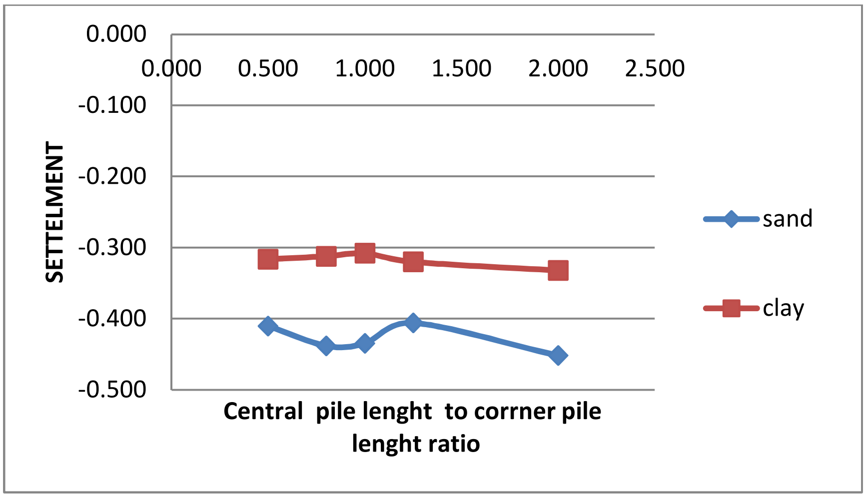


Fig. 12. Settlement graph with Width to diameter Ratio

5 Conclusions

In present study, different Piled Raft models with varying pile pattern and pile geometry had been used to predict the response of Piled Raft foundation to loading. From these results we can conclude that;

- Long piles in the outer row of pile matrix and small length size in the inner matrix can effectively reduce settlement as the consumption of material and time of construction will be less.
- Piled Raft foundation is an economical way of foundation design compared to conventional pile foundation design.
- Nearly Same amount of efficiency can be achieved by using different length of piles in pile pattern.
- Settlement of foundation can be co-related with width of raft, length of piles and diameter of piles to get an economical foundation.

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