PARAMETRIC ANALYSIS OF PILED RAFT FOUNDATION USING MIDAS GTS NX

A MAJOR-2

PROJECT REPORT

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE AWARD OF THE DEGREE

OF

MASTER OF TECHNOLOGY
IN
GEOTECHNICAL ENGINEERING

Submitted by:

SHIVANGI VASHISTH
(2K18/GTE/13)

Under the supervision of

Prof. AMIT KR. SHRIVASTAVA

DEPARTMENT OF CIVIL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Bawana Road, Delhi-110042

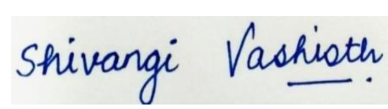
AUGUST-2020

DEPARTMENT OF CIVIL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Bawana Road, Delhi-110042

CANDIDATE'S DECLARATION

I, Shivangi Vashisth, Roll No. 2K18/GTE/13, student of M. Tech. (Geotechnical Engineering), hereby declare that the project Dissertation titled "Parametric Analysis of Piled Raft Foundation using Midas GTS NX" which is submitted to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the dergree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma, Fellowship or other similar title or recognition.



Place: Delhi (**SHIVANGI VASHISTH**)

Date: 31st August 2020

DEPARTMENT OF CIVIL ENGINEERING
DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Bawana Road, Delhi-110042

CERTIFICATE

I hereby certify that the Project Report titled "Parametric Analysis of Piled Raft Foundation using Midas GTS NX." Which is submitted by, Shivangi Vashisth, Roll No. 2K18/GTE/13, Geotechnical Engineering, Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any degree or Diploma to this University or elsewhere.

Place: Delhi
Date: 31st August 2020

(PROF. AMIT KR. SHRIVASTAVA)
SUPERVISOR
Professor
Department of Civil Engineering
Delhi Technological University
Bawana Road, Delhi-110042

ABSTRACT

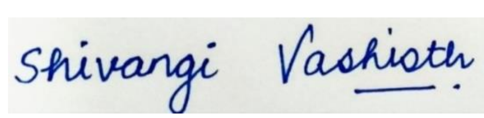
The project presents parametric study of a vertically loaded piled raft foundation using a finite element modeling in Midas GTS NX. The results obtained are validated by the results available in specialized literatures. Various graphs are plotted between settlement and parameters such as pile configuration, raft thickness, cohesion of soil and pile length to analyze and estimate their effect on piled raft settlement. The results are used for analyzing model from safety as well as economical point of view. All the data for analysis are referred from Piled Raft Foundations: design and applications: H.G Poulos (2001). The study concluded that increase in raft thickness led to a decrease in settlement but with further increase the decrease became insignificantly small, increase in pile length led to a marked decrease in settlement. The study also showed that increasing the number of piles does not always give best results, rather small number of piles placed strategically can prove to be really helpful in obtaining a safe and economical foundation.

ACKNOWLEDGEMENT

It gives me immense pleasure in expressing my gratitude to all those people who supported me and have had their contribution in making this major project-2 possible. I would like to express my gratitude to my mentor as well as our HOD who gave me the golden opportunity to do this project on the topic **"Parametric Analysis of Piled Raft Foundation using Midas GTS NX."**

I owe a debt of gratitude to my guide **Prof. Amit kr. Shrivastava** for incorporating in the idea of this Major-2 Project, helping me in undertaking this project and for being there whenever I needed his assistance. I am immensely grateful to all those who have helped me in making this project better, by providing me their valuable comments and guidance.

I am grateful to **Prof. Nirendra Dev, Head of Department,** Department of Civil Engineering, Delhi Technological University (Formerly Delhi College of Engineering) and all other faculty members of our department, for their astute guidance, constant encouragement and sincere support for this project work.



(SHIVANGI VASHISTH)
2K18/GTE/13

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

BEM	Boundary element method
FEM	Finite element method
FLAC	Fast Lagrangian Analysis of Continua
GARP	Geotechnical Analysis of Raft with Piles
GASP	Geotechnical Analysis of Strip with Piles
PRF	Piled Raft Foundation

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Foundation may appear as a simple part of a structure but it plays an incredibly important role. It forms the supporting base of the whole structure that transmits the load of the superstructure to the ground. So, it becomes really important to design the foundation such that it is both safe and efficient besides being economical. Earlier we only had shallow and deep foundations like raft and pile foundations respectively. But in recent decades when urbanization is at peak and limited lands are available, piled raft foundation have been developed to bear heavy loads from structures like high-rise buildings, power plants etc. and to avoid large settlement. The economical and serviceability aspect of piled raft foundation is alluring a number of geotechnical engineers. Various researchers are working on confederation of pile and raft parameters to get the adequate design plus cost saving. In piled raft foundation, piles help in reducing both total and differential settlement while the raft dispenses the total load of the structure as contact pressure and over the piles in the ground.

1.2 PILED RAFT FOUNDATION

Piled raft foundation cater an economical alternative to a simple raft foundation in the cases where raft alone cannot meet the design requirements. In such cases a defined number of piles, placed strategically are used to boost the performance of the raft which increases the ultimate load bearing capacity, reduces the settlement, the differential settlement and the also reduces the requisite thickness of the raft. Piled raft foundation is a deep foundation which is very pragmatic as well as economical in structures such as high-rise buildings, bridges etc. but still the researches in this field are underdeveloped because of the intricacy of the problem.

1.2.1 Design Issues

There are a number of issues of concern, that are needed to be considered for the designing of a Piled raft foundation just like any other foundation system, such as:

- Ultimate load bearing capacity against vertical, lateral and moment loading.
- maximum settlement
- differential settlement
- pile loads and moments, required for the designing of piles
- raft moments and shears, required for the designing of raft.

1.3 METHODS OF ANALYSIS

There are various methods, which have been refined for evaluating the piled raft foundation and some of them have been compiled by Poulos et al (1997). Three main classes of analysis method are:

- Simplified calculation methods
- Approximate computer-based methods
- More rigorous computer-based methods.

1.3.1 SIMPLIFIED ANALYSIS METHODS

1.3.1.1 Poulos-Davis-Randolph (PDR) Method

In order to access the vertical bearing capacity of a piled raft foundation system by simple approaches, the ultimate load capacity can be assumed as the minimum of the following two values:

- The sum of the ultimate capacities of the all the piles and raft.
- The ultimate capacity of a block consisting of the piles and the raft, plus the part of the raft outside the periphery of the piles.

To investigate the load-settlement behaviour, a method same as that illustrated by Poulos and Davis (1980) can be embraced. However, a convenient expansion to this approach can be developed by employing a simple estimation of load sharing between the raft and the piles, as mentioned by Randolph (1994). By adopting the approach given by Randolph (1994), the evaluation of piled raft foundation can be done as follows:

$$K_{pr} = \frac{K_p + K_r(1-\alpha_{rp})}{1-\alpha_{rp}^2 K_r/K_p} \qquad (1.1)$$

K_{pr} =Piled raft stiffness

K_p = Stiffness of pile group in isolation (computed by theory of elasticity for single pile and then considering group effect)

K_r = Stiffness of raft in isolation (computed by theory of elasticity)

α_{rp} = interaction factor for a pile on raft.

The fraction of the total applied load carried by the raft X is:

$$\frac{P_r}{P_t} = \frac{K_r(1-\alpha_{rp})}{K_p + K_r(1-\alpha_{rp})} = X \qquad (1.2)$$

P_r = Load endured by the raft, P_t = Total applied load

Interaction factor, $\alpha_{rp} = 1 - \frac{ln\left(\frac{r_r}{r_p}\right)}{ln\left(\frac{r_m}{r_p}\right)}$ (Randolph, 1994) (1.3)

r_r = average radius of the pile cap (equal to the raft area divided by the total number of piles)

r_p = pile radius

$$r_m = 2.5 + L\zeta[2.5r(1-n) - 0.25] \qquad (1.4)$$

$\zeta = E_{sl}/E_{sb}$

$r = E_{sav}/E_{sl}$

L = the length of the pile

E_{sl} =Young’s modulus of soil at level of pile tip

E_{sb} =Young’s modulus of soil of bearing stratum below pile tip

E_{sav} = Average soil Young's modulus along the pile shaft

n = Poisson ratio of the soil

Randolph approaches doesn't consider strength characteristics of soil or the flexibility of raft

Settlement of piled raft is given by:

$$\alpha_{rp} = \frac{k_p}{P_p}\left(w_{pr} - \frac{P_r}{k_r}\right) \text{(Clancy and Randolph, 1993)} \qquad (1.5)$$

k_r = overall stiffness of raft in isolation

w_{pr} = settlement of piled raft foundation

P_p = total load carried by pile group in combined foundation

P_r = total load carried by raft in combined foundation

k_p = overall stiffness of pile group in isolation

With the help of the equations stated above, a load – settlement curve can be plotted for a raft with different numbers of piles using a mathematical program like MATHCAD or a simple computer spreadsheet. In this manner, a relationship between the average settlement of the foundation and the number of piles incorporated can be computed easily.

1.3.1.2 Burland's Method (1995)

Burland (1995) developed a simplified process of design for the circumstances, where the piles reduces the settlement and are fashioned to develop their full geotechnical capacity at the design load. The procedure is as follows:

1) Evaluate the load-settlement relationship for the raft without piles (Fig.1.1). Total settlement S_0 is given by load P_0 .
2) Evaluate an admissible design settlement S_d, which includes a margin of safety.
3) P_1 is the load carried by the raft complementary to S_d.

4) It is assumed that the settlement-reducing piles carry the excess load $P_0 - P_1$. No factor of safety is applied because the shaft resistance of the piles will be fully mobilized. However, Burland introduces a "mobilization factor" of about 0.9 suggested to be applied to 'conservative best estimate' of ultimate shaft capacity, P_{su}.
5) The piled raft may be investigated as a raft on which reduced column loads act in the cases where the piles are positioned under the columns that carry a load in excess of P_{su}. At such columns, the reduced load Q_r is:

$$Q_r = Q - 0.9\,P_{su} \tag{1.6}$$

6) In order to compute bending moments in the raft, the piled raft can be evaluated as a raft subjected to the reduced loads Qr.
7) The method for investigating the settlement of the piled raft is not distinctly set out by Burland, but it is logical to calculate it with the help of approximate method as suggested by Randolph (1994) in which:

$$S_{pr} = S_r * K_r / K_{pr} \tag{1.7}$$

Where

S_{pr} = Piled raft settlement
S_r = Raft settlement, without piles subjected to the total applied loading
K_r = Raft stiffness
K_{pr} = Piled raft stiffness

1.3.2 APPROXIMATE COMPUTER METHODS

1.3.2.1 Strip on Springs Approach (GASP)

Poulos (1991) presented this method in which he used a computer program named GASP (Geotechnical Analysis of Strip with Piles) to analyze a problem as shown in Fig.1.2. In this approach, the raft is defined as a strip and the piles under the raft by springs. All four constituents of interaction (raft-raft elements, pile-pile, raft-pile, pile-raft) are taken into account in the study, and the effects of raft section outside the strip section being evaluated are taken into consideration by calculating the free-field soil settlements caused by these parts. These settlements are then assimilated into the investigation, and the strip section is studied to evaluate the moments and settlements due to the load applied on that strip section and the settlements of the soil due to the part outside the raft.

This method can take into consideration, the non-linearity of soil in an approximate manner by limiting the strip soil contact pressures to not outpace the bearing capacity (in compression) or the raft uplift capacity in tension. Similarly, the pile loads are limited not to excel the compressive and uplift capacities of the piles. However, the ultimate pile load capacities must be foreordained, and are usually assumed to be the similar to those of isolated piles. In reality, as shown by Katzenbach et al (1998), the load that is transmitted to the soil by the raft can have a constructive effect on the behaviour of the piles in the piled raft system. Thus, the assumptions involved in modelling the piles in the GASP method tend to be conservative.

In this method nonlinearity is considered in only one direction (the longer direction) and the behaviour of pile and raft in the other (shorter) direction is considered to be linear, when a nonlinear analysis of strips with two directions is to be carried out. This method avoids impractical yielding of the soil under the strip and hence leads to unrealistic settlement predictions.

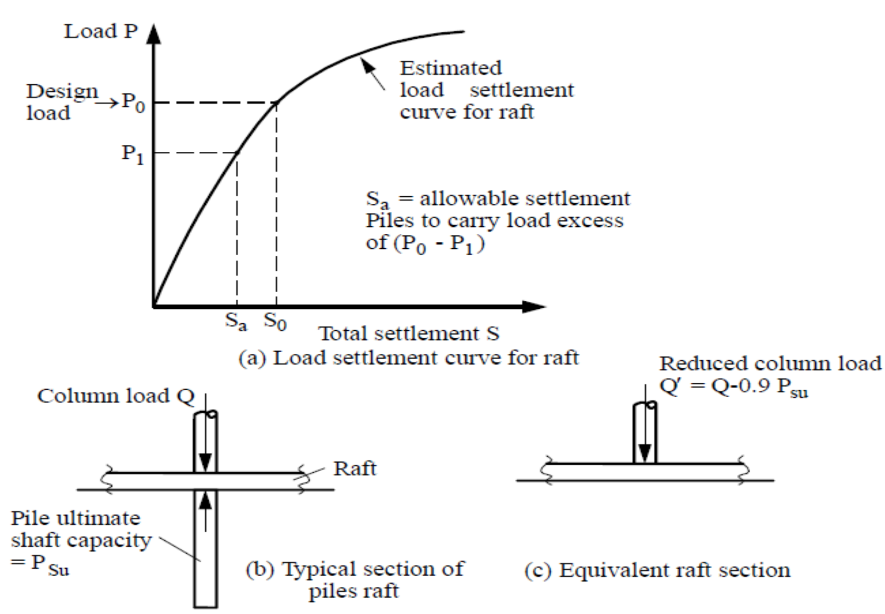


Fig. 1.1 Burland's simplified design concept (Burland,1995)

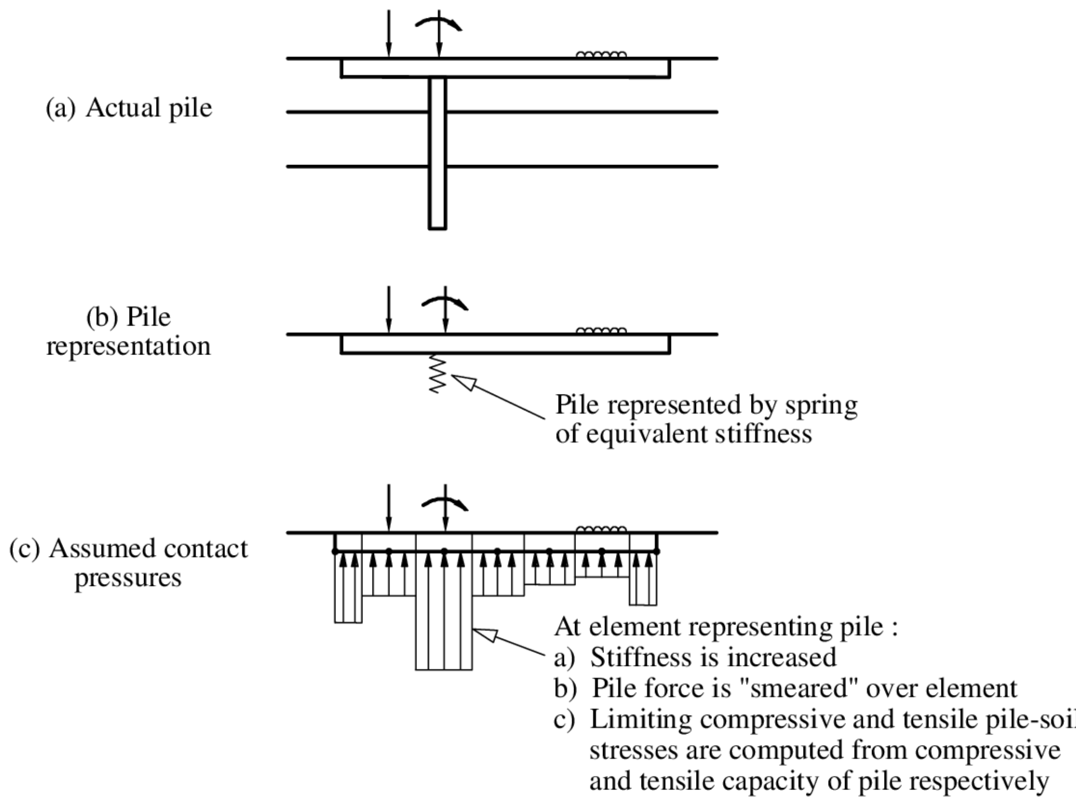


Fig. 1.2 Representation of piled strip problem via GASP analysis (Poulos, 1991).

1.3.2.2 Plate on Springs Approach (GARP)

In this method of investigation, the raft is simulated as an elastic plate, the soil is assumed to be an elastic continuum and the piles are modelled as interacting springs. A few of the early studies using this method undervalued some of the components of interaction and evaluated pile-raft stiffnesses that were too large.

Poulos in 1994 applied a finite difference method for the plate and various interactions using approximate elastic solutions were allowed. This method of investigation was implemented using a program GARP (Geotechnical Analysis of Raft with Piles). The effect of layered soil profile, the development of bearing capacity failure below the raft, piles reaching their ultimate capacity (in compression and tension), and the presence of free-field soil settlements acting on the foundation system were permitted. The approximations similar to those employed in the GASP for piled strips were made.

Russo (1998) and Russo and Viggiani (1997) have given a similar method, in which elastic theory has been used to obtain the interactions, and in order to contemplate the non-linear behaviour of the piles, a hyperbolic load-settlement curve for single piles is assumed. Pile-pile interaction is applied only to the elastic part of pile settlement, while the settlement of a pile that occurs due to the loading on that particular pile is assumed to be non-linear.

1.3.3 MORE RIGOROUS COMPUTER METHODS

1.3.3.1 Two – Dimensional Numerical Analysis

This method has been used for analysis by various researchers such as Desai (1974), Hewitt and Gue (1994) and Prakoso and Kulhawy (2001). In the former case, the FLAC computer program is used for modelling the piled raft, considering it to be a two-dimensional (plane strain) problem, or an axially symmetric three-dimensional problem. In both the cases, important approximations are required to be made, especially with respect to the piles, which must be "smeared" to a wall and given an equivalent stiffness equal to the total stiffness of the piles being represented. In such an analysis problem are experienced while representing concentrated loadings, since these must also be smeared. It may be crucial to carry out analyses for each of the directions in order to evaluate the settlement profile and the raft moments unless the problem involves uniform loading on a symmetrical raft. As with the plate on springs approach, this analysis cannot give torsional moments in the raft.

1.3.3.2 Three – Dimensional Numerical Analysis

A finite element analysis on a commercially available computer program such as FLAC 3D can be used to carry out a complete 3-D evaluation of a piled raft foundation system. This type of programs eliminates the requirement of making approximate assumptions implicit to all of the analyses mentioned above. Still some problems prevail, such as modelling of the pile-soil interfaces, and regarding the use of interface element.

CHAPTER 2

LITERATURE REVIEW

Poulos (2001) presented a design philosophy where piles are used as settlement reducers and discussed the circumstances in which this approach can be used. The study describes the designing of piled raft foundation as a three-step procedure. The first stage is the Preliminary stage is the one in which the influence of the number of piles on settlement and load capacity are examined. The second stage constitutes a further detailed evaluation to examine the positions where piles are needed to be placed and to get some idea about the piling requirements. The third stage is the step in which a detailed analysis is carried out to confirm the most favourable location and number of the piles. In this phase data required for the structural design of the foundation are also obtained. The study also discusses and demonstrates that an efficient foundation can be designed by using a major part (if not all) of the available capacity of the piles. The study concludes that using a large number of piles to boost the foundation performance helps only up to a certain limit, beyond which adding more piles leads to almost no further benefit.

Prakoso et al. (2001) examined the pile enhanced raft foundation known as piled raft foundation in order to introduce a more unified, displacement-based, design technique. Piled rafts were investigated using simplified linear elastic and nonlinear plane strain finite element models. The effects of geometries of raft and pile group system and the pile group compression capacity were examined on the average and differential displacements, bending moments developed in rafts, and pile butt load ratio of the piled rafts. The outcomes of the study were converted into an updated, displacement-based, design methodology for piled rafts. The important results that were obtained are that the pile group to raft width ratio and pile depth are the most important aspects of system geometry. A width ratio of about one is most adequate to minimize the average displacement, while a width ratio of about 0.5 is most effecient to minimize the differential displacement. An iteration process is used to determine the width ratio and pile depth to minimize both displacements

Mossallamy (2002) developed an improved numerical model which is based on a mixed technique of the Boundary Element Method (BEM) the Finite Element Method (FEM). In this study, data of various location such as high-rise buildings in Frankfurt, Torhaus Exhibition grounds, High-rise Building Westendstrasse I (DG Bank) were investigated and the results of the FEM and BEM were compared. The results of both the analysis are in good agreement with each other.

Novak et al. (2005) analyzed two piled-raft foundations using the Finite Element Method program. Comparisons were drawn between analytical and experimental results and the results obtained from the FEM analysis were excellent for the cases that were analyzed. The first case study was done on High-rise buildings in Frankfurt, Germany and the other one on a five storey building in Urawa City, Japan. The study shows that the application of a 3D finite-element method in the analysis of a composite foundation presents a feasible approach that have many advantages over simplified methods. The results from numerical and the experimental studies are in good agreement with each other and hence FEM analysis proves to be a good alternative for designing of the Piled Raft Foundations.

Liang et al. (2006) studied the way to achieve optimization by means of varied cushion rigidity. Fictitious pile model was used to set up the model of pile raft foundation for the analysis. The effect of cushion was taken into account by simulating the cushion with Winkler springs. The method given in this study is suitable for the analyses of the foundation under working loads and can also be used to solve problems of different rigidities of the piles and the cushion

Rabiei (2009) performed a parametric study to explore the effects of parameters like pile configuration, pile number, pile length and raft thickness on the performance of the piled raft foundation. This study shows that the maximum bending moment in raft increases with increase in the raft thickness, decrease in the number of piles and decrease in the pile length. The central and differential settlement of the foundation decreases with increase in raft thickness and uniform increase in pile length. It has also shown that pile configuration plays a very important role in designing of pile raft foundation. The study presents the results of the parametric study and the design strategies for piled raft foundation are discussed. The study concludes that Piled raft foundations have the potential to provide a safe and economical foundation systems, under the appropriate geotechnical conditions. The study also suggests that a design philosophy should be based on both ultimate load capacity and settlement criteria. The number of piles that should be placed below the raft to satisfy both the before mentioned criterions should be given more importance. The results outlined in this study can be used to assist the foundation designer in designing of piled raft foundation.

Sinha et al. (2016) carried out a 3D numerical analysis of a Piled Raft Foundation. In this study a 3-dimensional finite element model was created in ABAQUS to simulate the case of Piled Raft Foundation. This model was used to evaluate the effect of various key parameters such as geometry of the foundation, raft thickness, pile radius, spacing of the piles, pile shape etc. on the performance of the foundation. The effect of mechanical properties of the surrounding soil was also evaluated. The results were used to suggest some guidelines for an economical design of Piled Raft Foundation. The study concluded that the shape of the cross section of the piles does not have any effect on the results whereas a thicker raft can be used to minimize differential settlement. The study also shows that the settlement of the raft decreases with increase in angle of shearing resistance and cohesion of the soil.

Bhartiya et al. (2019) carried out a Systematic linear-elastic finite-element analyses on a series of pile groups, unpiled rafts (rafts without piles) and piled rafts with different pile configurations and geometries in order to obtain the stiffness of these rafts, pile groups, and piled rafts. In this study, various parametric studies were carried out in alliance with regression analysis and on the basis of these studies, equations were suggested for quick assessment of piled raft stiffness by combining the stiffnesses of rafts and pile groups. The average and maximum settlements of piled rafts were evaluated with the help of piled raft stiffness equations. The results obtained from numerical and experimental studies of piled rafts were used to verify and validate the effectiveness of the proposed stiffness and settlement equations. The study shows that the proposed equations can be used for obtaining a quick initial estimate of piled raft settlement which can be further used in designing. The developed settlement calculation method is suitable for piled rafts of shapes and sizes similar to those that have been considered in this study. The method of predicting PRF settlement given in this study can be really helpful for the practitioners to obtain a quick initial estimate of average settlement of PRF.

.

CHAPTER 3

METHOD AND WORKING

3.1 GENERAL

In this study a 3-dimensional finite element model was created in Midas GTS NX to simulate the case of Piled Raft Foundation and then the parametric analysis was carried out in order to examine the effects of various parameters such as pile configuration, raft thickness, cohesion of the soil and pile length on the performance of the foundation.

3.1.1 Midas GTS NX

Midas GTS NX is a finite element analysis software that is used for advanced geotechnical analysis of soil, rock deformation and rock stability. It is also used for analysis of groundwater flow, dynamic vibrations and soil-structure interaction in 2D and 3D. GTS NX is mainly used for analysis, testing, and design by geotechnical, mining, and civil engineers. The software has numerous advanced modeling functions which helps to model difficult and complex problems with unparalleled levels of ease and precision.

3.2 MODELLING OF PILED RAFT FOUNDATION

3.2.1 GEOMETRY

The first step of modelling includes the development of the geometry of the soil, raft and the piles. A soil mass of $20x20x20m^3$ and raft of $10x6m^2$ with thickness of 0.5 m are modeled using a 3D solid extrusion, the dimensions were taken from the problem statement as shown in Fig. 3.2. A 3x3 Pile configuration with pile length of 10m as shown in the figure are also modelled using the line and translate functions.

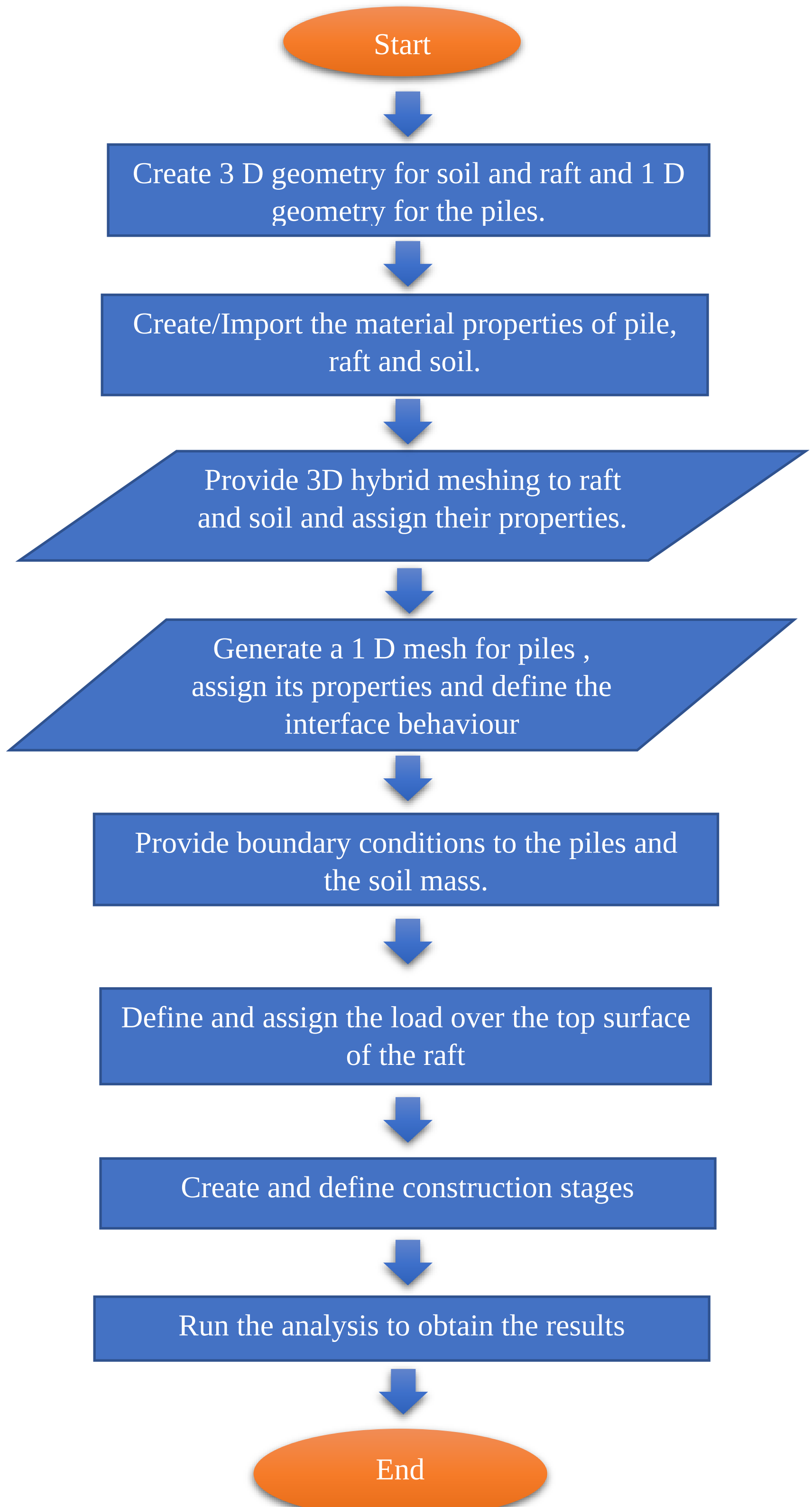


Fig. 3.1 Flowchart of the working in Midas GTS NX

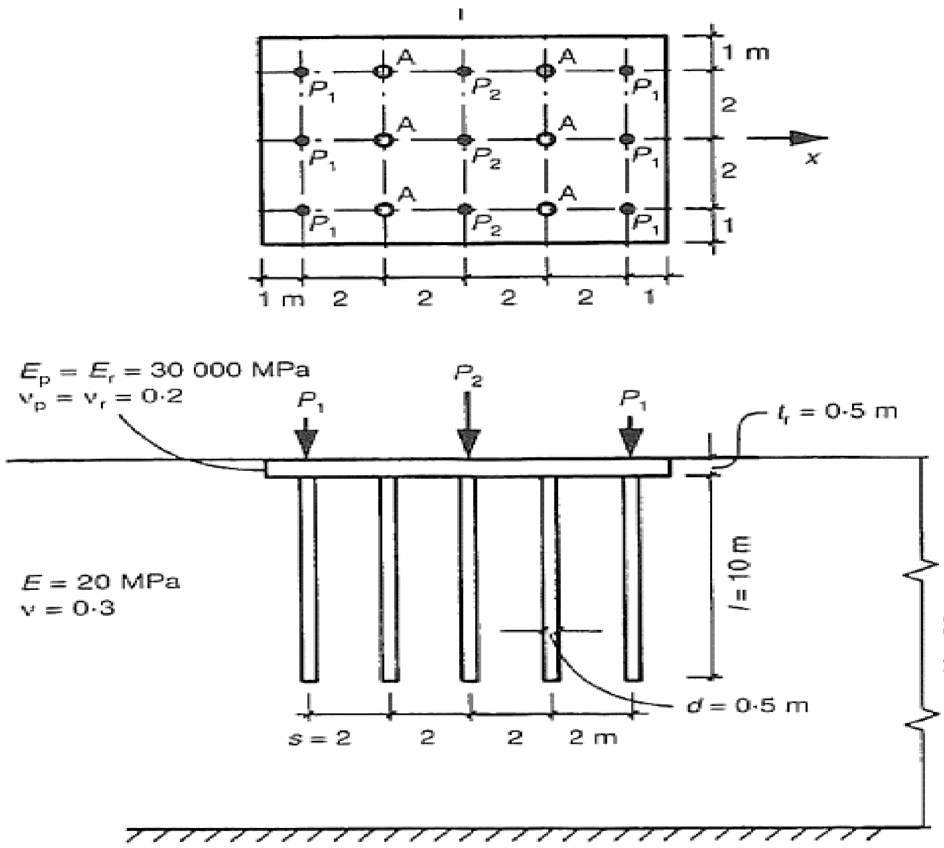


Fig.3.2 Piled raft model considered in the present analysis (Poulos, 2001)

3.2.2 MATERIAL PROPERTIES

After the geometry is developed the next step is to define the material properties whose values have been shown in Table 3.1. The soil is modelled as a Mohr Coulomb soil while the raft is assigned isotropic properties. The piles are modelled as 1 D elements.

3.2.3 MESH GENERATION

A three-dimensional hybrid mesh of size 0.5 is generated for both soil and the raft. For piles, 1 D fine meshing with division equal to 1 is generated and pile to soil interface property and pile tip properties are defined. Hybrid mesher is a feature provided in GTS NX in which combination of hexahedral and tetrahedral elements is incorporated. The main benefit of using a hexahedron element is that they provide stress results which are comparatively more accurate than tetrahedral elements, and the leverage of using tetrahedral elements is that they are more effective for modeling sharper curves and corners of complex geometry. GTS NX take advantage of both tetrahedral and hexahedron elements in the form of hybrid mesher without any major loss in modeling or analysis speed.

SERIAL NO.	List of Parameters	
	Parameters	**Values**
1	Pile length, L_P(m)	10.00
2	Pile radius, r_P (m)	0.25
3	No of piles, n_p	9.00
4	Raft length, L_r(m)	10.00
5	Raft width, B_r(m)	6.00
6	Raft thickness, T_r(m)	0.50
7	Poisson's ratio of soil (√)	0.30
8	Young's modulus of raft, E_r (MN/m^2)	30000.00
9	Young's modulus of pile, E_p (MN/m^2)	30000.00
10	Young's modulus of soil E_{soil} (MN/m^2)	20.00
11	Total applied load, P (MN)	12.00
12	Pile group efficiency, η_g (%)	80.00
13	Bearing capacity of soil, Q_U (kN/m^2)	300.00

Table 3.1 Material properties and parameters for the study (Poulos,2001)

3.2.4 ANALYSIS

Boundary conditions are applied to the piles and the soil mass. Piles are restricted to displace in only z- direction while auto mode provides the suitable boundary condition to the soil mass. The load is applied on the top surface of the raft and then stage sets are defined in order to carry out the construction stage analysis of the model. The construction stage analysis is allowed to run and results are obtained after the analysis is completed.

3.2.5 OBSERVATION

Fig. 3.3 shows the displacement of raft in z direction when a load of 12MN was applied on the piled raft foundation modelled as per the above-mentioned problem statement. It can be seen that the settlement of the center of the raft is coming out to be 38.8mm.

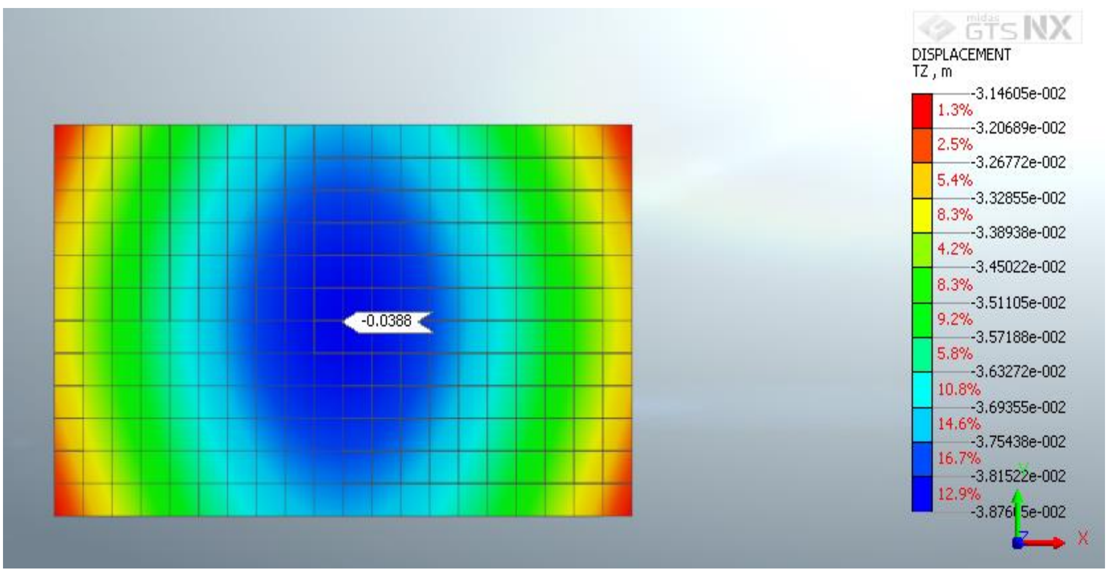


Fig. 3.3 Settlement of the raft in z -direction under a load of 12MN

3.2 MODEL VALIDATION

In order to validate the results, the report presented by The Technical Committee on piled foundation (Poulos 2001) was taken into consideration. The report summarizes the results obtained by Poulos-Davis-Randolph (PDR), Geotechnical Analysis of Raft with Piles (GARP5), Geotechnical Analysis of Strip on Piles (GASP), FLAC 2D and FLAC 3D simulation as shown in the Table 3.2. Same model as shown in Fig. 3.2 was modelled in Midas GTS NX., the material properties used in the analysis are summarized in Table 3.1. It can be noted that there is a good agreement of results obtained in the study with the results of PDR, GARP5 and GASP.

Method	Central Settlement mm	Corner Pile Settlement mm	Maximum Raft Moment MNm/m	Percentage of Load Taken by Piles
Poulos-Davis-Randolph	36.8	-	-	77.0
GARP5	34.2	26.0	0.684	65.1
GASP	33.8	22.0	0.563	65.5
Burland	33.8	29.7	0.688	65.5
FLAC 2-D	65.9	60.5	0.284	79.5
FLAC 3-D	39.9	35.8	(see below)	58.2
-moments directly from output stresses			0.326	
-moments from extrapolated stresses			0.421	
-moments from displacements			0.484	

Table 3.2 Summary of Computed Piled Raft Behaviour for Total Load = 12 MN {A Report Prepared on Behalf of Technical Committee TC18 on Piled Foundations (Poulos,2001)}

It can be very well observed that the settlement obtained by analysis of the same piled raft model in Midas GTS NX gives a settlement of 38.8mm which is in good agreement with the results summarized in the report as shown in Table 3.2

CHAPTER 4
RESULTS AND DISCUSSIONS

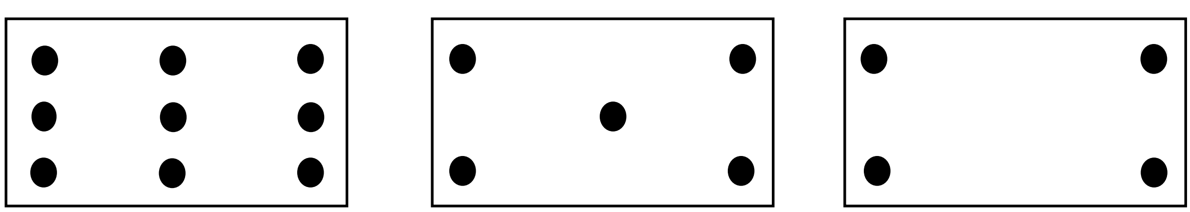
4.1 PARAMETRIC STUDY

The parameters study was carried out by varying different parameters such pile configuration, raft thickness, cohesion of the soil and pile length so as to study their effect on the performance of the piled raft foundation.

4.1.1 EFFECT OF PILE CONFIGURATION

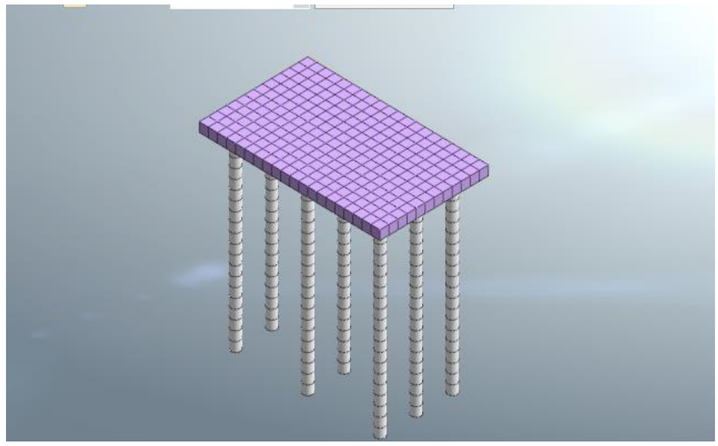
Three different pile configurations were modelled and analyzed to see the effect of pile configuration on the settlement behaviour.

In pile configuration 1, a pile raft system with 3x3 pile is modelled as shown in Fig. 4.1(a). Pile configuration 2 has a pile system in which four piles are placed at the corners of the raft and one at the center (Fig. 4.1(b)) and lastly, Pile configuration 3 has piles placed at the four corners of the raft (Fig. 4.1(c)) with uniformly distributed load acting over the raft. All three pile configurations are analyzed at three different loads 5 MN, 12 MN and 15 MN. Material properties remains same as mentioned in Table3.1.

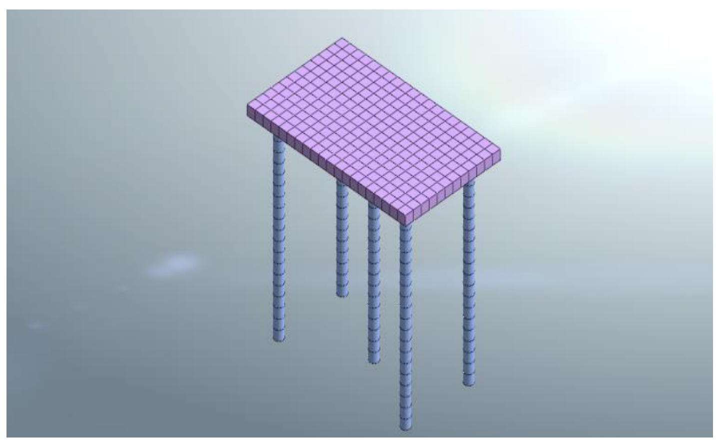


(a) (b) (c)

Fig. 4.1 Pile configurations - (a) Pile configuration 1 (b) Pile configuration 2 (c)Pile configuration 3



(a)



(b)

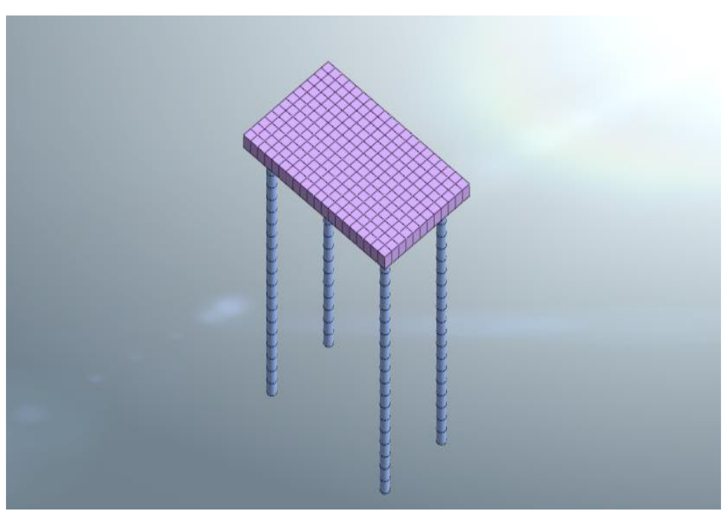


Fig. 4.2 Pile configurations - (a) Pile configuration 1 (b) Pile configuration 2 (c)Pile configuration 3 in Midas GTS NX

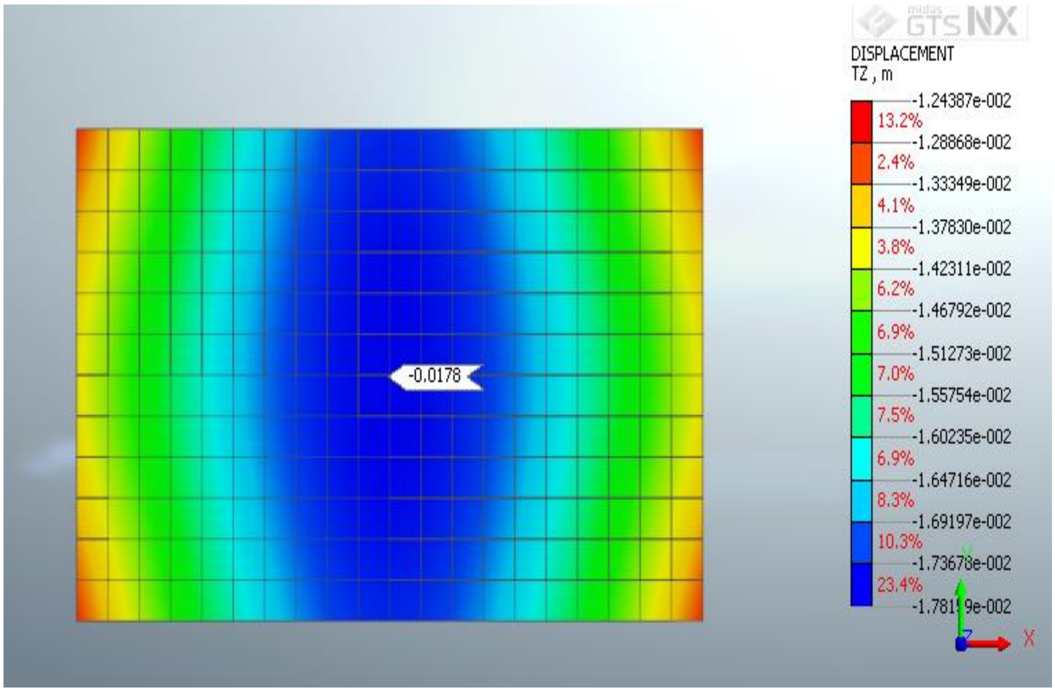


Fig. 4.3 Settlement in pile configuration 1 at a load of 5MN.

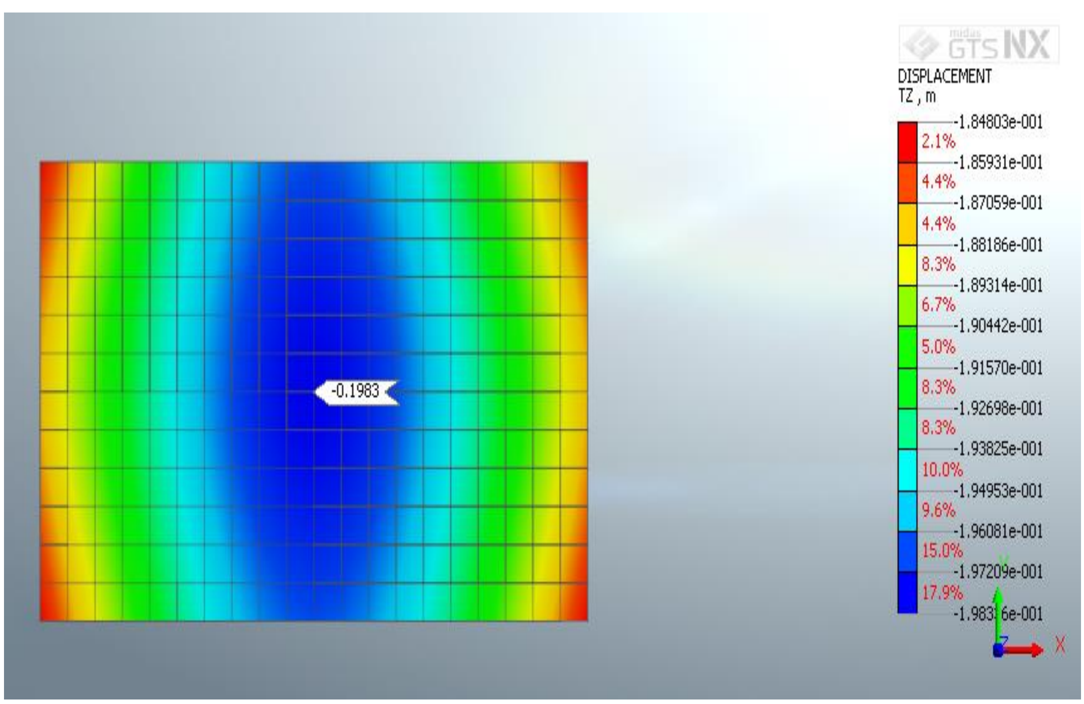


Fig. 4.4 Settlement in pile configuration 2 at a load of 5MN.

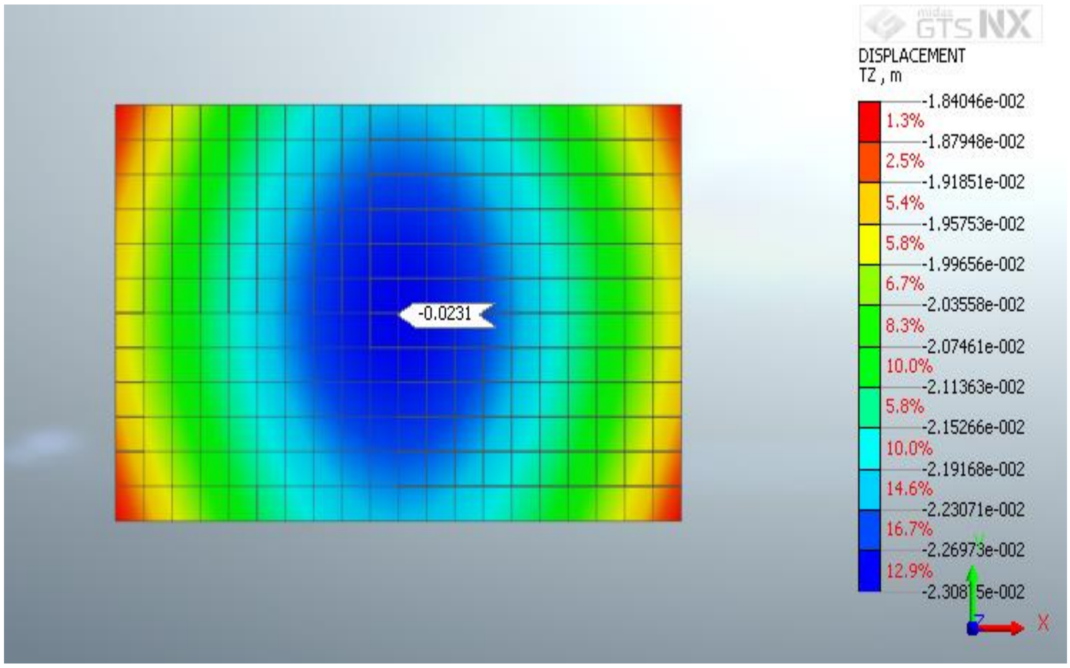


Fig. 4.5 Settlement in pile configuration 3 at a load of 5MN.

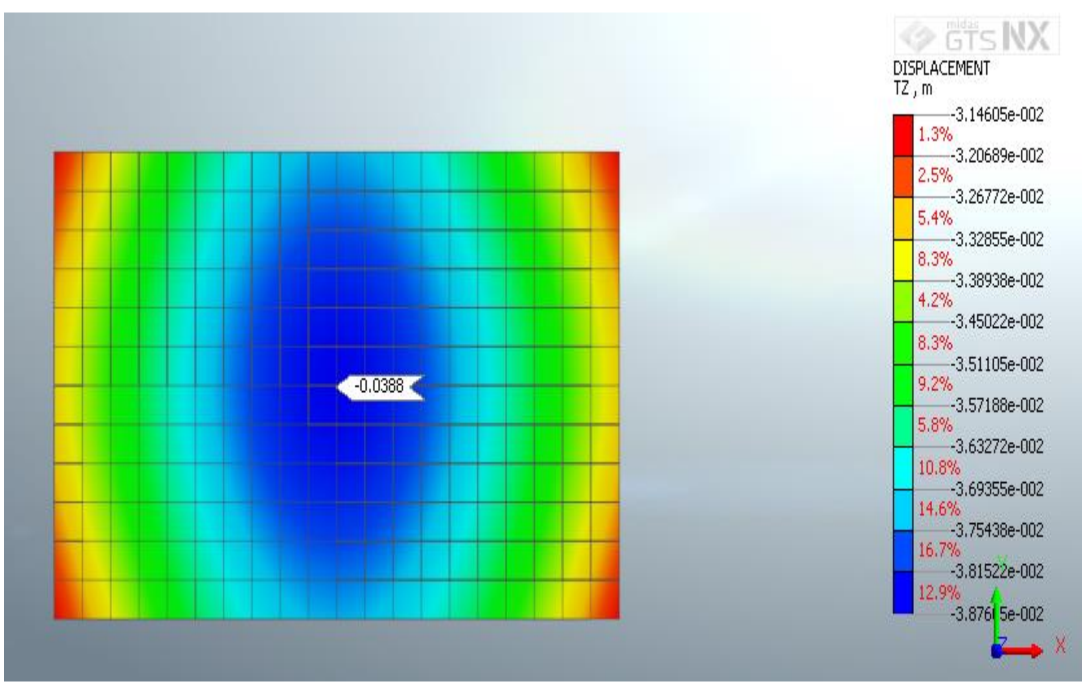


Fig. 4.6 Settlement in pile configuration 1 at a load of 12MN.

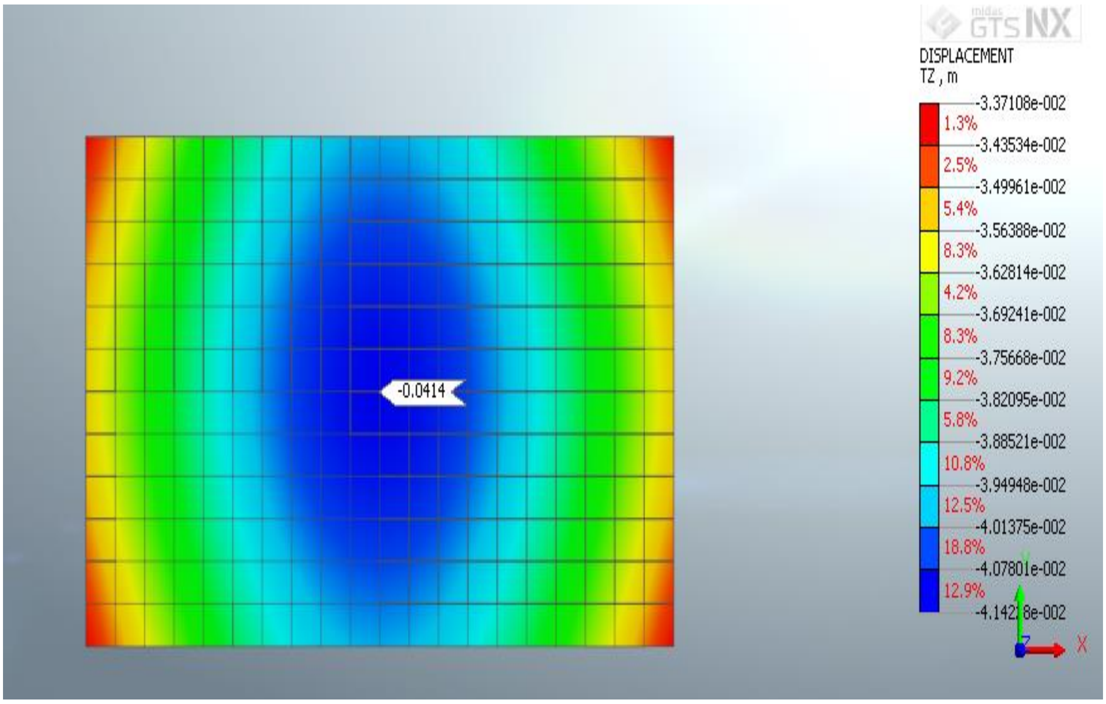


Fig. 4.7 Settlement in pile configuration 2 at a load of 12MN.

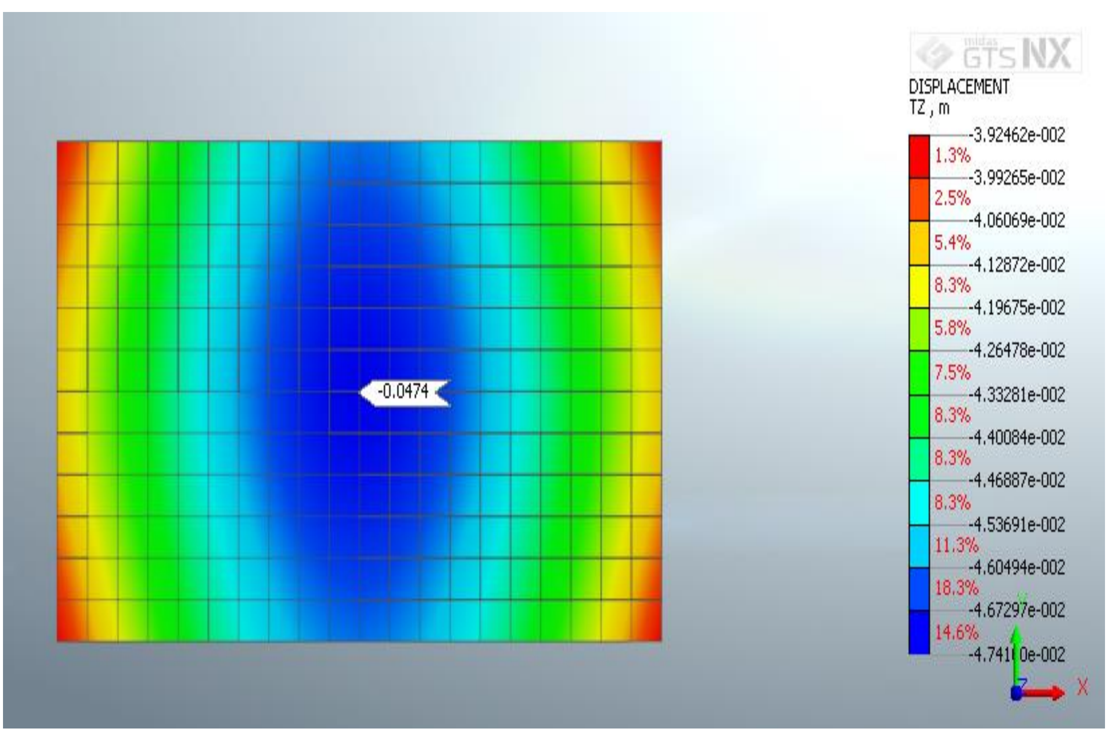


Fig. 4.8 Settlement in pile configuration 3 at a load of 12MN.

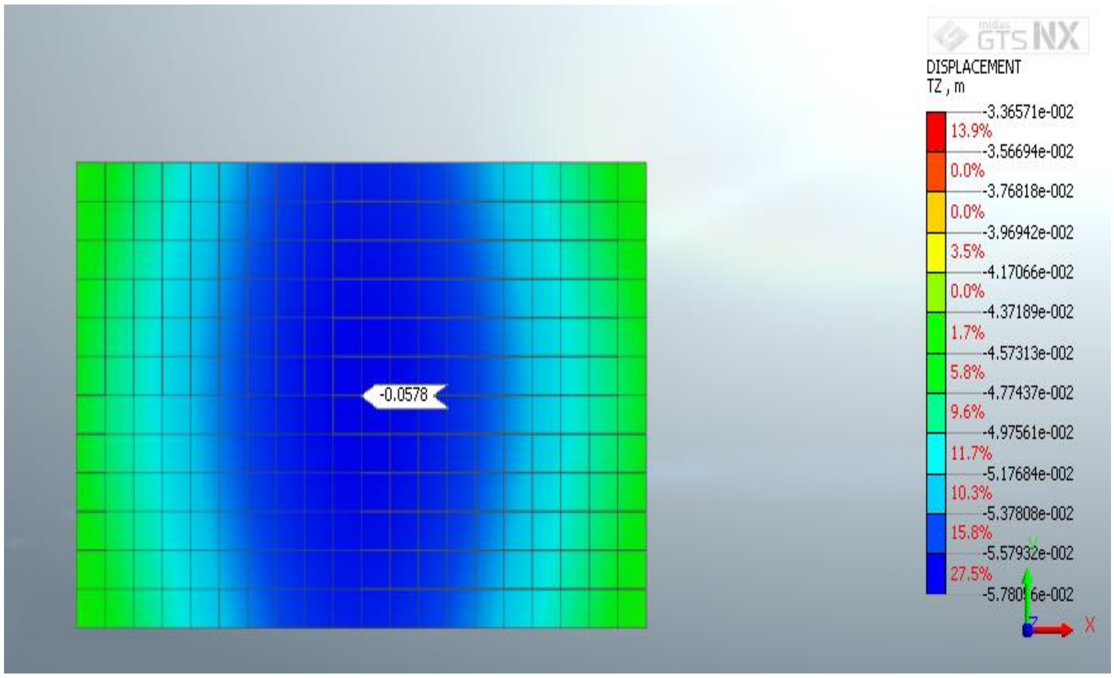


Fig. 4.9 Settlement in pile configuration 1 at a load of 15MN.

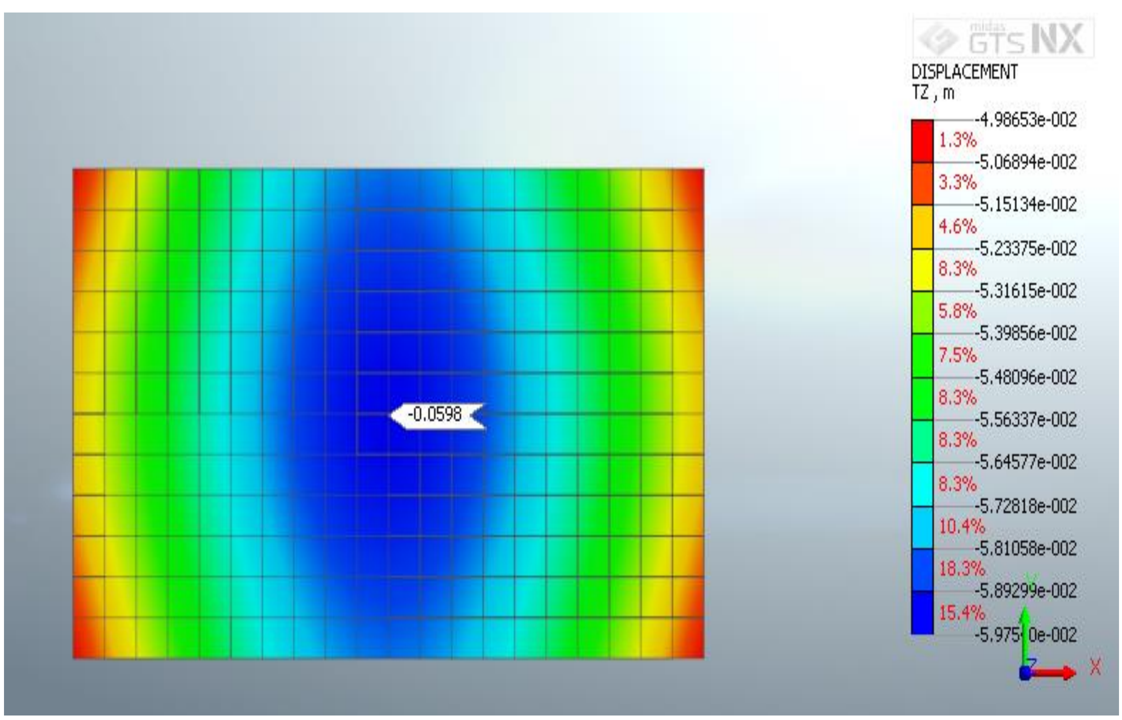


Fig. 4.10 Settlement in pile configuration 2 at a load of 15MN.

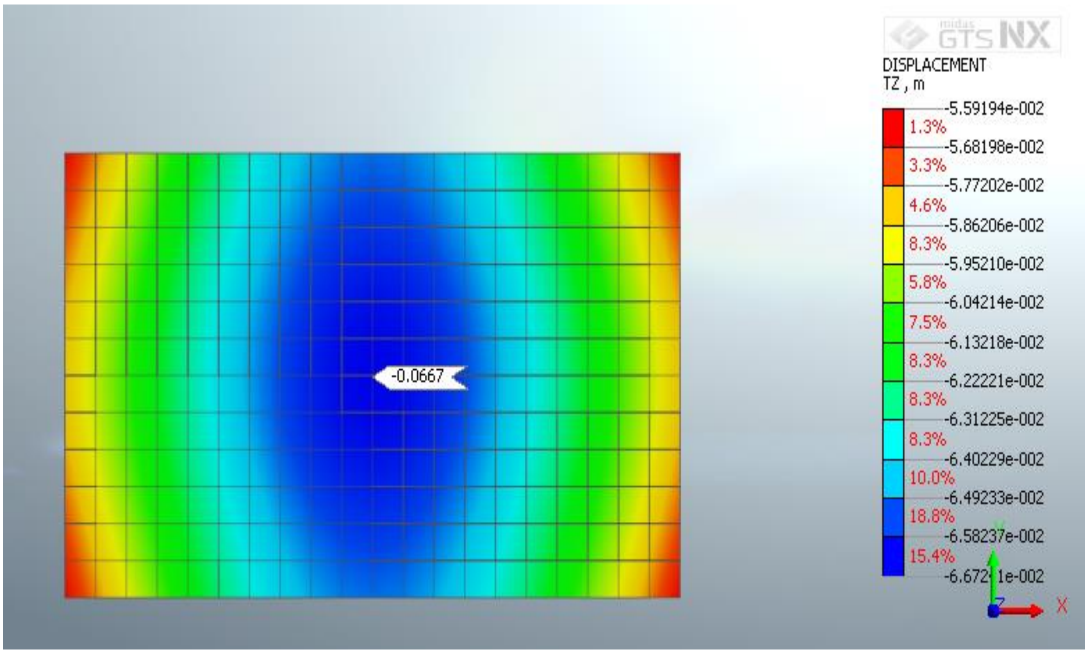


Fig. 4.11 Settlement in pile configuration 3 at a load of 15MN.

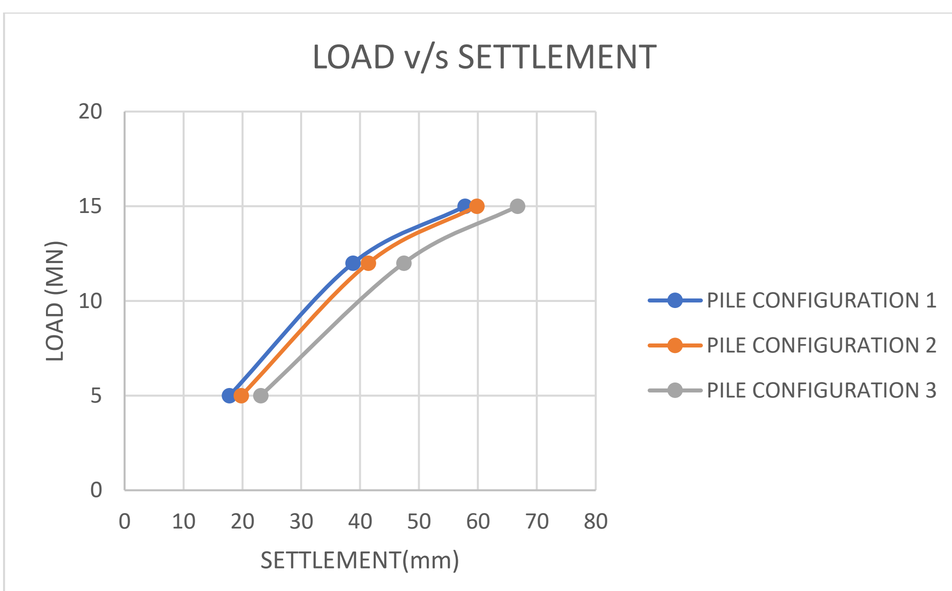


Fig. 4.12 Graph between settlement and load for different pile configurations

4.1.2 EFFECT OF RAFT THICKNESS

The piled raft configuration 1 was taken into consideration having standard values of pile length, pile radius, pile spacing etc. as mentioned in Table 3.1. The effect of raft thickness on the settlement was investigated by varying values of raft thickness from 0.5 to 2m.

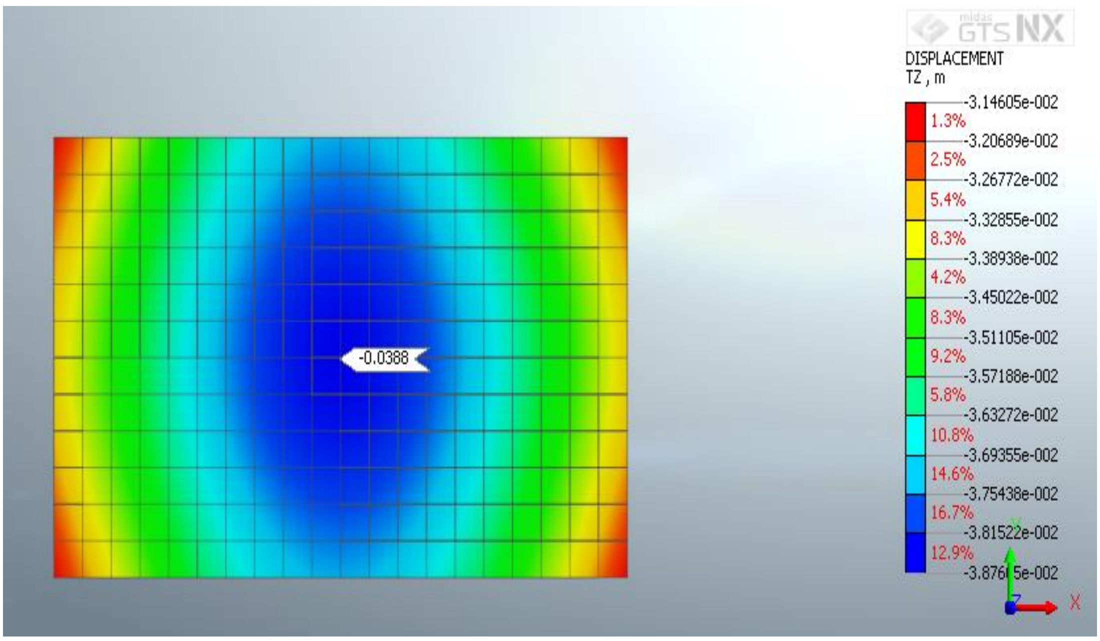


Fig. 4.13 Settlement of raft of thickness 0.5m at a load of 12MN

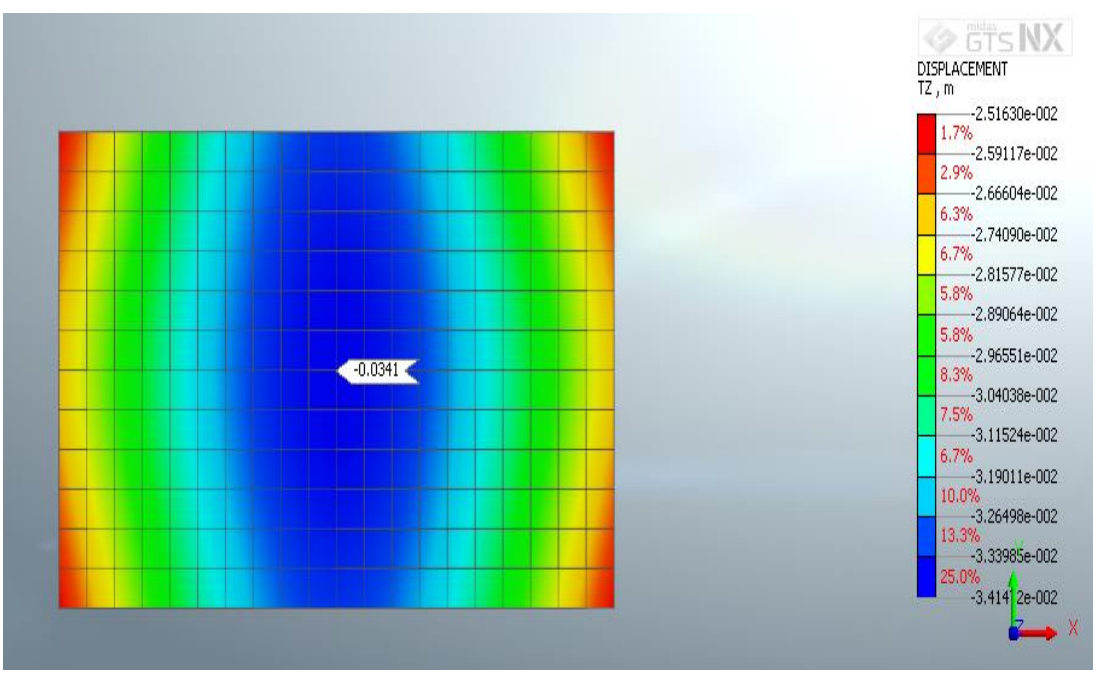


Fig. 4.14 Settlement of raft of thickness 0.70m at a load of 12MN.

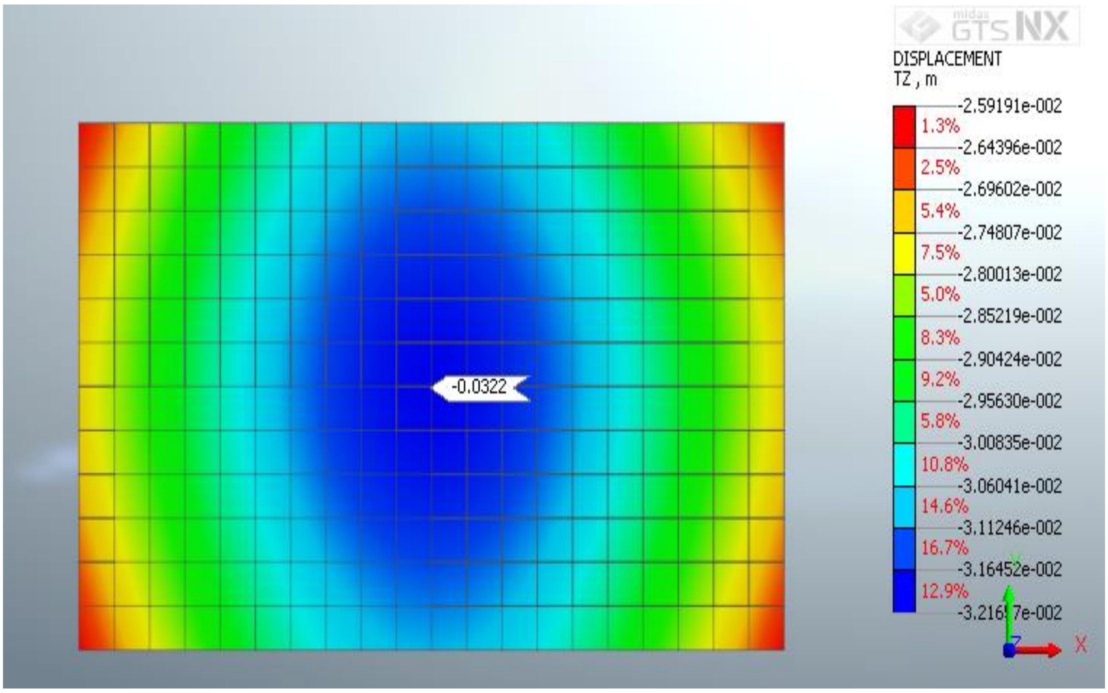


Fig. 4.15 Settlement of raft of thickness 1m at a load of 12MN.

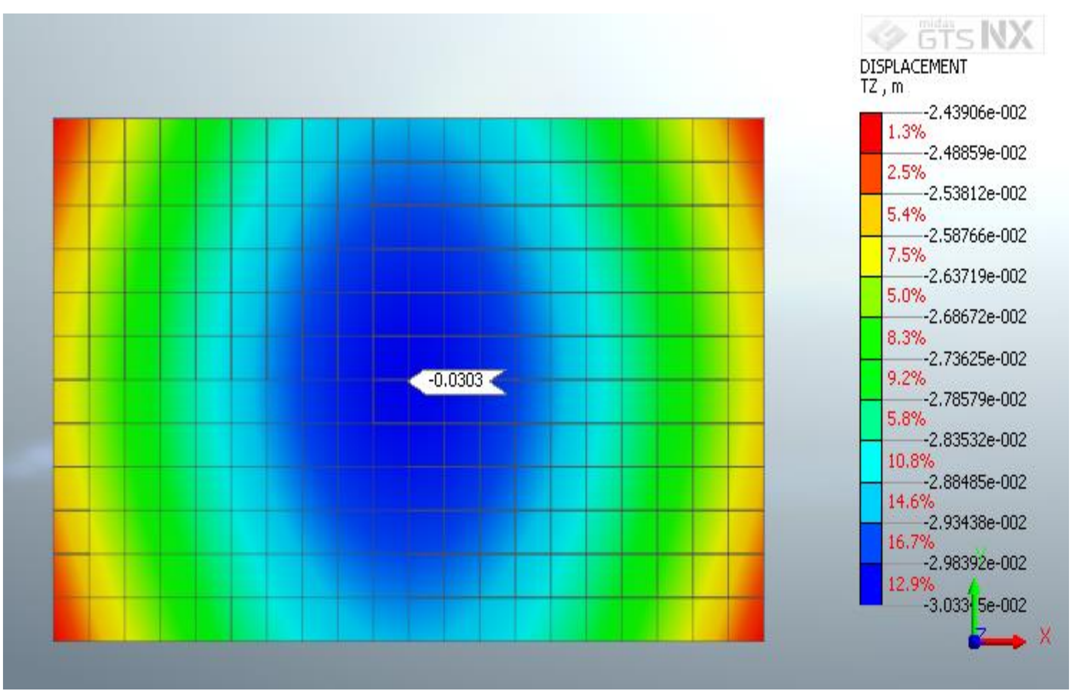


Fig. 4.16 Settlement of raft of thickness 1.5m at a load of 12MN.

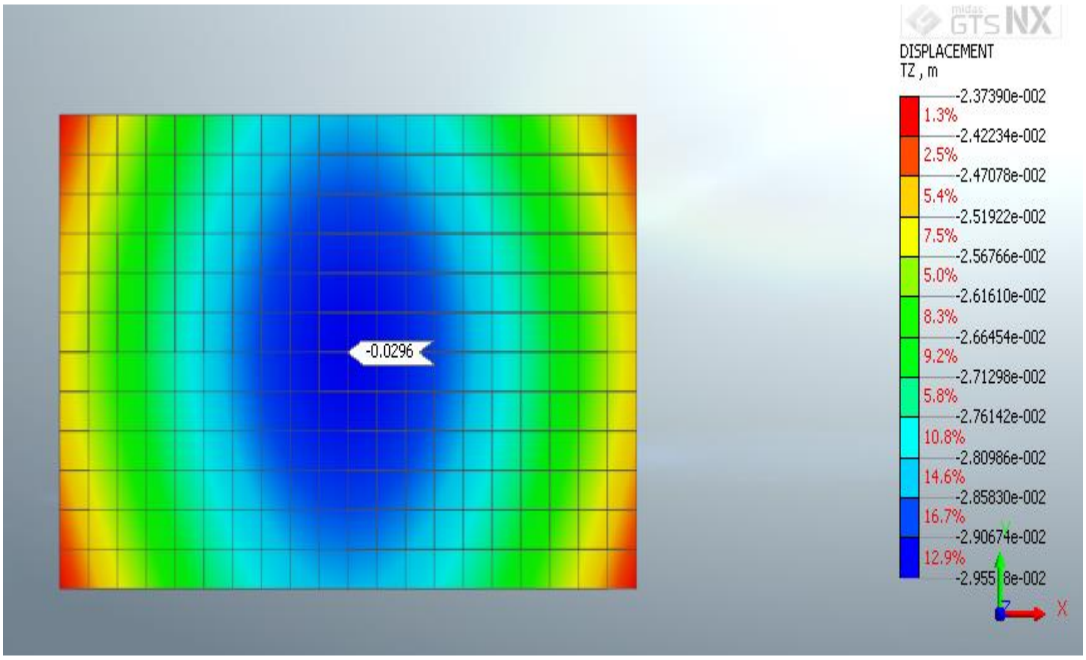


Fig. 4.17 Settlement of raft of thickness 2m at a load of 12MN.

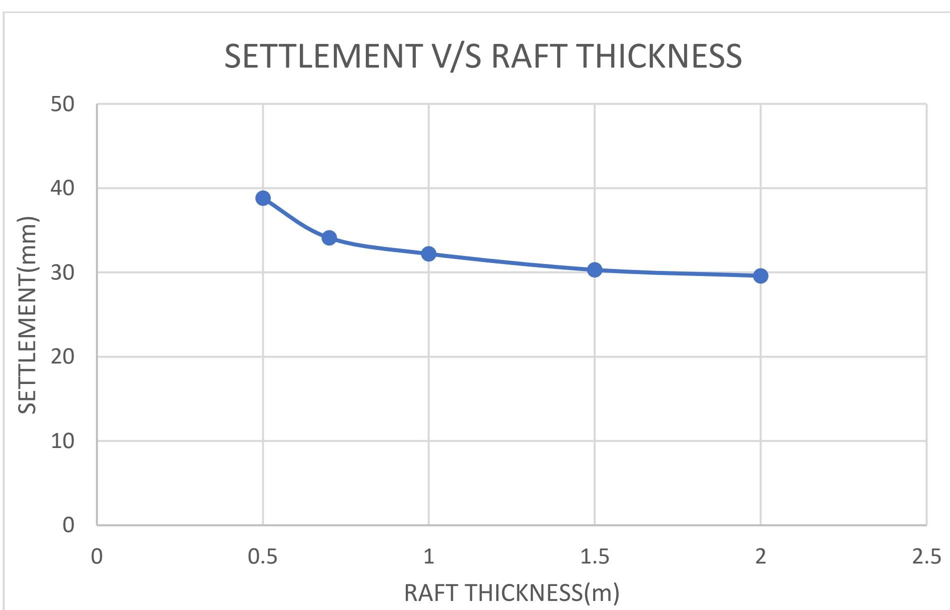


Fig. 4.18 Graph between settlement and raft thickness

4.1.3 EFFECT OF COHESION

Pile configuration 1 was analyzed for different values of cohesion of the soil and its effect on the overall settlement was investigated. The values of the cohesion that are considered in the study are 10, 30 and 40 kN/m^2.

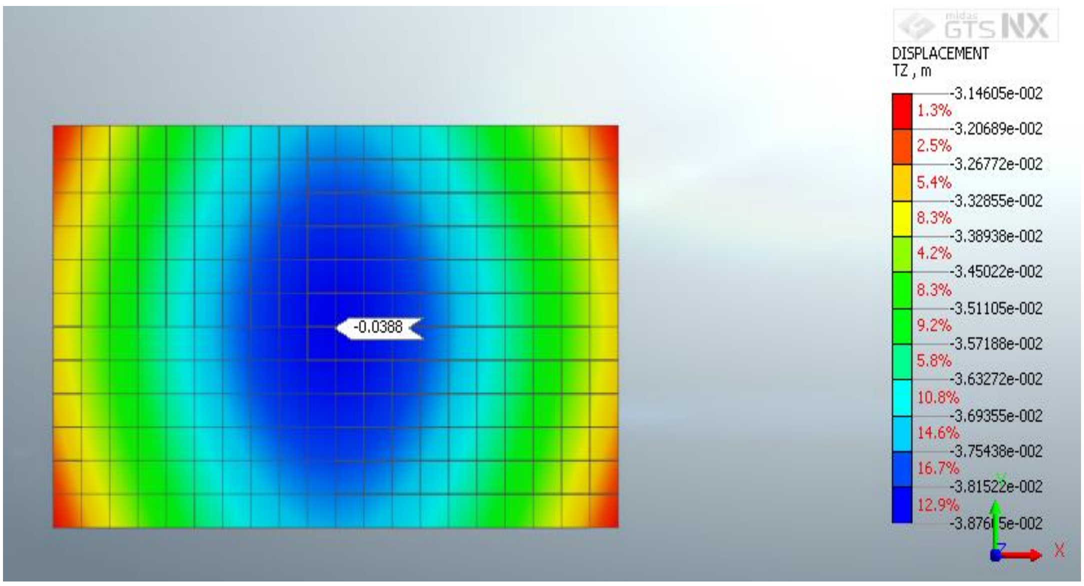


Fig. 4.19 Settlement of raft in soil with cohesion =10 kN/m^2 at a load of 12MN.

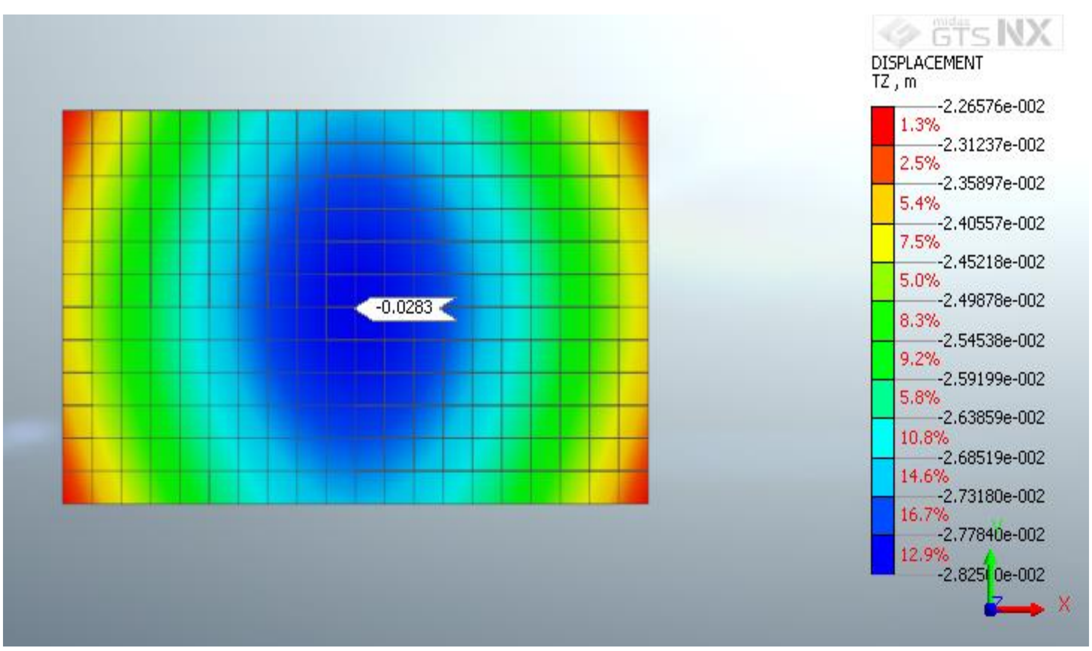


Fig. 4.20 Settlement of raft in soil with cohesion =30 kN/m^2 at a load of 12MN.

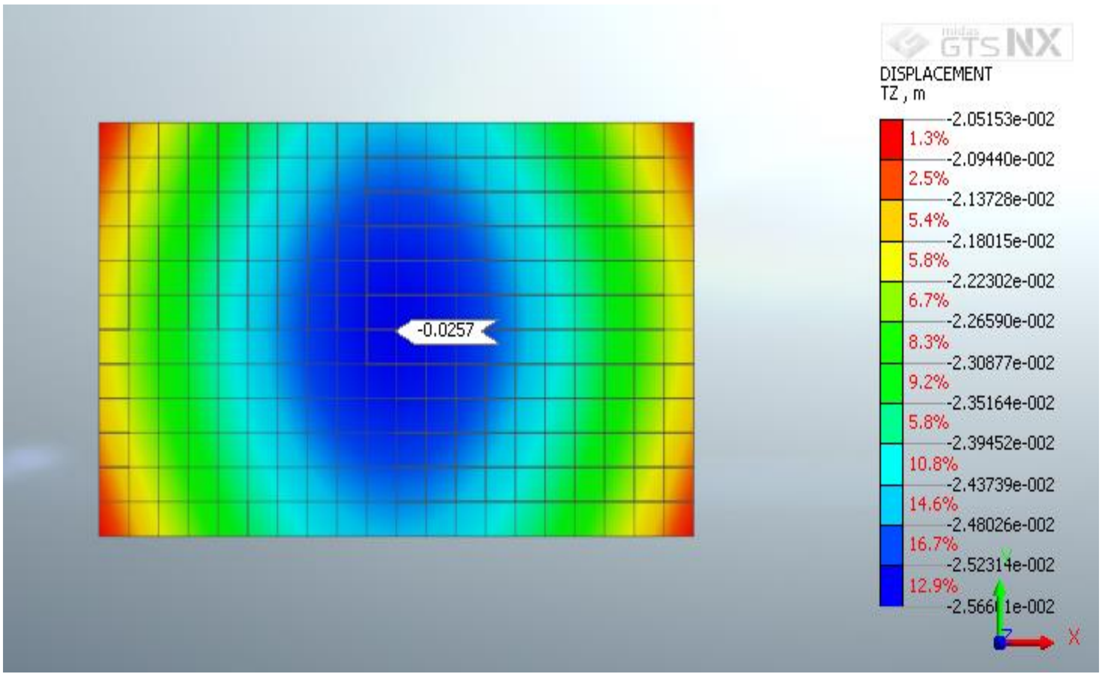


Fig. 4.21 Settlement of raft in soil with cohesion =40 kN/m^2 at a load of 12MN.

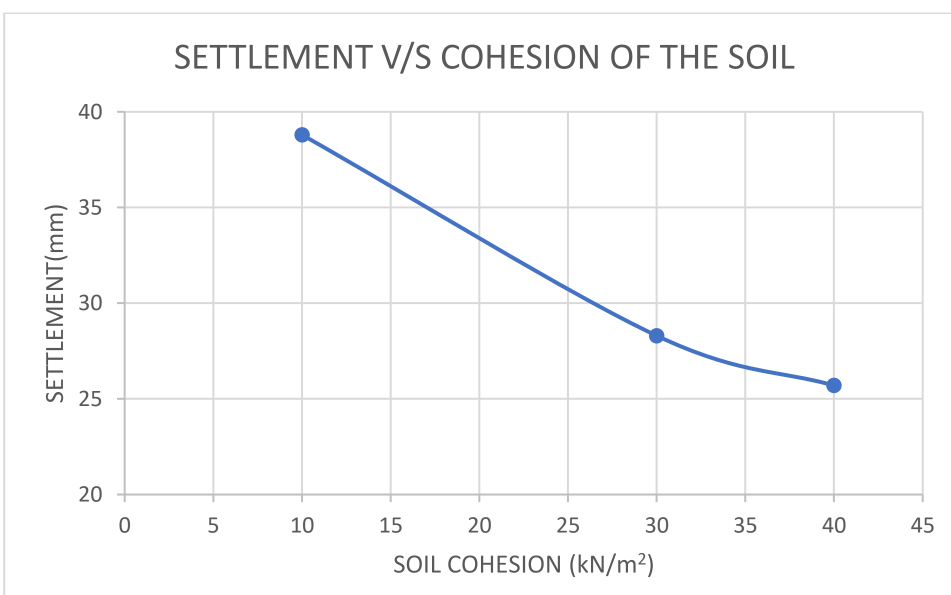


Fig. 4.22 Graph between settlement and cohesion of the soil

4.1.4 EFFECT OF PILE LENGTH

The effect of pile length on the settlement was investigated by varying the length of the pile in pile configuration 1. The three lengths that were considered in the investigation are 5, 10 and 15m.

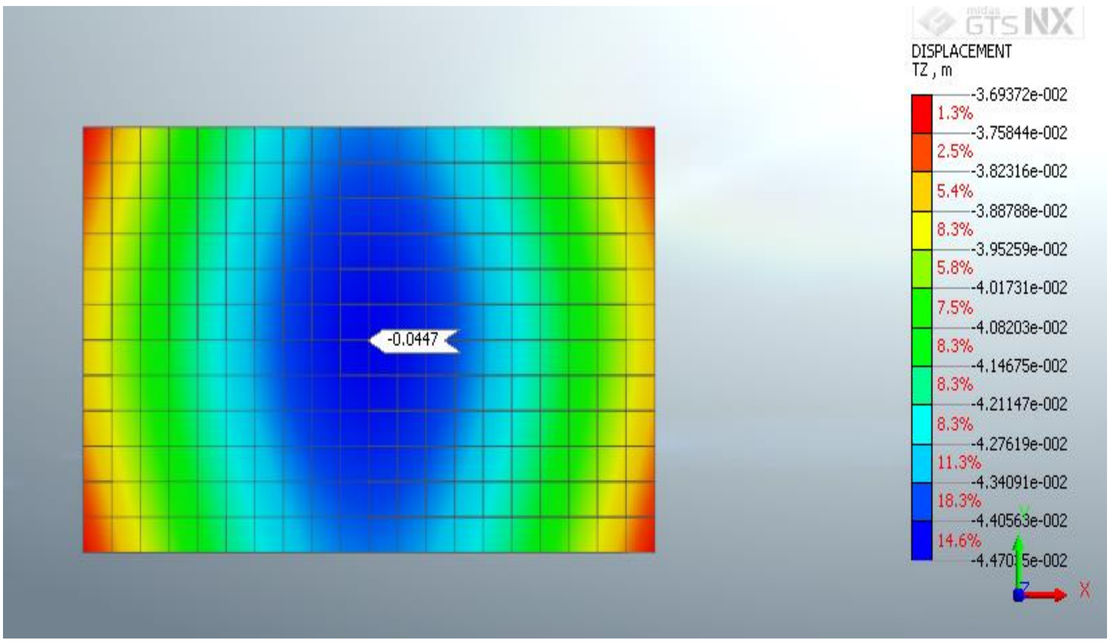


Fig. 4.23 Settlement of raft when pile length =5m at a load of 12MN.

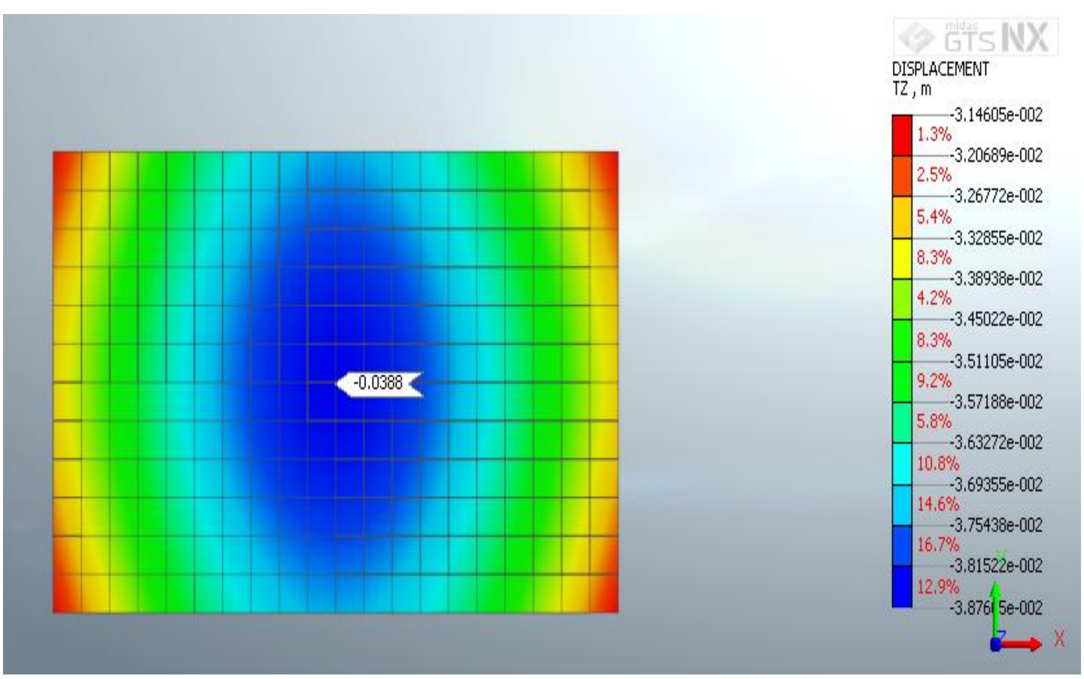


Fig. 4.24 Settlement of raft when pile length =10m at a load of 12MN.

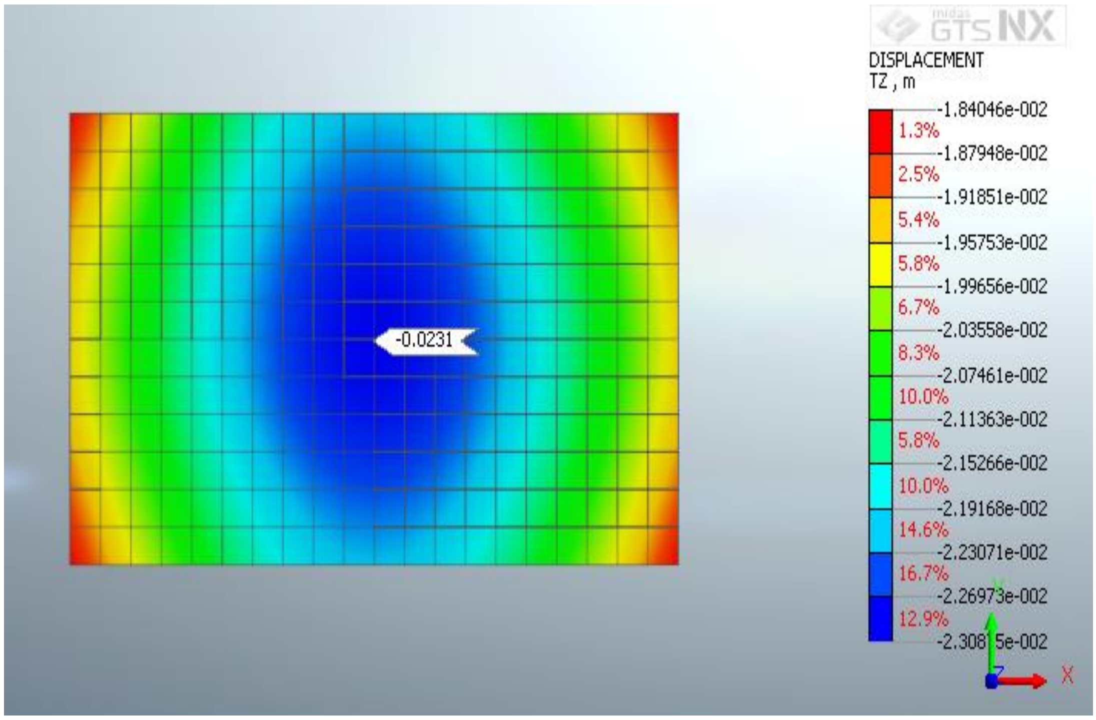


Fig. 4.25 Settlement of raft when pile length =15m at a load of 12MN

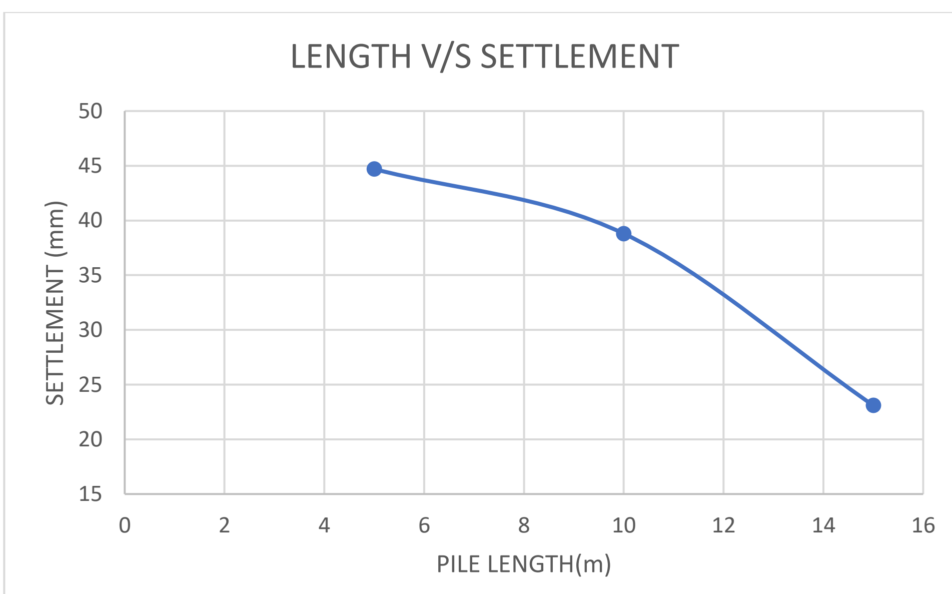


Fig. 4.26 Graph between Pile length and the settlement

CONCLUSION

1.The study shows that when the pile length is increased, there is a marked decrease in the settlement of the piled raft foundation. When the pile length is increased from 5m to 10m, a decrease of approximately 13% is observed in the settlement of the raft while the percentage decrease in settlement increases (approximately 40%) as we further increase the pile length as concluded from Fig.4.26.

2. The study shows that as we increase the number of piles in different configurations, the settlement of the piled raft foundation is reduced as can be seen in Fig. 4.12. But using a large number of piles is not always beneficial from economical point of view. Pile configuration 1 and 2 shows little difference in settlements so, we can use the configuration with lesser number of piles in such cases to make the structure economical.

3.From the above discussion, it can be concluded that the increase in raft thickness from 0.5m to 0.7m showed a significant decrease in the settlement from 38.8mm to 34.1mm (approx. 12%) but as the raft thickness is further increased the decrease in settlement became insignificant as observed in Fig. 4.18. So, it would not be economical to increase raft thickness in order to reduce the settlement of the PRF.

4.As the cohesion of the soil increases, the settlement of the raft decreases which can be observed in Fig. 4.22. In this study settlement against three values of cohesion i.e. 10,30 and 40 kN/m^2 were evaluated.

.

FUTURE SCOPE OF WORK

The work in this project is limited to parametric study of piled raft foundation in Mohr -Coulomb soil, in future research plastic nature of soil can be taken into consideration.

Variation in the shapes of cross section of piles and the pile material can also be done to check the effect on the performance of the foundation.

The scope of the research in this field is very vast, at present a very basic study has been done and it will be continued to explore other corners of design aspects to provide a sustainable ecofriendly foundation system in field of civil engineering

REFERENCES

[1] Poulos, H. G., “Piled raft foundations: Design and applications.” Geotechnique 51 (2): 95–113, 2001.

[2] Poulos, H. G., Small, J. C., Ta L. D., Sinha J., and Chen L., “Comparison of some methods for analysis of piled rafts.” In Vol. 2 of Proc., 14th ICSMFE, 1119–1124. Rotterdam, Netherlands: A.A. Balkema, 1997.

[3] Poulos, H. G., and Davis E. H., “Pile foundation analysis and design.” New York: Wiley, 1980.

[4] Randolph, M. F., “Design methods for pile groups and piled rafts.” In Proc., XIII ICSMFE, 61–82. Rotterdam, Netherlands: A.A. Balkema, 1994.

[5] Clancy P., Randolph M. F., “An approximate analysis procedure for piled raft foundations.” Int. J. Numer. Anal. Geomech. 17 (12): 849–869, 1993.

[6] Burland J. B., “Piles as settlement reducers.” In Vol. 2 of Proc., 19th Italian National Geotechnical Congress, 21–34. Padova, Italy: SF Editoriali,1995.

[7] Poulos, H. G., “Foundation economy via piled-raft systems.” Proc., Keynote Paper of Pile Talk Int. 91, 97–106. Kuala Lumpur, Malaysia,1991.

[8] Katzenbach, R., Arslan, U., Moormann, C., and Reul, O., “Piled raft foundation—Interaction between piles and raft.” In Vol. 4 of Darmstadt geotechnics, 279–296. Darmstadt, Germany: Darmstadt Univ. of Technology, 1998.

[9] Poulos, H. G., “An approximate numerical analysis of pile-raft interaction.” Int. J. Numer. Anal. Methods Geomech. 18 (2): 73–92,1994.

[10] Russo, G., “Numerical analysis of piled rafts.” Int. J. Numerical Analysis. Methods Geomech. 22 (6): 477–493, 1998.

[11] Russo, G., and Viggiani, C., “Factors controlling soil-structure interaction for piled rafts.” Darmstadt Geotech. 2 (4): 297–321,1997.

[12] Desai, C.S., “Numerical design analysis for piles in sands.” J. Geotech. Eng. Div. 100 (GT6): 613–63, 1974.

[13] Prakoso, W. A., and Kulhawy, F. H., “Contribution to Piled Raft Foundation Design.” J. Geotech. Geoenviron. Engg. 2001.127:17-24: ASCE, 2001.

[14] El-Mossallamy, Y., “Innovative application of piled raft foundation in stiff and soft subsoil.” ASCE Conf. on Deep Foundations, 2002.

[15] Novak, L.J., Reese, L.C., and Wang, S.T., “Analysis of Pile-Raft Foundations with 3D Finite-Element Method.” Structures Congress, New York, United States: ASCE, 2005.

[16] Liang, F., and Chen, L., “Optimization of composite Piled Raft Foundation with varied rigidity of cushion.” Foundation Analysis and Design: Innovative Methods (GSP 153): ASCE, 2006.

[17] Rabiei, M., “Parametric study for piled raft foundations.” Electron. J. Geotech. Eng. 14: 1–11. Randolph, M. F. 1994. “Design methods for pile groups and piled rafts.” In Proc., XIII ICSMFE, 61–82. Rotterdam, Netherlands: A.A. Balkema, 2009.

[18] Sinha, A., and Hanna, A. M., “3D Numerical Model for Piled Raft Foundation.” Int. J. Geomech., 04016055: ASCE ,2016.

[19] Bhartiya, P., Chakraborty, T., and Basu, D., “Settlement Estimation of Piled Rafts for Initial Design**.”** J. Geotech. Geoenviron. Eng., 2020,146(2):04019127: ASCE, 2019.

[20] Poulos, H. G., “Methods of analysis of piled raft foundations.” TC 18 Rep., International Society of Soil Mechanics and Geotechnical Engineering, London, 2001