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Parametric Study of Pile-Raft foundation System Using PLAXIS-3D

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Abstract: The growth of urban infrastructure has forced the introduction of tall buildings under any subsoil condition. Many a times, Pile foundation becomes an absolute choice causing increased cost of construction. In such situations, Pile-raft foundation can be a convenient alternative, wherein, the raft also contributes towards a part of the load transfer and hence number of piles required to transfer the remaining portion of load can be reduced. Thereby, the total foundation cost can be reduced leading towards sustainable solution. Many tall towers across the globe (example Petronas Tower in Kualalampur in Malaysia, Burj-Khalifa in Dubai, Messeturm building in Frankfurt etc.) have been built on Pile raft foundation and they are performing successfully.

The present paper focuses on the study of different parameters influencing the performance of Pile-Raft foundation system. The effects of various parameters such as Number, Length, Diameter and Spacing of Piles have been considered in the analysis of Pile-raft foundation system. In addition the effects of elastic properties of piles and soil such as Young's modulus and Poisson's ratio have also been studied. Further, the influence of properties of ground such as shear parameters and density of soil are studied. The soil is modeled using Mohr–Coulomb criteria and structural components of the foundation system are modeled as elastic and rigid concrete structures. The analysis is carried out by using the Finite Element software PLAXIS-3D. Load carrying capacity and settlement of Pile raft foundation system, stresses in soil are the parameters studied to represent the performance of Pile Raft foundation.

Keywords: Pile-raft foundation System, Finite Element Analysis, PLAXIS-3D.

1. INTRODUCTION:

Pile foundations are the most popular form of deep foundations used for both onshore and offshore structures. They are often used to transfer large loads from the superstructure into deeper and competent soil layers particularly when the structure is to be located on shallow, weak soil layers. In the last few years, the concept of Pile-Raft has been introduced and accordingly these are very useful for high rise buildings and tall towers. Petronas Tower in Kualalampur in Malaysia, Burj-Khalifa in

Dubai, Messeturm building in Frankfurt are few of the landmark tall towers built on Pile Raft foundations. Deep foundations consisting of driven or drilled-in piles and piers are routinely employed to transfer axial structural loads through soft soils to stronger bearing strata at depth. The research study indicates that Pile-Raft foundation is a more economical design approach when compared to the design of Pile foundation. In pile foundations, entire load of the structure is transferred to the soil through shaft resistance and bearing of piles. Pile cap acts as a rigid base supporting the superstructure and transferring all the loads to the piles. In the case of piled raft foundation, the pile cap itself acts as raft and rests on ground. Hence, some of the loads are transferred to the upper strata through raft; thereby the load carried by piles is tremendously reduced. The location of piles is strategically planned to improve the overall stability of the system, increase the load carrying capacity of rafts and decrease the amount of settlement of the system. Pile raft foundation becomes effective when complete shear is mobilized in soil on which the raft is resting. Presence of very weak soil at shallow depths, lack of contact between raft and underlying soil may result in inadequate efficiency of pile raft foundation.

This study concentrates on the effect of engineering factors related to pile in raft foundation such as number of piles, pile length, pile diameter and pile spacing on the behavior of the pile raft foundation. The concept of load transfer from superstructure to Raft, then to Piles and finally to the soil stratum should be clearly understood. The advantage of Pile-Raft is the contribution of raft in taking partial load which results in reduction in the number of piles. Pile cap which is a rigid member not in contact with ground is replaced by raft. The biggest challenge is to identify what portion of total load is carried by raft. In pile foundation with Pile cap, the loads are transferred directly to the piles through pile cap and then to the soil mass. The international guidelines for the design, construction and practice of Pile Raft Foundation system was introduced by International Society of Soil Mechanics and Geotechnical Engineering (2013). In a pile Raft foundation, the axial load carried by pile is likely to be affected by the spacing and the structural capacity of the piles. Understanding the mechanism of axial load transfer and the corresponding settlement of the system in pile raft foundation is an essential requirement and the present study intends to discuss these aspects

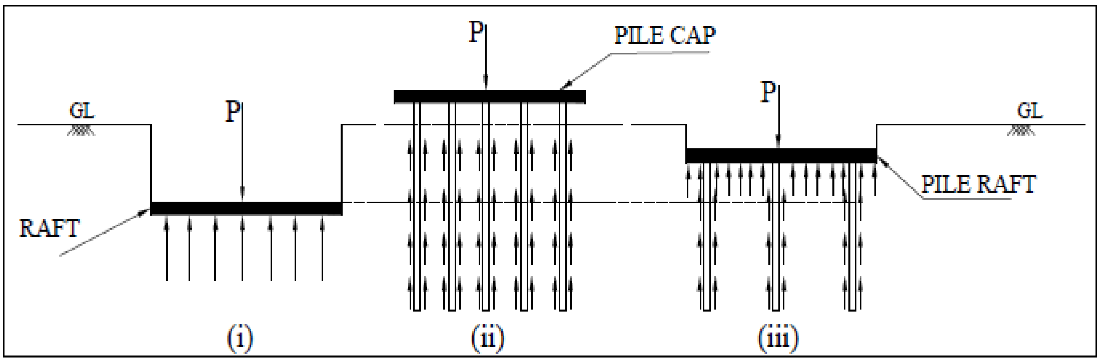

Fig.1 Raft, Pile with Pile Cap and Pile-Raft foundation system

Fig. 1 shows different foundation systems, namely raft foundation, pile foundation and pile raft foundation. It should be noted that raft foundation may not be suitable under all situations. Specially, when the super structure carries considerable load, and when top soil is not sufficiently stiff and strong, it may be necessary to transfer the load to lower stronger strata through piles. This calls for more number of piles. It should be noted that pile cap does not carry any load. Hence the length, diameter, number of piles and their geometry will decide the total load carried. On the other hand, the pile raft foundation will be able to distribute the loads to piles and raft as well. Hence the number of piles required will be reduced and the raft shall be provided at shallow depths only.

2. Problem Statement

The present study of assessing the parameters influencing the performance of pile raft foundation and the contributions of pile and raft in carrying the total load is based on Finite Element approach using the software PLAXIS-3D. The 3-Dimensional model has been developed to consider the infinite soil system comprising of piles and raft. The objectives are to identify the effects of Number of Piles, Length of the Piles, Spacing of Piles and diameter of piles, soil properties such as soil stiffness and soil strength on the load carrying capacity and settlement characteristics of Pile Raft foundation system.

18mx18mx0.5m raft with circular piles of **diameter of 1.0m** was used for the parametric studies. Pile-Raft is subjected to a **300 kN/m²** uniformly distributed load throughout the plate. Number of piles and length of piles were varied to identify the settlement and load carrying capacity of pile-raft foundation. Soil was idealized as uniform medium soft clay with sufficient quantity of sand having unit cohesion of 15 kN/sq.m and friction angle of 30 degrees. Number of piles was varied from 25, 17, 9 to 4 and the length of Piles was varied from 22m, 16m, 10m to 4m.

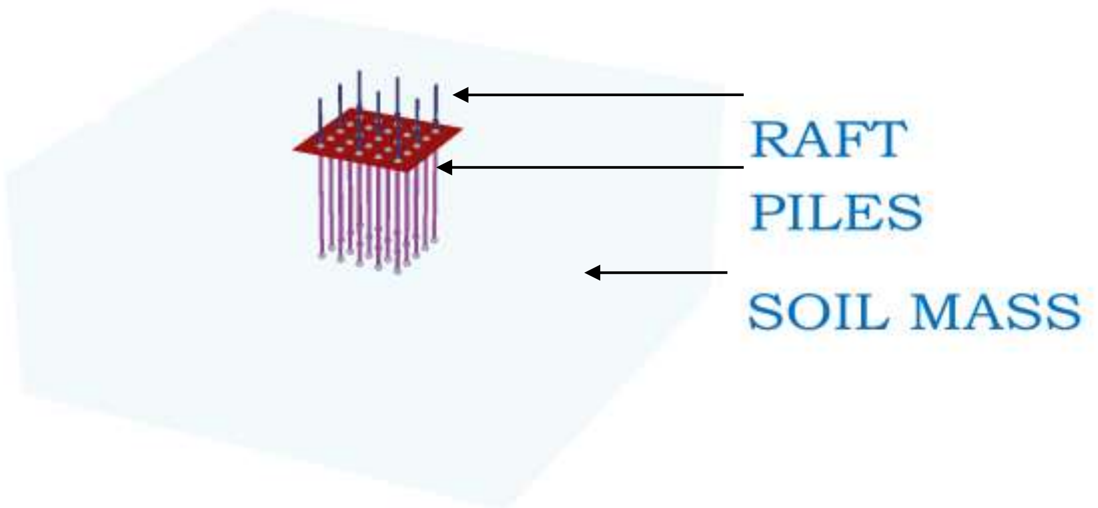

Fig. 2 PLAXIS 3D-Geometrical Model

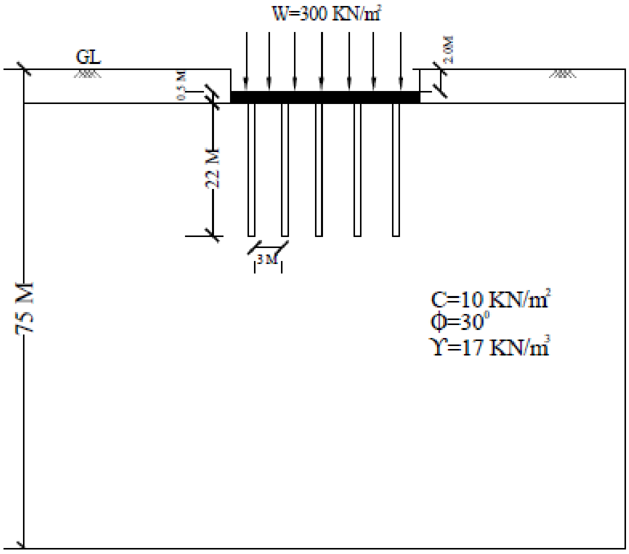

Fig. 3 Geometrical Model (Cross Section)

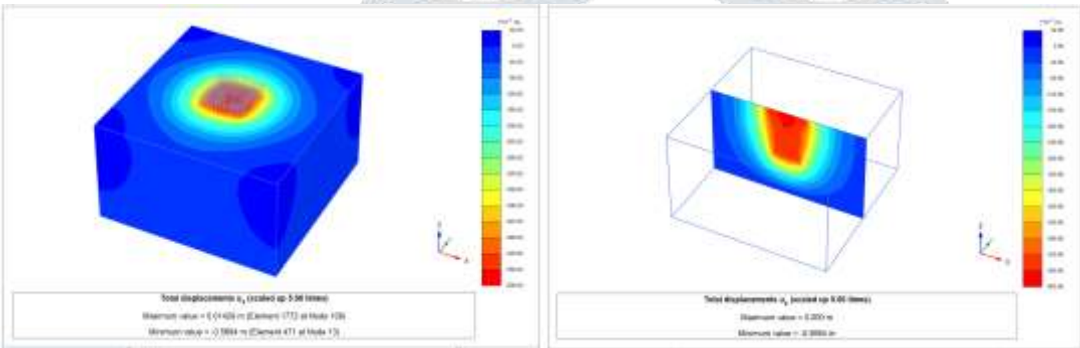

Fig. 4 PLAXIS 3D-Effect of Displacement uz

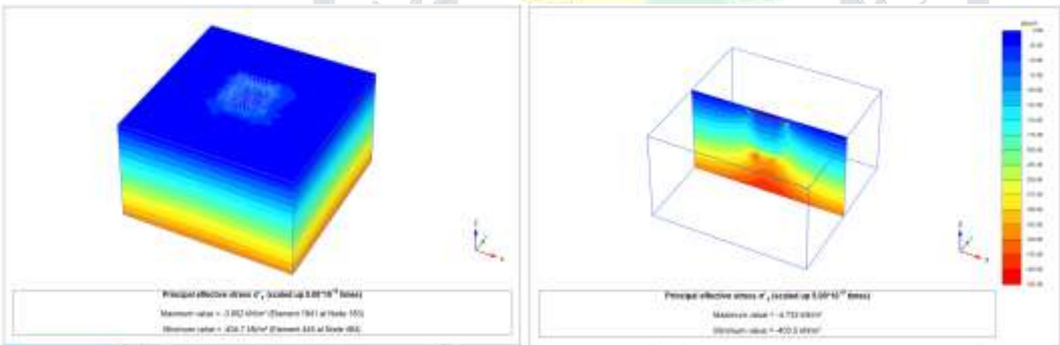

Fig. 5 PLAXIS 3D-Effective Stress σ1

3. *Literature Review*

Irfan Jamil and Irshad Ahmad (2022) discussed combined piled raft foundation (CPRF) considering both raft and piles to take their share of the total load applied. However, in practice, the contribution of a raft in taking load is usually ignored and the load is assumed to be supported on piles. To economize the design, relative load sharing of raft and piles in CPRF has to be studied. In this context, different simplified methods have been developed, each one with some limitations. In this study, three simplified methods have been applied to two cases of pile-raft systems.(methods include Randolph, Poulos-Davis-Randolph, and modified Poulos-Davis-Randolph. The first case is a hypothetical case consisting of a 12 m × 12 m raft supported on a square group of nine piles. The second case study is an actual eight-story building to be constructed in Peshawar, Pakistan. The building is supported on a pile-raft system, with raft resting on very soft clay underlain by dense sand. The two case studies are also modelled in the finite element program PLAXIS 3D for comparison. The results of all the simplified methods are comparable with PLAXIS 3D. However, the Randolph method is much closer to PLAXIS 3D for the two cases studied. Furthermore, it is also shown that piles in a piled raft system can be used as “stress reducers” as well as a “settlement reducers.” Additionally, the effect of interaction factors is also evaluated with the s/d ratio as well as with varying soil stiffness. It was concluded that ignoring these factors leads to a very unsafe design of the pile-raft system.

Abdel-Azim and Abdel-Rahman (2020) explained that Piled rafts have been used as a foundation system for high-rise buildings worldwide in different soil conditions, e.g., in soft to stiff clay as well as in medium-to-dense sand. Piled raft is currently used not only to control the foundation settlement but also to minimize the required raft thickness to reach the most optimized foundation design. The purpose of this study is to investigate the behavior of piled raft as a foundation system for Frankfurt over-consolidated clay based on the well-monitored Messeturm building in Germany. The numerical tool used in analysis is Plaxis 3D, a finite element software with hardening soil material model. The piled raft foundation behavior will be evaluated based on the total settlement, differential settlement and the pile skin friction. Based on this study, it was found that the chosen foundation system “plied raft foundation” for Messeturm was an optimized solution for the proposed building.

Abdolrezayi and Khayat-(2021) discussed dimensional finite element method as a general method to solve complex geotechnical engineering problems. It is one of the most powerful numerical methods which can be used for analyzing pile raft foundation. These models can consider the complex interaction between soil and structure. Among available 3D FEM software for modelling Pile raft foundations, MIDAS GTS is used considering its various element type and modeling abilities. In this article, different pile modeling techniques in MIDAS GTS software (like pile modeling by solid elements, modeling by beam elements connected to soil elements and modeling by EPM2) are compared with real pile loading test data. Results showed that all three methods have excellent compatibility with the results of loading test in the linear area of the load-settlement curve, and SEM3 and EPM kept their conformity further in the non-linear area as well. One of the most critical problems in 3D FEM modeling process of piled raft foundations with SEM was an increase in the number of elements when the number of piles increases and that leads to model's slowness and convergence problem. Piles modeling by EPM needs much lower elements; using this method, skin friction resistance, tip resistance and displacement between pile and soil can be easily calibrated with a pile loading test data which facilitates piled raft analysis with a large number of piles. After comparing different pile modeling techniques through MIDAS GTS software, the ability of the software for modeling piled raft foundations had been verified; Results show acceptable agreement between software output and monitored values and also outputs from other methods.

Muhammad Rehan Hakro and Aneel Kumar (2022) showed that numerical modeling can simulate the interaction between structural elements and the soil continuum in a piled-raft foundation. The present work utilized two-dimensional finite element Plaxis 2D software to investigate the settlement, swelling, and structural behavior of foundations during the settlement and swelling of soil on various soil profiles under various load combinations and geometry conditions. The field and laboratory testing have been performed to determine the behavior of soil parameters necessary for numerical modelling. The Mohr–Coulomb model is utilized to simulate the behavior of soil, as this model requires very few input parameters, which is important for the practical geotechnical behavior of soil. From this study, it was inferred that the un-piled raft was not sufficient to resist higher loads and exceeds the limits of settlement as soil is soft and has less stiffness. Piled raft increases the load carrying capacity of soil, and the lower soil layer has a higher stiffness where the pile rests, decreasing the significant settlement. Further, the effects of (L/d) and (s/d) of the pile and Krs on the settlement are also discussed, detailed numerically under different scenarios. The swelling of expansive soil was also simulated in Plaxis 2D with an application of positive volumetric strain. The above-mentioned parametric study was similarly implemented for the heaving of foundation on expansive soil.

Kumar and Choudhury (2015) showed the effect of pile head connection condition on the behavior of Combined Pile-Raft Foundation (CPRF) by using finite element based geotechnical program PLAXIS3D. The finite element model was first validated with experimental results from available literature. Thereafter, the responses of CPRF in terms of settlements, normalized bending moments (M/Mmax) and normalized lateral displacements (u/D) under available input earthquake loadings such as that from 2001 Bhuj, 1989 Loma Prieta and 1995 Kobe earthquakes are studied. Results show that connection condition has little influence on settlement under vertical load alone whereas load sharing by raft varies from 30% for hinged connection to 54% for rigidly connected CPRF model. Under the application of lateral load including various earthquake loads, raft mobilizes ultimate resistance at faster rate compared to pile irrespective of connection rigidity. Connection rigidity played an important role in bending moment variations, lateral displacements and rotations.

Kajal Tarenia and Nihar Ranjan Patra (2019) discussed on both connected and disconnected piled raft foundations subjected to compressive load and analyzed using PLAXIS 3D considering time effects. Pile rafts of sizes single pile, 3×1, 3×3 and 5×5 have been considered in the analysis. The field study reported by Mattsson et al. (2013) has been considered for the analysis and validation. In PLAXIS 3D, the soil model consists of 10-noded tetrahedral soil elements. The piles are modelled with the use of embedded pile option. The calibrated parameters from the analysis have been taken for the prediction of settlement of raft and pile heads with respect to time for both connected and disconnected pile rafts. The settlement of concrete slab of 3×3 disconnected piled raft foundation obtained by PLAXIS 3D is 22% less as compared to the measured field test values for a period of six months. The settlements of slab of connected piled raft foundations are about 13% to 68% lower as compared to disconnected piled raft foundations irrespective of pile group configurations for a period of one year. The settlements of pile heads of connected piled raft foundations are about 20% to 65% lower as compared to disconnected piled raft foundations irrespective of pile group configurations for a span of one year. The settlement of slab and pile heads of 5×5 connected piled raft foundation has least settlement than other piled raft foundations for a period of one year.

Ankit Sharma1 and Mohit Verma (2022) narrated that urbanization is taking place these days, which has led to the development of many towering structures. Because of the scarcity of land, the recent structures that will be made are in whatever soil is available, whether soft soils or hard strata. In this report, numerical analysis was carried out by finite element analysis using PLAXIS 2D on soft soil. Structures built on soft ground are different from a regular strategy in that they are used in raft pile foundations because of the differential settlement property of the ground. In the present investigation, the mathematical examination focused on single raft and piled raft of various arrangements. The results showed that the extreme load expanded and the settlement decreased. The parametric investigation also showed that the decrease in settlement occurs due to the expansion in the length of the piles, as well as in the expansion of the number of piles. The parametric study showed that the reduction of settlement occurs due to the increase in the length of the piles, as well as with the increase in the number of piles. This study is useful in deciding various parameters needed to economically design the piled raft foundation.

Yasser El-Mossallamy The quick growth of cities in the last two decades all over the world led to a rapid increase in the number and height of high rise buildings even in unfavourable subground conditions. Since the 80's, a new foundation technique, the so-called piled rafts, has been developed and used extensively in order to reduce the maximum as well as the differential settlements and the associated tilting of the buildings. The analysis of piled raft is a very interesting example of the soil-structure interaction that requires the co-operation between the geotechnical and structural engineers to reach the most economic foundation system. Enhanced numerical analyses play a decisive role for the analyses of such complex foundation system. The piled raft foundation has shown its validity as a very economic geotechnical foundation type, where the structural loads are carried partly by the piles and partly by the raft contact stresses. This foundation system was successfully applied in stiff as well as soft subsoil. An innovative application of the piled raft is its special adjustment to cases of foundations with large load eccentricities or very different loaded parts of buildings to avoid the need of complex settlement joints especially below ground water table.

Mahmood Mahmood and Saad Al-Wakel (2018) Three-dimensional analysis for the dynamic response of a piled raft foundation subjected to vertical vibration is presented in this study. The analysis considers several factors affecting the amplitude of displacement for deep foundation such as pile cap embedment, pile cap thickness, relative density of the sand and the boundary effect. A validation for an experimental piled raft model depending on a scale factor of (20) using at (Plaxis 3D) computer program was performed. The sand is simulated using Mohr-Coloumb model while the concrete is simulated as linear elastic material. It has been found that embedding the pile cap in the soil and increasing its thickness lead to decrease the maximum amplitude of displacement. Furthermore, the predictions showed that increasing the distance between the foundation and the boundaries and increasing the relative density of the sand can significantly minimize the dynamic response of the foundation.

Raj Banerjee and Srijit Bandyopadhyay (2020) the performances of a piled raft system in terms of serviceability and load-carrying capacity are reviewed. The settlement behaviour of a square-piled raft in a layered soil is investigated using numerical analysis. The emphasis is given on quantifying the reduction of the average and the differential settlements of the raft in layered soil. A 3D finite element analysis using commercial software called PLAXIS 3D (Version 2) is performed for various pile positions, pile numbers and pile lengths under the raft subjected to a uniform vertical loading. The settlement aspects for an efficient design of a piled raft subjected to vertical loadings have been addressed. It is found that the required piled group-raft area ratio (Bg/Br) for minimizing the differential settlement of a raft in a layered soil should be within a range of 0.4 to 0.6.

Simeneh Abate (2015) The design of group piles depends on either the group or single pile capacity of piles. In conventional design method of such foundations, the stiffness of the pile cap is barely taken into account. Such design becomes too conservative if the pile cap is in contact with the ground. Because the pile cap contributes in transferring load to the ground and distributing load over the piles. The design method that considers the contribution of the pile cap and interaction between the different elements of group piles is called piled raft foundation. The concept of piled raft foundation leads to economical design. In this paper, analysis and parametric study of piled raft foundation has been conducted. The study is performed using powerful finite element based software, PLAXIS. A number of parameters were selected from the elements of the piled raft system.

According to their effect on the response of piled raft system, some are taken to be constant while others are varied. Among the varied parameters, raft thickness, pile length, pile spacing and pile number were considered. Other possibilities were also investigated in search of an optimum placement of piles. The analysis results from the PLAXIS software have shown a close prediction to that of in-situ measurements and other numerical methods. From the parametric study, concentrating piles around the center for uniformly loaded rectangular piled raft foundation reduce the differential settlement.

Thasleena Haris and Niranjana K Pile-raft foundation is a composite construction which consists of piles and raft is one of the alternatives over conventional pile or raft foundations. This study is directed to develop a numerical model capable to analyse and identify the parameters governing the performance of pile-raft system. The effect of number of piles, pile length and pile spacing on the behaviour of pile raft was studied. This study also focused on the influence of these parameters on the settlement behaviour and the load sharing between the raft and piles of the system. The analysis was carried out by considering sand (at loose, medium and dense condition) as foundation soil. The results show that value of vertical deformation decreases as the result of the increase of pile number, pile length and pile spacing. However, the load carrying capacity of the pile-raft system in- creases only up to an optimum value on varying the pile parameters.

From the above literature review, it has been inferred that pile raft foundation can be an effective foundation treatment, sometimes far more superior than pile foundation, specially when the top soil has reasonable strength and hard rock is at great depth. It is essential to understand the factors influencing the behavior of pile raft foundation and the mechanism of load transfer. Hence the present work focuses on these issues.

4. Results and discussions

Boundary Effect

The pile raft soil system is modeled as shown in Fig.3. Mention the type of element, number of elements, boundary conditions, loading on the raft.

Table 1. properties of soil sample, Piles and Raft

SOIL PROPERTIES

Soil Type=	CLAYEY SAND	
Material Model =	Mohr-Coulomb	
Density γ =	17	kN/m^3
Youngs Modulus E=	3000	kN/m^3
Poissons Ratio μ=	0.3	
Cohesion C =	10	kN/m^2
Angle of Friction Φ=	30	^{o}

PILE PROPERTIES

Pile Size in diameter =	1.0	m
Youngs Modulus E=	$20x10^6$	kN/m^2
Length of Pile L=	4 to 22	m
No. of Pile S=	4 to 25	Nos.
Density of Pile γ =	25	kN/m^3
Axial Skin Resistance=	200	kN/m
Base Resistance=	10000	kN

RAFT PROPERTIES

Raft Size =	18.0 x18.0	m
Youngs Modulus E=	20×10^6	kN/m^2
Density of Raft γ =	25	kN/m^3
Thickness=	0.5	m
Poissons Ratio μ=	0.2	

Floor Load on Raft=300 KN/m^2

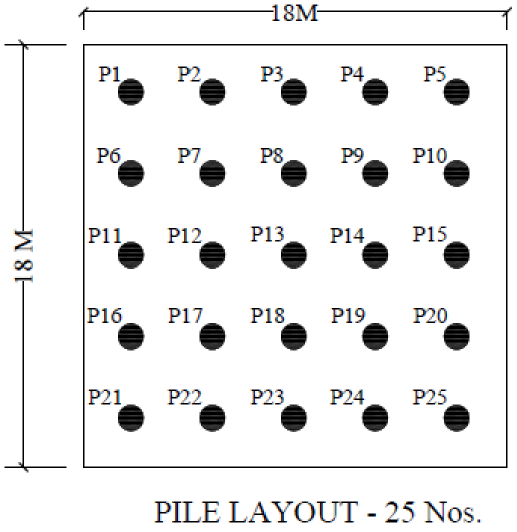

Fig.6 Pile Layout with nos.

Results from PLAXIS 3D analysis

The Results obtained such as Settlement, Effective Stress and Axial Loads with effect of pile length, number of piles and spacing between the piles and studied about the behavior of pile-raft foundation system by using PLAXIS-3D finite element approach. The foundation soils were considered as Clay soil.

The focus of the present work shows the mechanism of pile-raft foundation system in a uniform soil when subjected to uniformly distribute axial force for the purpose of clarity. Parametric studies have been made by varying the length of pile and number of piles. The parameter studied include settlement, total axial force, shear force, bending moment in both the directions, shear stress at the base of the pile and base of the raft in different directions. The length of pile varied from 4 to 22m at the interval of 6m and number of piles have been changed from 25, 17, 9, 5 to 4 pile as detailed in fig. 16.

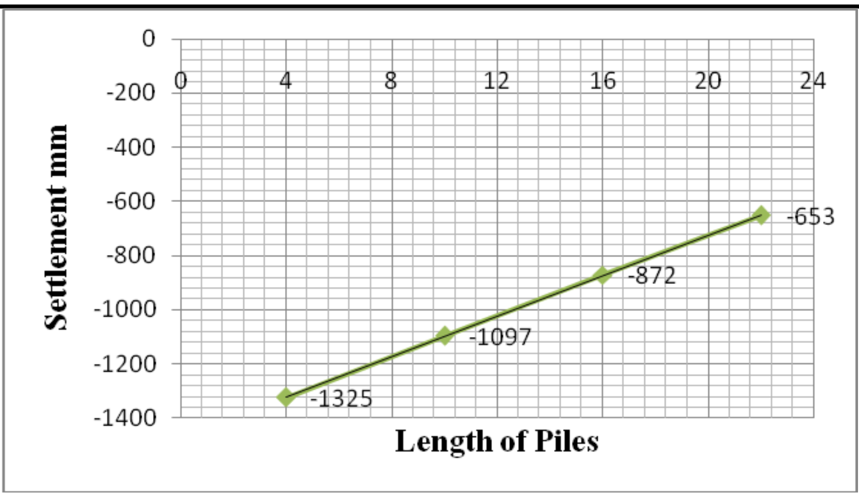

Fig.7 Effect of variation in length of Pile Vs Settlement

Fig. 7 represents the effect of variation in length on the total Settlement of pile-raft foundation system. It can be seen that the increase in the length of pile reduces the settlement and variation is linear.

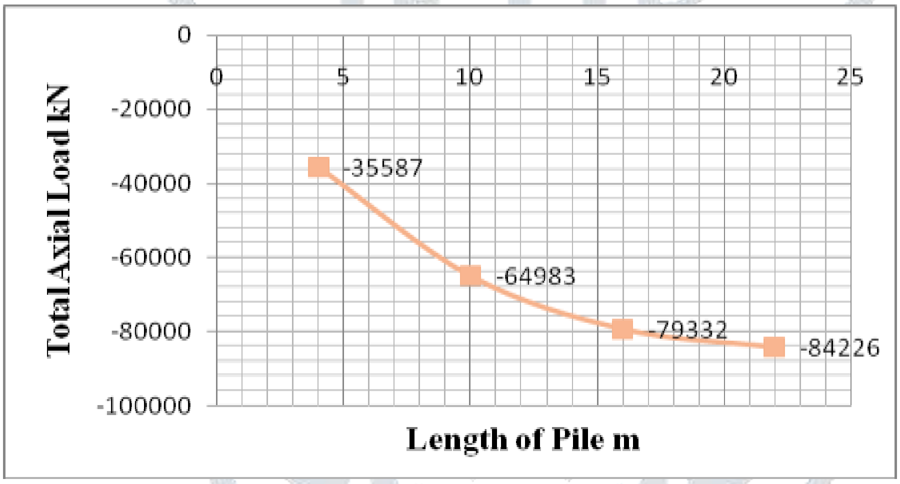

Fig.8 Effect of variation of length of Pile Vs Total Axial Load

Fig. 8 represents the total axial load carried by pile-raft system as a function of length of the pile. It can be seen that the total axial load carried increases with increase the length of the pile. However the variation is non-linear and when the length of pile reaches a limit. It is seen that load carried by the system does not increase appreciably with further increase in length of the pile.

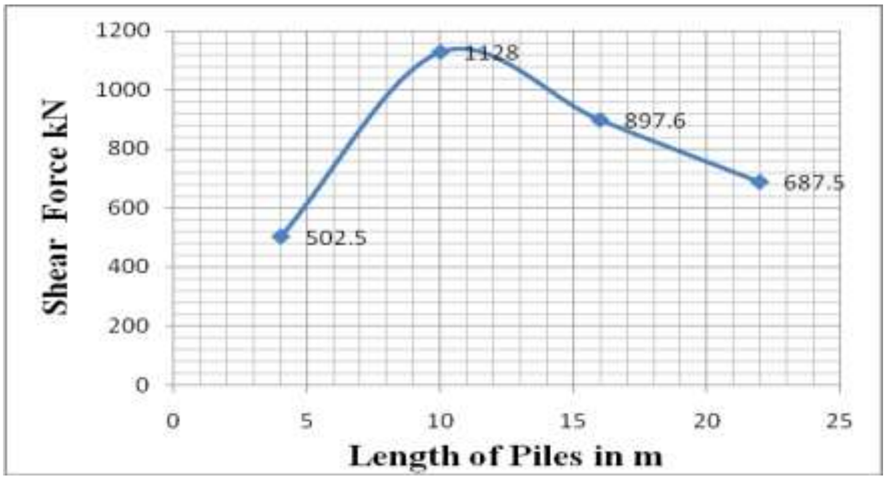

Fig.9 Effect of variation of length of Pile Vs Shear Force in Pile no.21

Fig. 9 represents the effect of increase in length of pile on the maximum shear force experienced by pile. It is observe that, the shear force is maximum near the top of the pile. It can be seen that, the shear force experienced increases with increase in length and reaches a maximum value. Further increase in length the shear force decreases. In the present situation, shear force is maximum when the length of pile is 10m, so this effect may be contemplated or understood because when the pile become too long, the actual length becomes insignificant.

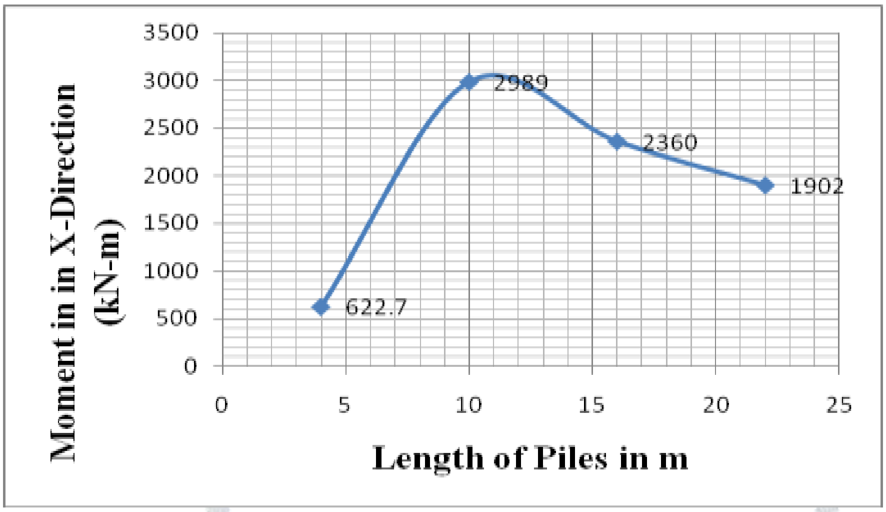

Fig.10 Effect of variation of length of Pile Vs Moment in X-direction at Pile no.21

Fig. 10 represents the effect of increase in length of pile on the maximum bending moment in X-direction experienced by pile. It is observed that the moment is maximum near the top of the pile. It can be seen that, the moment experienced increases with increase in length and reaches a maximum value. Further increase in length the moment decreases. In the present situation, moment is maximum when the length of pile is 10m. So, this effect may be contemplated or understood because when the pile becomes too long, the actual length becomes insignificant.

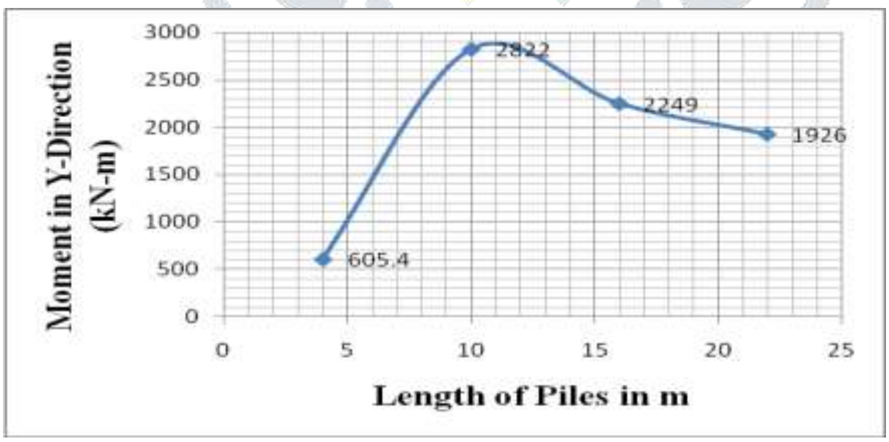

Fig.11 Effect of variation of length of Pile Vs Moment in Y-direction at Pile no.21

Fig. 11 represents the effect of increase in length of pile on the maximum bending moment in Y-direction experienced by pile. It is observe that, here also the moment is maximum near the top of the pile. It also can be seen that, the moment experienced increases with increase in length and reaches a maximum value. Further increase in length the moment decreases. In the present situation, moment is maximum when the length of pile is 10m. So, this effect may be contemplated or understood because when the pile become too long, the actual length becomes insignificant.

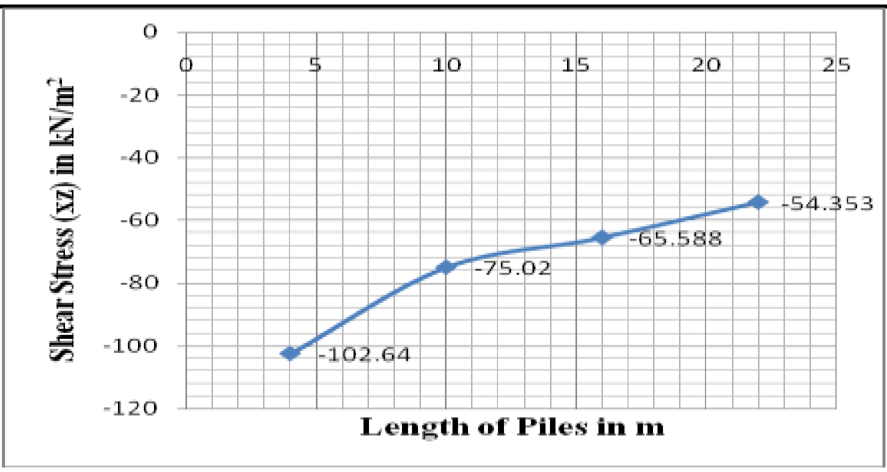

Fig.12 Effect of variation of length of Pile Vs Shear stress in XZ-direction ***(Base of Raft)***

Fig. 12 represents the effect of variation in length on the maximum shear stress in XZ-direction at base of the raft of pile-raft foundation system. It can be seen that the increase in the length of pile reduces the shear stress. However the variation is non-linear and when the length of pile reaches a limit.

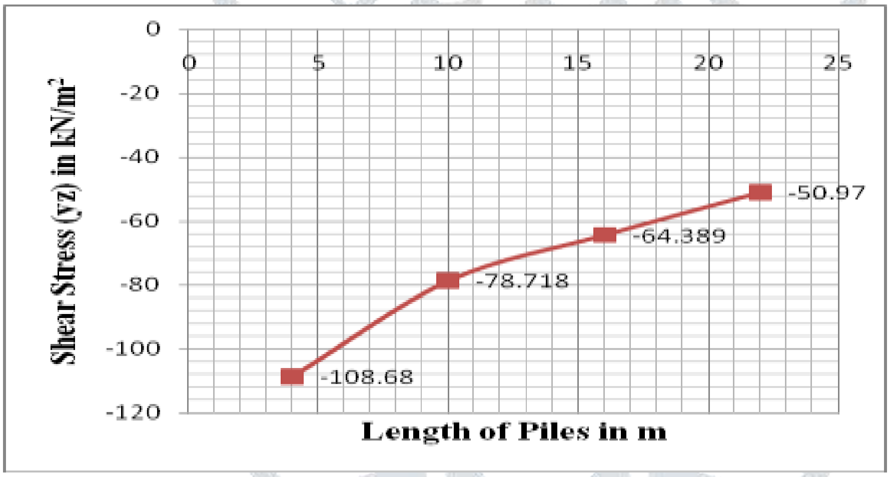

Fig.13 Effect of variation of length of Pile Vs Shear stress in YZ-direction ***(Base of Raft)***

Fig. 13 represents the effect of variation in length on the maximum shear stress in YZ-direction at base of the raft of pile-raft foundation system. It can be seen that the increase in the length of pile reduces the shear stress. However the variation is linear and when the length of pile reaches a limit.

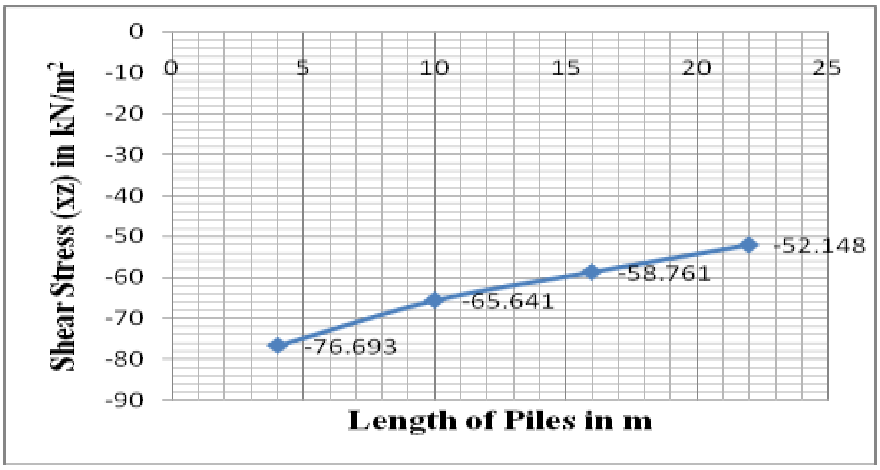

Fig.14 Effect of variation of length of Pile Vs Shear stress in XZ-direction ***(Below pile)***

Fig. 14 represents the effect of variation in length on the maximum shear stress in XZ-direction at base of the pile of pile-raft foundation system. It can be seen that the increase in the length of pile reduces the shear stress. However the variation is linear and when the length of pile reaches a limit.

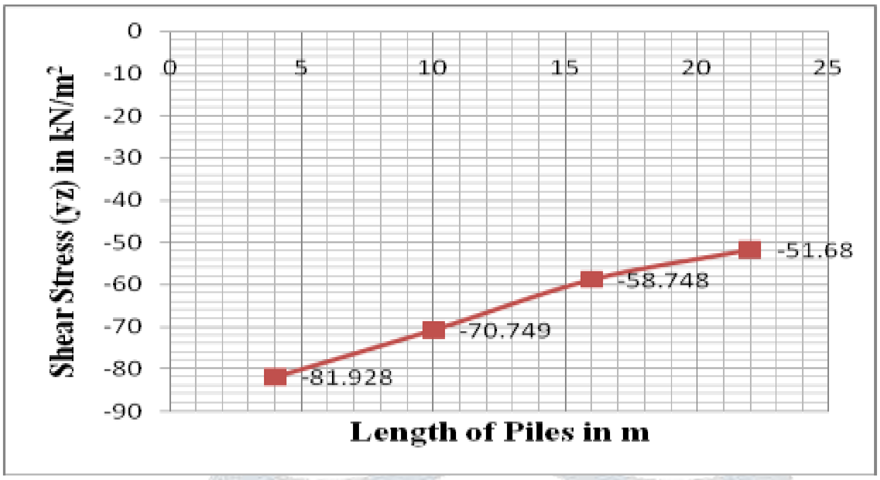

Fig.15 Effect of variation of length of Pile Vs Shear stress in YZ-direction ***(Below pile)***

Fig. 15 represents the effect of variation in length on the maximum shear stress in YZ-direction at base of the pile of pile-raft foundation system. It can be seen that the increase in the length of pile reduces the shear stress. However the variation is linear and when the length of pile reaches a limit.

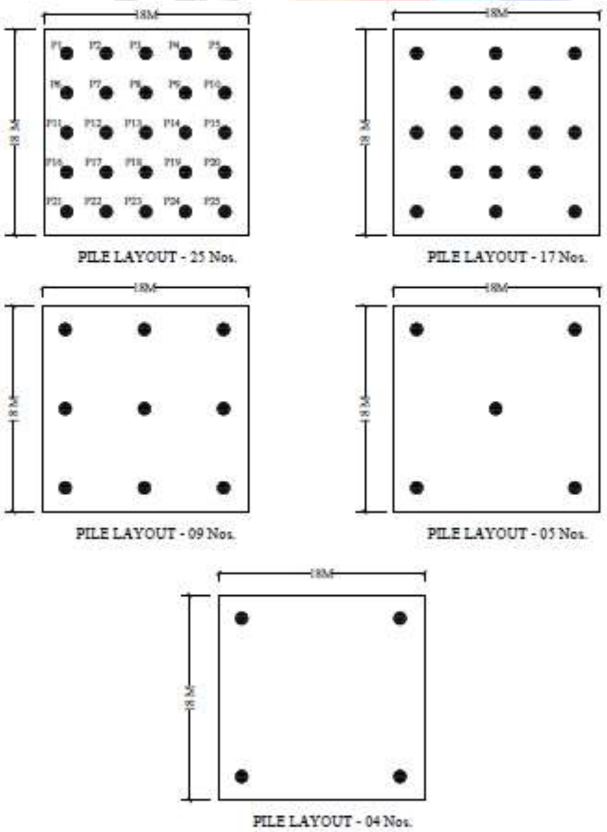

Fig.16 Pile Layout

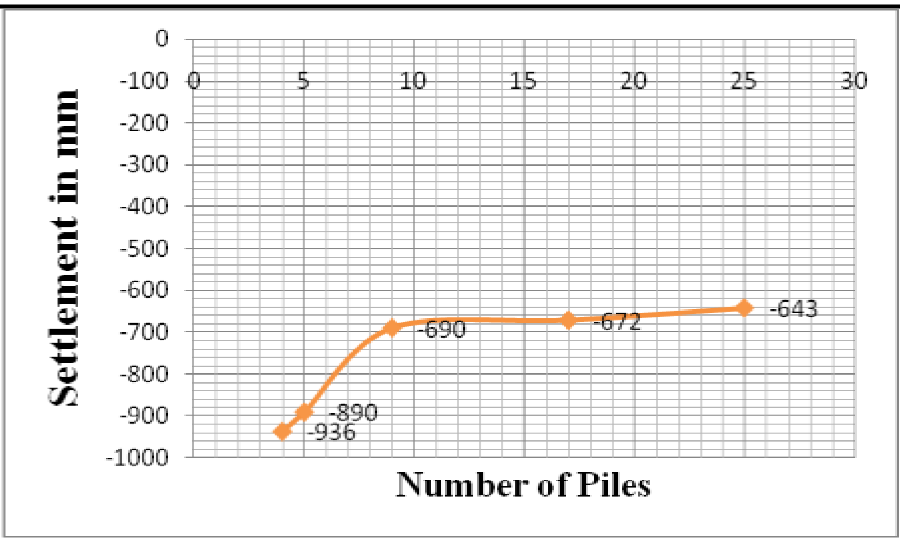

Fig.17 Effect of variation of number of Piles Vs Settlement

Fig. 17 represents the effect of variation in number of piles on the total settlement of pile-raft foundation system. It is observe that, the maximum settlement experienced increases with decrease in number of piles and reaches a maximum value. Further increase in number of piles it is seen that the settlement does not increase appreciably with further increase in number of piles.

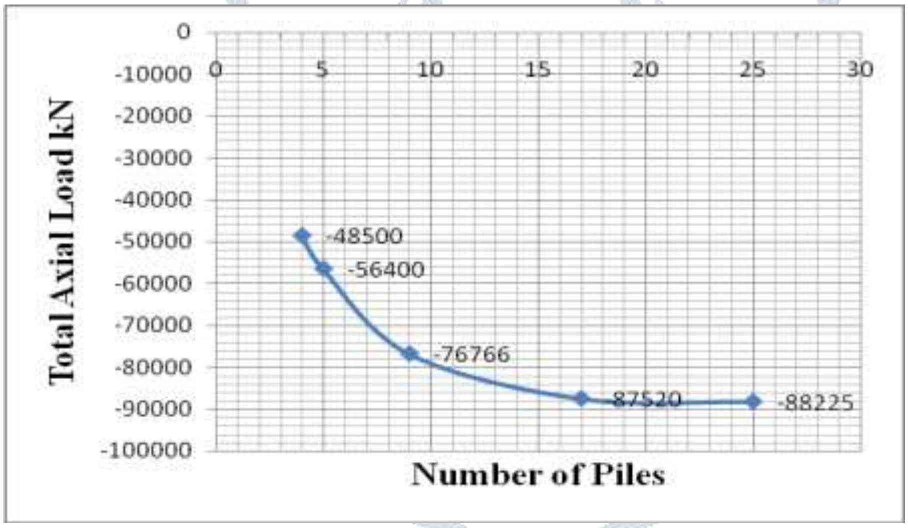

Fig.18 Effect of variation of number of Piles Vs Total Axial Loads

Fig. 18 represents the total axial load carried by pile-raft system as a function of number of piles. It can be seen that the total axial load carried increases with increase the number of the piles. However the variation is non-linear and when the number of piles reaches a limit. It is seen that load carried by the system does not increase appreciably with further increase in number of piles.

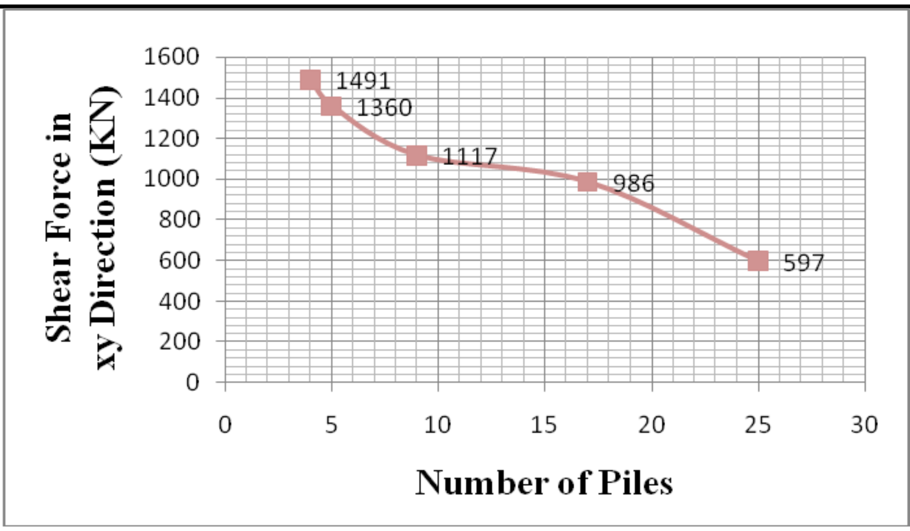

Fig.19 Effect of variation of number of Piles Vs Shear force in XY-direction

Fig. 19 represents the shear force in XY-direction is carried by pile-raft system as a function of number of piles. It can be seen that the shear force increases with decrease the number of the piles. However, the variation is non-linear and when the number of piles reaches a limit.

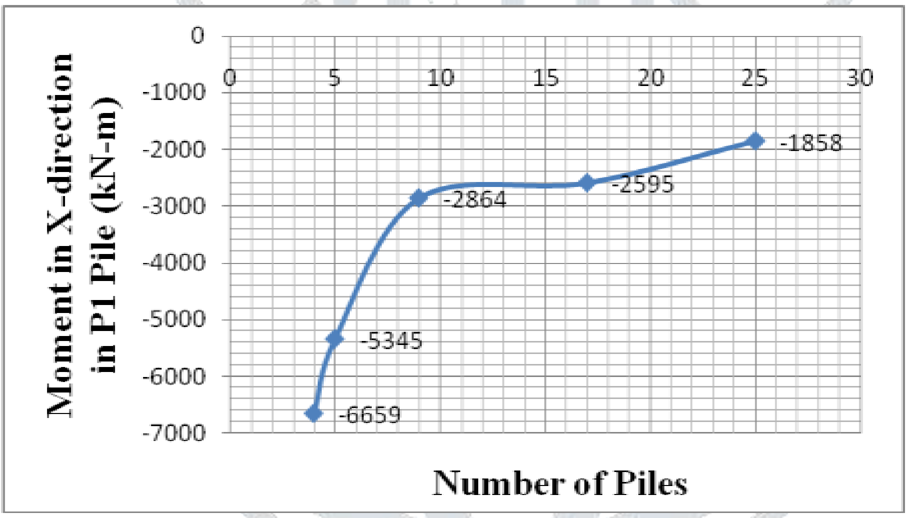

Fig.20 Effect of variation of number of Piles Vs moment in X-direction

Fig. 20 represents the moment in X-direction carried by pile-raft system as a function of number of piles. It can be seen that the maximum moment in the pile increases with decreases the number of the piles. However the variation is non-linear and when the number of piles reaches a limit. It is seen that the moment carried by the pile does not increase appreciably with further increase in number of piles.

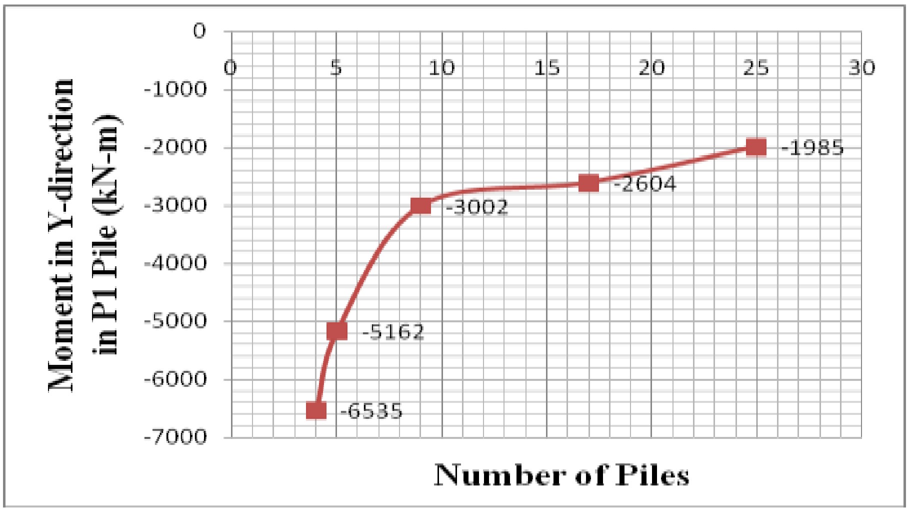

Fig.21 Effect of variation of number of Piles Vs moment in Y-direction

Fig. 21 represents the moment in Y-direction carried by pile-raft system as a function of number of piles. It can be seen that the maximum moment in the pile increases with decreases the number of the piles. However the variation is non-linear and when the number of piles reaches a limit. It is seen that the moment carried by the pile does not increase appreciably with further increase in number of piles.

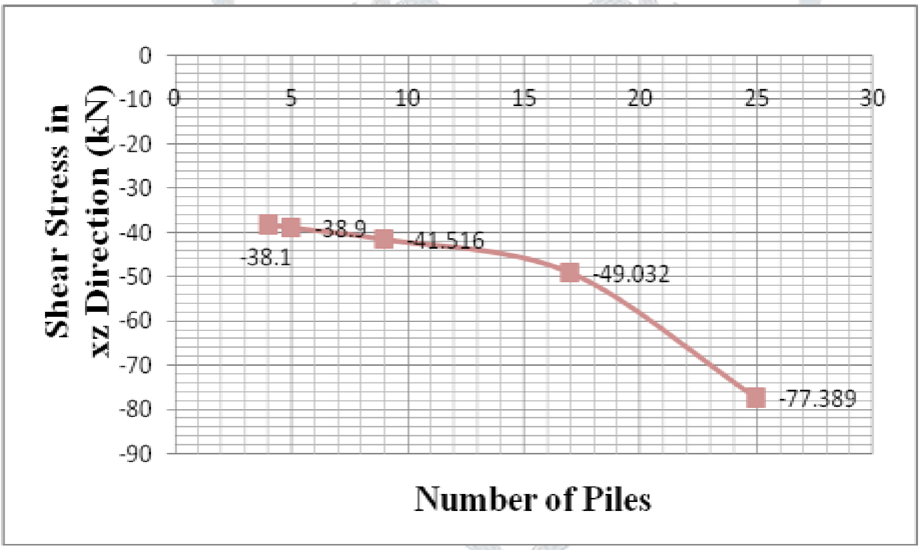

Fig.22 Effect of variation of number of Piles Vs Shear stress in XZ-direction

Fig. 22 represents the maximum shear stress in XZ-direction carried by pile-raft system as a function of number of piles. It can be seen that the maximum shear stress increases with increase number of the piles. However the variation is non-linear and when the number of piles reaches a limit. It is seen that the shear stress does not increase appreciably with further decrease in number of piles.

Concluding Remarks

The performance of piled raft foundation system subjected to vertical loadings has been addressed. The parameters considered include shear stress and bending moment in the system, settlement of pile raft system and axial load carried by piles as a function of pile length and number of piles. It has been observed that the total load carried by the pile raft is shared by the piles and raft. Because of the introduction of raft on ground, the stresses and bending moment in piles are considerably reduced. With increase in length of piles and the number of piles, the load carrying capacity of the system increases and the settlement decreases. Hence, pile raft can be an excellent choice, instead of pile foundation, particularly when the top soil is relatively stiff. Hence, choice of pile raft foundation system for tall structures is understandable.

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