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A Critical Review on Numerical parametric studies to understand theBehavior of Piled raft foundation

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Abstract: *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 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 which is highly non-economical. 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 the required thickness of the raft. In this study, an attempt is made to describe the behavior of piled raft foundation with the help of various researches carried out in this field. The studyis very useful to understand the effect of the key parameters influencing the performance of foundation during different loading on Piled Raft in case of various soil conditions.*

Keywords–*Pile raft foundation, Numerical Analysis, Pile foundation, Loadings.*

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I. INTRODUCTION

In general foundation design is 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 load bearing capacity and settlement criterion of the foundations are not full filled, we need to redesign the foundation. In this situation, we consider deep foundation options like piles.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 [1]).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 conventional design approach we assumed 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]).

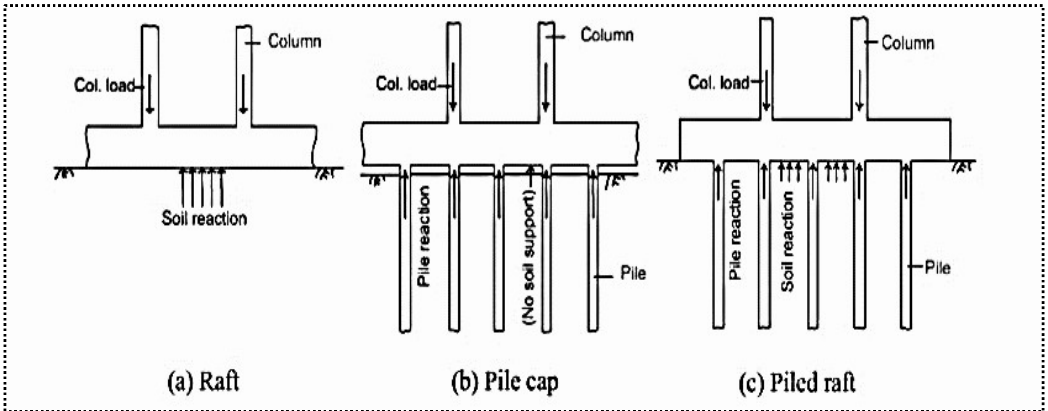

Fig1: Behavior of different foundation under loading condition

Obviously 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. In addition, the piles may be used to control the settlement rather than carry the entire load in the piled rafts. Tan and Chow (2004)[3] illustrated the usage benefit of piles and raft together in the design of foundations in Fig. 2.

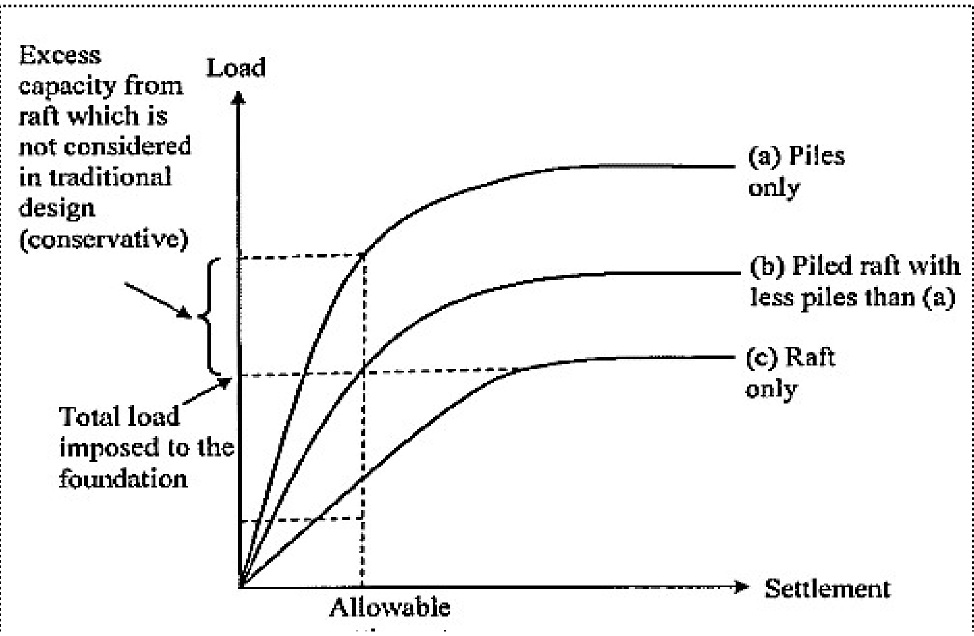

Fig.1 :Concept of piled raft [3]

Randolph (1994) has presented three design approaches for the piled raft foundations in his state-of-the-art report as:

1. The Conventional Approach: Piles are designed to carry the majority of the load.
2. Differential Settlement Control: Piles are located in order to reduce the differential settlement, rather than the overall average settlement.
3. Creep Piling: Piles are designed to operate at a working load (70-80% of the ultimate capacity) at which significant creep occurs.

Advantages of Piled Raft Foundation

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, we can reduce the required number of piles when the raft provides this additional capacity to foundation. So by proper geotechnical assessment we could help a lot for increase in 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.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. We can also reduce number of piles as compared to conventional piled foundation because in piled raft we consider bearing effect of raft which was ignored in conventional pile design.If eccentric loading or difficult subsoil conditions arises there will be a risk of foundation tilting which can be decreases by piled raft foundation because in piled raft foundation a centralization of actions and resistances occurs for the cases of large eccentricities. 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. Provides economical foundation where structural loads are carried partly by piles and partly by raft contact stresses hence it works as cost optimizer for the whole foundation.

II. REVIEW OF LITERATURE

Sommer et al. (1985) used piled raft foundation for the construction of a 30-story building due to narrow site with settlement & sensitive neighboring structures. The tall building rests on floating pilings in Frankfurt Clay. The FE – computations performed, permitted a qualitatively acceptable prediction of the bearing behavior of the piled raft foundation. The computed behavior was confirmed by initial measurements, and these agree with measurements on comparable buildings in London clay. At this writing, about 75 % of the structural load had been applied whereas only 30 % of the computed final settlements have been measured[4].

Clancy and Randolph (1993) developed a rigorous numerical method of piled raft analysis which was based on a hybrid approach of load transfer analysis of individual piles, together with elastic interaction between piles and between the various raft elements and the piles. A comprehensive range of foundation geometries were analyzed, within the practical limitations of the method in which computational times become excessive for groups of more than 100 piles. The numerical analysis was used to evaluate an existing approximate method for estimating the overall stiffness of the foundation and the proportion of load carried by the pile[1].

Horikoshi and Randolph (1998) carried out a parametric study of piled-raft behaviour to establish a framework for the optimum design in form of differential settlement. In their study they conclude that piles should be distributed over the central 16± 25% of the raft area and pile group or equivalent-pier stiffness should be approximately equal to the stiffness. They also said that the total pile capacity should be designed for of the raft alone which should between 40 and 70% of the design load, depending on the pile group area ratio and the Poisson's ratio of the soil profile. However, the pile capacity should be achieved primarily through shaft friction, rather than end bearing, in order to achieve a reasonably `ductile' pile response[2].

Katzenbach et al. (1998) illustrated that the piled raft foundation indicates a new philosophy of soil – structure interaction under static loads as shown in Fig 3. The contribution of the rafts as well as the piles is taken into consideration to satisfy the proof of the ultimate bearing capacity and the serviceability of a piled raft as an overall system. Besides this, the interaction between raft and piles makes it possible to use the piles up to a load level which can be significantly higher than the permissible design value for the bearing capacity of comparable single standing pile. This leads to different design philosophies with respect to piled raft foundation[5].

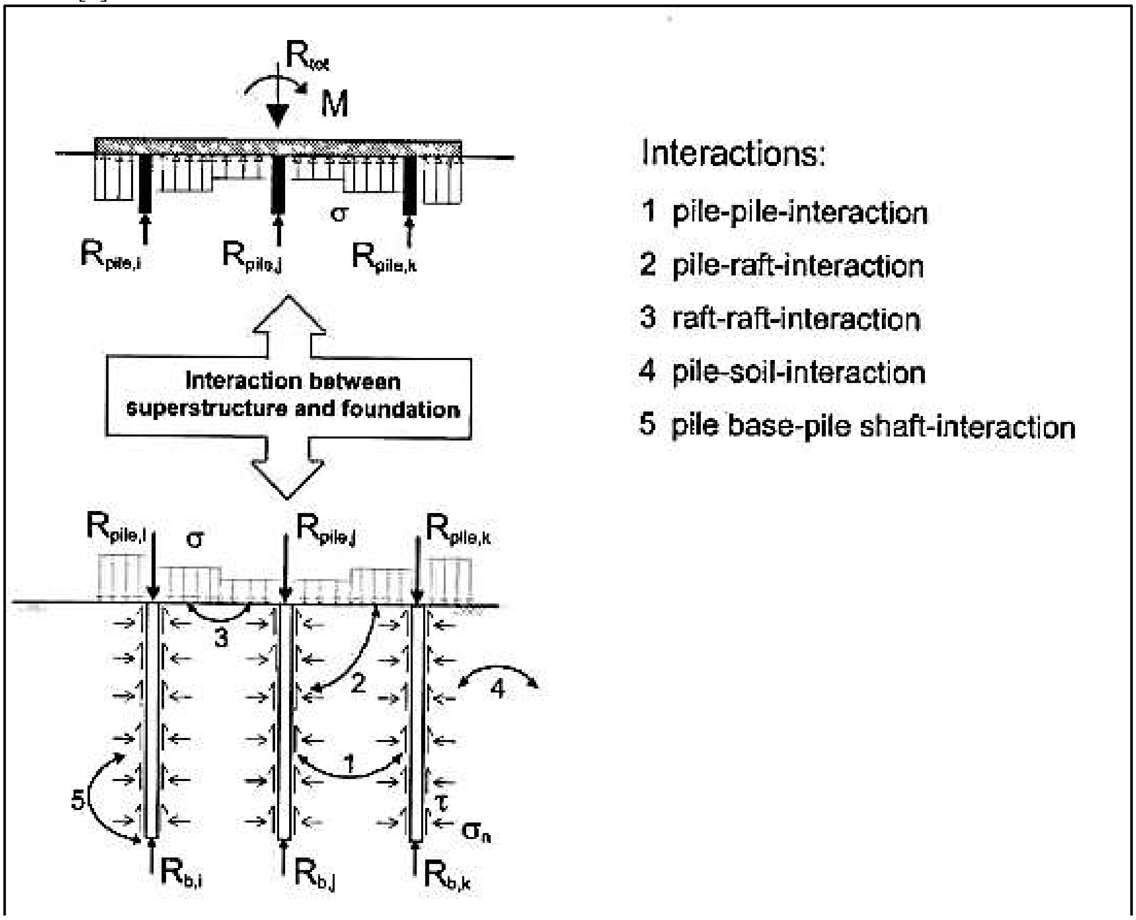

Fig. 3 : Soil-structure interaction of piled rafts [5]

Poulos (2001) describe a design process for a piled raft that contains three-stage process. The first one is preliminary stage in which the effects of the number of piles on load bearing capacity and settlement are assessed with help of an approximate analysis. After this in second stage the more detailed examination to assess where piles are required and to obtain some indication of the piling requirements and the third one is a detailed design phase in which a more refined analysis is conducted to confirm the optimum number and location of the piles, and to obtain essential information for the structural design of the foundation system. Poulos also describe Some typical applications of piled rafts including comparisons between computed and measured foundation behavior. The analyses have been carried out and compared using Six methods Poulos& Davis (1980) analysis, Randolph (1994) analysis, strip on springs analysis, using the program GASP (Poulos, 1991), plate on springs approach, using the program GARP (Poulos, 1994a), finite element and boundary element method of Ta & Small (1996), finite element and boundary element method of Sinha (1996)[7].

Engin and Brinkgreve (2009) proposed the embedded pile model consisting of beam elements with non-linear skin and tip interfaces which was developed in Plaxis 3D to describe the pile-soil interaction in an efficient manner. In this analysis at the pile tip, the soil resistance against compression is represented by means of embedded non-linear spring elements hence, there is no need for mesh refinement around piles as 3D mesh is not distorted by introducing these elements which make embedded piles very efficient and time saving especially when a large group of piles is modeled[8].

Roy et al. (2011) analysis was a simplified design approach based on the nature of the subsoil profile and field tests on pile. The proposed simplified approach for the piled raft foundation on soft consolidating subsoil condition is very helpful for the designer in the first design stage to check the rationality of a piled raft foundation and to investigate both the serviceability requirements as well as the ultimate limit states of the foundation required for a specific project and site condition. It was clearly described that to minimize the differential settlement in piled raft foundation due consideration must be given to both initial as well as consolidation settlement of the raft[9].

Singh B. and Singh N.T. (2011) presents the results of two different types of analysis for the load-settlement behavior of piled raft foundation, namely simplified analysis using MATLAB program and finite element analysis using ANSYS software. Based on the simplified analysis, they found that the load sharing ratio between piles and raft depends on the settlement of the piled raft, and there is no linear relation between them. It was observed that piles reach their ultimate capacity earlier than the raft and increasing the number of piles does not produce the best foundation performance, and there is an upper useful limit. Based on the finite element analysis, it was found that the value of contact stress is found to be a minimum at the center of the piled raft and is a maximum at the corner. The raft thickness affect differential settlement, but has few effects on maximum settlement as well as on load sharing of the piled raft foundation. It was also concluded that for control of differential settlement, optimum performance, a small number of piles can place in the central portion, rather than using a large number of piles uniformly distributed over the raft area[11].

Cho et al. (2012) a series of numerical analysis using ABAQUS (2010) were conducted to investigate the behavior of a square piled raft subjected to vertical load. The 3D elastoplastic FE analyses with slip interface model of pile–soil contact were carried out with drained shear parameters and no consolidation effect for a clay layer. Parameters like pile positions, pile number, pile length and load distribution on the raft were varied and the effects of pile geometries, load levels and loading types were examined. It was found from study that the average settlement could be reduced effectively with wider spaced pile groups with the same number of piles and the differential settlement was minimized by the center area being supported by piles.it was found that the required installation area ratio of pile group for minimizing differential settlement was affected by not only the pile number and length, but also to the load level[10].

Chaudhari and Kadam (2013) explain the need for SSI and methods use for its analysis. By different parametric studies it was observe that the maximum moments of soft clay were much larger than that of silty sand and stiff clay for different cases while the maximum settlements are little affected by soil types. They found that Moment carrying capacity of soil pile structure system is a function of Soil type, pile diameter, Pile configuration and Quantity of concrete. They found that V-shape and U-shape models are optimum combination of pile length in moments as well as concrete quantity point of view[13].

Johnson et al. (2016) did a parametric study on multilayer soil that includes the effect of diameter and spacing of piles with varying raft thickness on settlement. It was observed that raft took more settlement than pile in piled raft foundation while effect of raft thickness has a very little role on reducing total and differential settlements. It was found that pile spacing has important role on both maximum settlement and differential settlement and they reduce with decrease in pile spacing while when the pile diameter is increased we found decrease in maximum and differential settlement under all loading conditions[14].

Sinha and Hanna (2016) were developed a 3D finite-element model for study the effect of the governing parameters on the performance behavior of piled raft foundations. They used Abaqus software (based on solid mechanic's principles) and the modified Drucker–Prager cap plasticity model which provides a suitable basis for analyzing the stress–strain of soil continuum constitutive law. In their study they consider mesh of 30 times the pile size in width and twice the pile length which is suitable for analysis of the problem without any boundary effects. They found that pile cross-sectional shape (rectangular, octagonal, and circular) does not have any effect on the results. In analysis the raft settlement increases when we increase in pile spacing and decreases with the increase in the length & pile size and for pile spacing greater than 6 times the pile size, the system tends to function as a raft foundation. When thinner raft was considered the non-uniform load shared by the piles, which caused differential settlement within the raft and failure of the overloaded piles while a thicker raft was minimized or eliminate differential settlements. The settlement of the raft decreases with the increase of the angle of shearing resistance and the cohesion of the soil. The study shows that for economical design, engineers can make correlation between the pile spacing and pile length[15].

Thoidingjam and Devi (2017) researched for the utility of piled raft foundation for soils present in the valley areas of Manipur which are fluvial-alluvial soils with clay interspersed with organic clay. In their paper they give the details of tests carried out on piled raft system of foundation embedded in clay soil. With different numbers of piles, it was observed that settlement decreases as the number of piles increase so piles contribute as settlement reducers in the system and the rigidity of the raft influences the load carrying capacity of the pile. Higher rigidity gives higher load and lesser settlement of piled raft system in organic clay[16].

Aswathy and Bindu (2017) perform a series of experiments and numerical analyses to investigate the behavior of piled raft with various stiffness inserts and come with the result that it improves the overall behavior of piled raft. It was resulted that the effective of material for controlled stiffness inserts (CSI) should be more elastic under loading and its deformation should be within limits. When they did changes in thickness of CSI, a minimal effect on performance of piled raft foundation was observed[17].

Chenari et al.2018 study the effect of heterogeneity of clayey soil on the bearing ratio of piled rafts was studied considering the coefficient of variation (COV) as the most affecting statistical parameter. The contribution of the raft and the piles in bearing capacity were calculated employing the log-normally distributed undrained shear strength and Monte Carlo simulation. Regarding the effect of geometrical position of the piles on their load bearing contribution, it can be concluded that the corner and central piles have the most and the least role in bearing capacity, respectively, mainly due to the axi-symmetrical nature of the model[18].

Mali and Singh, 2019 prepared a three-dimensional finite element model to evaluate the settlement, load sharing, maximum bending moment and maximum shear force behavior of piled raft foundation for different load configurations, pile raft configurations and soil profiles. They found that for any pile spacing, the average settlement, load-sharing ratio, maximum shear force are observed to be maximum in varying soil profile, whereas maximum bending moment is observed to be maximum in homogeneous soil profile.For any PRC and any pile spacing, the average settlement is marginally affected by the load configurations, whereas differential settlement is noted to be more for PRC with equivalent point loading. The load-sharing ratio is observed to be lesser for uniform distribution load , and the difference becomes marginal at larger pile spacing. The maximum bending moment and maximum shear force (except 6 m pile spacing) are observed to be lesser for UDL and EPL, respectively[11].

III. CONCLUDING REMARKS

1. Piled Raft foundation is economical way of foundation design in compared to conventional pile foundation design.
2. Research shows that the interaction between raft and piles makes it possible to use the piles up to a load level which can be significantly higher than the permissible design value for the bearing capacity of comparable single standing pile.
3. It was observed that piles reach their ultimate capacity earlier than the raft and increasing the number of piles does not produce the best foundation performance, and there is an upper useful limit.
4. It was also found in many finite element analysis, that the value of contact stress is minimum at the center of the piled raft and is a maximum at the corner which shows that for control of differential settlement, optimum performance, a small number of piles can place in the central portion, rather than using a large number of piles uniformly distributed over the raft area. The average settlement could be reduced effectively with wider spaced pile groups with the same number of piles.

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