Performance Assessment and Design Review of Piled Raft Foundations on Silty Sand Beds

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Abstract

This review study gives an in-depth look at the analytical and design concerns for PRF designed particularly for silty sand soil beds. Because of its intermediate particle sizes and intrinsic variability, silty sand presents distinct geotechnical issues. The research investigates the mechanical characteristics, settlement behaviour, and load-bearing capacity of silty sand soils, emphasising the complications of differential settlements and probable liquefaction. It brings together previous research on analytical methodologies, numerical modelling techniques, and novel tools for forecasting the performance of piled raft foundation on silty sand. Real-world case studies are scrutinised in order to get insights into successful applications and problems. The study also assesses existing design codes, addresses sustainability issues, and suggests future research possibilities, making it a significant resource for geotechnical engineers and researchers in the subject. It strives to discover research trends, authors, nations, and organisations using Vos viewer. This article shows how development efforts may be continued in the present climate. The Scopus and Web of Science databases are utilised to gather relevant literature on the issue as the study object.

Keyword: Piled Raft Foundation, Silty Sand, Geotechnical Engineers, Vos viewer.

1. Introduction

A structure's foundation is vital because it fortifies and conveys the weight of the higher levels to the earth below, strengthening the building. In the sphere of shallow and deep foundations, the use of horizontal or vertical reinforcing devices to enhance bearing capacity and decrease settlements is a disputed subject. One solution to geotechnical crises is a "Piled Raft Foundation (PRF)", which combines a small raft footing with a deep pile foundation. The raft has an appropriate number of piles to maximise bearing capacity and settling, both of which are key geotechnical design factors. Unconnected raft foundations entail the separation of the raft and piles, while linked raft foundations feature the connectivity of the raft and piles. The unconnected piled raft system is a cost-effective and efficient way to ensure the stability of high-rise buildings, structures built on unstable soils, and structures capable of withstanding horizontal pressures. When the raft and piles are structurally coupled, lateral forces are quickly transmitted to the piling head, potentially causing connection damage. Even if separate stakes are used to stop the ground from shifting, the passive pressures on the basement walls and the adhesion at the soil surface contact may be stronger than the lateral forces. This stickiness, when combined with passive resistance, is sufficient to stop lateral forces such as earthquakes. Detachable foundations are most often seen in bridges, where a gravel layer prevents shear and bending forces from flowing from the superstructure to the substructure. The mudline level of the bridge is made up of a solid layer of sand and silt up to a particular height, followed by a pier. This stratum's soil profile is made up of silty clay, silty sand, and silty sand. In such circumstances, the structural integrity of the pile rather than its geotechnical resilience determines its load-bearing capacity. Shifting the load to the pier will strengthen the structure's resilience to intense seismic loads and gradually minimise settling by ensuring that the weight is distributed equally throughout the sediment base.

Numerous studies have been conducted to explore PRF with no connections. Load resistance capacity increased significantly throughout the three soil density stages (loose, medium, and denser). When compared to the unstructured state, the denser condition resulted in a 50% drop in settling and an increase in pile count [1]. The change in the raft's length, stiffness, arrangement, and pile count resulted in a decrease in bending moment and differential settling. Although lengthening the length of the piles stabilised the foundation system, it did not result in an increase in the bearing capacity of the foundation [2–5]. Following research into the characteristics of piles used as soil reinforcing devices [6, 7], a decreased factor of safety was introduced in the pile design. Over a six-month period, the 3x3 disconnected PRF solution reduced concrete slab settling by 22% as compared to field values. In terms of settlement reduction, the PRF outperformed the detached raft foundation. Slab settlements decreased by 13% to 68%, and pile head settlements decreased by 20% to 65% [8, 9]. When the ABAQUS finite element analysis package was used to look into how piles move load in a cushion-divided, unconnected raft [10], the biggest settlement was cut by 78%. The load-sharing processes of connected and unlinked piled rafts were investigated, taking into account the relative stiffness of the pile and raft as well as the effects of negative skin friction. If the stiffness of the particulate material does not improve, the linked PRF will be more efficient than the unconnected one [11, 12]. It is vital to build settlement reducer foundations that can withstand seismic loads and have a bearing capacity of at least 80% of the service load [13]. The thickness of a raft has a significant effect on its load-bearing capacity, whereas its impact on the load capacity ratio and the settlement degradation ratio is insignificant [14–16]. Poulos and Davis pioneered the idea of (PRF) [17]. Burland et al. advocated applying the piling group in a second experiment to alleviate the effects of settling [18]. Numerous studies have been conducted to study the load-bearing capability of piles and rafts in order to develop piled-raft foundation systems. Fundamental processes [19], semi-analytical approaches [20], and numerical methods [21] are among the tools available for analysing the load-bearing capability and behaviour of PRF. When using a traditional PRF, the raft's function in resisting lateral and vertical loads is sometimes overlooked [22]. Recent research used both small-scale and large-scale models to investigate the influence of the raft on vertical load. When defining the length, spacing, and soil-carrying capability of pilings, modern architects consider the lateral load contribution in addition to the vertical load[23] [24]. CPRF (CPRF) use rafts to lower the cost of creating foundations for tall structures. The importance of lateral load is often overlooked. Wind, seismic activity, and retaining wall pressure are all examples of unexplored lateral stresses in pile rafts. Several characteristics impact the response of piled rafted rafts to lateral stresses, including pile-head rigidity, relative stiffness, pile spacing, pile-raft interactions, and pile-soil interactions [25]. The horizontal stress response of PRF is still poorly understood [26]. In seismically active areas such as Kutch, Gujarat, and India, piled rafted-raft foundations must be constructed using a seismic approach [27]. While piles are seldom employed in seismic designs, pile-raft foundations have been used in India [28]. As performance-based design becomes increasingly common in geotechnical engineering [29], the behaviour of PRF under horizontal loads must be considered. This paper investigates the use of centrifuge modelling for PRF foundations. Pile-raft interactions in silty soils may be studied using centrifuge modelling [30].

2. Literature review

PRF are popular due to their ability to increase bearing capacity, decrease settlement and reduce differential deflection. They support some of the superstructure's weight through earth contact, while the piles support the rest through skin friction. PRF are less expensive and require less drilling for termination at higher elevations. However, they sink more than pile-raft foundations. Factors such as raft size, thickness, pile diameter, length, spacing, and the interconnection of a G+20-story tower affect piled-raft foundations. The appropriate mix of foundations is crucial for minimising differential settling and moment [31].

This study uses a 1G model to look at a PRF base that is under vertical axial stress. It focuses on finding the best way to build a PRF based on the settling ratio. The foundation is composed of multilayered earth and load-settling graphs show different pile arrangements, lengths, and spacings. The raft's thickness is kept constant to maintain capacity. The optimal PRF construction is chosen based on the settling ratio, which decreases and vanishes beyond a 4x4 pile design with a 3.75D gap between piles. The study found that as the number of piles increases, the settlement ratio decreases from 0.929 to 0.032, while as the L/D ratio increases, the (settlement ratio) SR remains constant. The research examined how combined pile-raft foundations with various pile group configurations settle using numerical models and real-world data. The study used "static loading," but "dynamic loading" could be explored. Instead of "circular piles," "bulb piles" can extend the research [32].

According to Jaymin patel et.al. global urbanisation has increased the quantity and height of structures, some with poor subsurface infrastructure. These challenging subsurface conditions need piled rafted rafts. It uses a significant vertical force to regulate structural tilting, differential settlement, and settling. The PRF approach is cheaper than piling foundation. Structural and geotechnical engineers must work together to find the most cost-effective and secure piling raft foundation system that accounts for soil-structure interactions. PRF operate effectively in layered, Silty, and clayey soils, according to analysis and experimentation [33].

PRF combine the best of deep and shallow foundations, consisting of raft, piles, and subsoil. These foundations transfer loads between the raft and piles to support the foundation, reducing settlements and ensuring proper performance. These interactions must be modelled using reliable analytical methods like finite element analysis and a good constitutive rule. This research examines pile diameter and raft thickness in piled-raft foundations using computer models. The study examines medium-thick sand (-soil), clayey sand (c-soil), and clayey soil for a 25-story building using elasto-plastic springs in FEM modelling. The research also includes temporal history analysis, finding that the first three modes have the lowest time period for soil and the longest for C soil. The footing's foundation was subjected to three-time histories with different PGAs and lengths for dynamic investigation. Bhuj has the longest and greatest PGA experience, while El Centro has the shortest [34].

Piled raft-raft foundations are superior to deep or shallow ones, consisting of raft, piles, and subsoil. These foundations transfer loads between the raft and piles, reducing settlements and structural tilting. The seismic bearing of a PRF foundation is determined by complex soil-structure interactions, which must be modelled using reliable analytical methods like the finite element approach and a good constitutive rule. This study examines the seismic behaviour of a 25-story PRF foundation system on different subsoils, highlighting the importance of soil-structure interaction studies in high-rise construction projects. The study found that cohesion-less piles at 15 and 30 metres had the lowest acceleration response and X-direction displacement. After thorough testing, a thick sand subsurface and piled-raft foundation significantly increased the structure's bearing capacity [35].

A finite element geotechnical tool called PLAXIS3D is used to look at the Combined Pile-Raft Foundation (CPRF) pile head connection reaction. The study uses experimental data to examine the CPRF's reactions to earthquake loadings, such areas ares 2001 Bhuj, 1995 Kobe and 1989 Loma Prieta, and. The results show that vertical load alone does not affect settling, with hinged connections having a 30% raft load sharing, while properly connected devices have a 54% load sharing. Regardless of connection stiffness, rafts mobilise ultimate resistance quicker than piles under earthquake loads [36].

The study also investigates the cost-effectiveness of coupled pile raft foundations when they can fulfil bearing capacity but cannot keep differential and maximum settlement below the limit. The study uses PLAXIS 3D to model and investigate three pile diameter combinations for CPRF permuted piles. The researchers calculated the loads to be transferred from a 10-story medium-density sand construction using STAAD.Pro.

Multiple pile designs were employed in PRF models and evaluations. Comparing the results showed that placing high-capacity piles in the load concentration and strengthening the rest of the raft with medium-capacity piles reduced differential settlement and maximum settlement the most. The study recommends using larger-diameter piles in the interior to minimise differential settlement and maximum settlement and using variable-diameter heaps instead of equal ones in any soil. The pile designs in the raft minimise differential and maximum settling, notably in the centre [37].

In the Manipur valley of Imphal, construction problems are common due to organic clay in the soil substratum. To reduce settlements caused by concentrated building loads, use a pile-raft foundation. The study found that increasing the number of heaps from 1 to 9 enhanced final bearing capacity and settling. Settlement is slow when the raft is alone and fast when the pile group is alone, but slows with big loads. The study highlights the importance of using a PRF with more piles to minimise differential and maximum settlement and improve bearing capacity in hardening organic, clayey, and soft soil [38].

Laboratory experiments on sand soil have been conducted to study vertical stresses on PRF constructions. The study includes a model test on two-by-two and three-pile groups, an un-piled raft, and a single-pile raft. The model piles are stationary and use 10 mm-diameter, 200-mm-long model mild steel piles with a slenderness ratio of 20 L/D. The load improvement ratio increases bearing capacity, while the settlement reduction ratio decreases settling. The test results show that adding piles beneath the raft improves load improvement and settling reduction ratios while reducing load. A thicker raft does not affect its load improvement ratio, settling reduction ratio, or maximum load [39].

PRF have become popular due to their ability to increase bearing capacity, decrease settlement, and reduce differential deflection. They cost less than pile foundations and can be terminated at higher elevations without drilling through the clay layer. This study examines factors affecting PRF behaviour, including raft size, thickness, diameter, length, pile arrangement, stiffness, and the pile-raft stiffness relationship. The interconnectedness of these factors may help determine piled rafted-raft foundation standards [40].

Geotechnical engineers face problems when planning and erecting foundations on soft ground, including excessive settlement and bearing capacity failure. This study investigates the load-settling behaviour of piled and un-piled rafts in soft clay. The model tests employ 1x1, 2x2, and 3x3 raft layouts, with slimness ratios of 23, 27, and 30. The SR and LIR ratios showed that settling decreased while the final load increased. A metric study showed that pile length and heap number reduce settling [41].

For high-rise buildings, piled-raft foundations are preferable to pile or mat foundations. Conventional pile raft foundations lack contact impact calculations and should support axial loads with a safety factor and controlled settling under operational load. This research analyses how uneven vertical stresses affect a pile-raft foundation with different-sized piles. PRFhave less vertical settling than single and typical ones. To avoid vertical settling and enhance load bearing, use the pile raft method with different-sized piles for the same number [42].

By carefully placing piles under the raft, connected pile raft foundations (CPRF) may decrease differential and total settling [43]. Ataa et al. [2] explore the Unconnected Pile Raft Foundation. After looking beneath the raft, he spotted the cushion spreading the weight. Like CPRF, UCPRF is well-positioned. However, UCPRF is a rudimentary method that might be ineffective in some situations. The author believes CPRF-UCPRF foundation systems will be more efficient and cost-effective. Combining CPRF with UCPRF may be cost-effective after further investigation. When built at a critical point (identified by modelling or another way), a connected pile system may minimise differential settling. To reduce settling, use thicker cushions with higher elastic moduli [43].

India has seen numerous large-scale construction projects in the last two years, with buildings above 40 floors and 150 metres tall. Foundations for these projects can vary greatly based on structural load and underlying circumstances. Piled rafting rafts have become a popular foundation for construction to reduce differentials and total settlements. Sap2000 v14 uses computer-aided finite element coding to evaluate different foundation structures, using the modulus of each soil layer to calculate piled rafted rafts buried in layered soil. A flexible structure has a longer natural period than a comparable supported structure without soil-structure interaction. A time history analysis shows that the structure's top acceleration at 0.5 and 1 hour is less than that of a rigidly supported structure, reducing acceleration for SSI. Both SSI and non-SSI designs accelerate more towards the peak. Piled raft-raft foundations detect tops better than raft foundations, and raft foundations tilt under lateral static strain [44].

3. Methods of PRF

- Site Investigation
- Pile Installation
- Pile Types
- Pile Arrangement Raft Design
- Pile-Raft Interaction
- Geotechnical Considerations
- Load Testing
- Construction Sequencing
- Quality Control
- Settlement Monitoring
- Water Table Considerations

PRF are particularly useful in areas with complex soil conditions or where traditional foundations may not be suitable. Professional geotechnical and structural engineering expertise is essential for the successful design and implementation of PRF.

4. Methods analysis of PRF

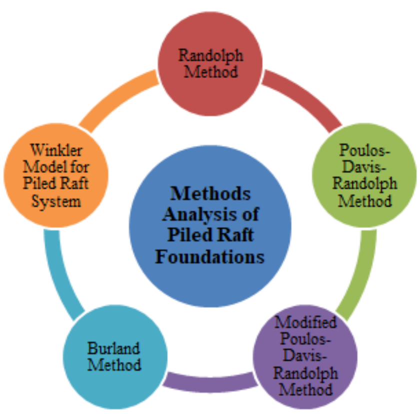

Fig. 1. Methods analysis of PRF

4.1 Randolph Method (1994)

In this method, analogous rafts with a single pile reaction are utilized to anticipate the CPRF system response. This approach may be used to estimate common CPRF system settling as well as pile and raft load percentages. Randolph accommodates for differences in soil depth and stiffness along the shaft, head, and tip of the pile. Randolph disregards the soil's strength (cohesion, friction angle) and the raft's flexibility [20].

4.2 Poulos-Davis-Randolph Method (2001)

The trilinear settling curve defines this strategy. The ultimate capacity of the CPRF (Pu) and the load (P1) at which the pile capacity is completely mobilized are determined using this approach. We can derive "K_{pr}" by combining the stiffness of the pile group "K_p" and the raft "Kr." This approach may be used to calculate the weight distribution between the pile and the raft. The Randolph technique and elastic theory are used to calculate the raft stiffness and pile-raft interaction factor. The intricate interaction between piles, rafts, and soil was the focus of the Poulos-Davis-Randolph approach for assessing PRF, proposed in 2001. Renowned geotechnical scientists have developed a system that combines classic geotechnical concepts with cutting-edge computational technologies. To define the foundation system, a cutting-edge finite element analysis (FEA) framework is applied. This approach treats piles as distinct entities and takes into consideration non-linear soil-pile interactions. This technique takes into consideration the soil's nonlinearity, raft stiffness, and pile flexibility to characterize load distribution, settlement behaviour, and the performance of PRF. The Poulos-Davis-Randolph method includes advanced soil-structure interaction features that make it easier to get more accurate and reliable assessments of PRF. This is important for engineers who have to design foundations in tough soil conditions [45].

4.3 Modified Poulos-Davis-Randolph Method

For PRF design, this approach uses a hyperbolic settling curve rather than a trilinear one. The load affects both the raft and the pile stiffness in this manner. This method shows the nonlinear part of

PRF systems by figuring out the maximum settlement that CPRF can handle and the load level at which it stops being linear. The PRF must not exceed the nonlinear load threshold to prevent plasticizing. As the load grows, the CPRF becomes nonlinear. SA emphasizes the CPRF system's ability to settle. It is always the objective of the design process to avoid exceeding the threshold in order to prevent plastic CPRF behaviour and excessive settlement [46].

4.4 Burland Method

Only after the piles have reached their maximum geotechnical capacity can this simplified approach for the geotechnical and structural design of PRF be employed. The load is calculated by subtracting the permissible raft settlement from the total load. Professor John Burland devised the simple and economical Burland Method for PRF foundation analysis. Using subgrade response, this technique manages the interaction between the soil, piles, and rafts as springs with variable stiffnesses. Separate the raft into rectangular portions that simulate the foundation system by displaying subgrade response via springs and interacting with the earth. Engineers may use this approach to quickly study the settling and load distribution of PRF for preliminary evaluations with minimal calculations. When a more extensive study is not possible, the Burland Method's simplicity and ability to give insights into the functioning of PRF systems make it useful, despite its simplified model [47].

4.5 Winkler Model for piled raft foundation (WMPR)

Randolph is the foundation of WMPR. Any finite element program can be used to assign Winkler Springs and figure out the stiffness of piles and rafts using Randolph's findings on settling. The interaction variables between piles and rafts were entered into the Randolph (1994) and Poulos (2000) models to estimate stiffness. This simpler method may be used to calculate the bending moments of piled rafted rafts. The Winkler Model for Piled Raft System (WMPR) is a simple yet effective technique for assessing PRF. The earth underneath the building, according to the Winkler foundation idea, operates as a network of separate springs. A WMPR increases the number of piled rafts. This view sees the raft as a flexible plate resting on individual springs, which represent the soil-pile system. We can observe how the raft reacts to stresses by measuring the lateral and vertical stiffness of the piles. WMPR allows engineers to anticipate the performance of piled-raft foundations in situations where more extensive numerical simulations are not required or possible. It makes the interaction between soil and structure easier [48].

5 Bibliometric analysis

This report provides the findings of a bibliometric analysis of computer vision publications and their applications to piled raft foundation analysis. The investigation's primary objectives are scientific mapping and performance analysis. Scientific mapping exposes the links between these records, while performance analysis provides users with statistics on bibliographic data. Vos viewer is a go-to tool for creating nodes and links in bibliometric connection diagrams. Each "node" in the network diagram represents a person, place, publication, or organization. The connections between nodes might reflect the degree to which two events occur concurrently. The breadth indicates how often an item occurs with other nodes, while the size indicates how frequently it occurs. The closeness of nodes and the colours used to depict them in a network diagram indicate the strength of the connections between them.

5.1 Presentation analysis

Performance analysis is significantly used in literature reviews since it exposes trends in the most relevant areas of the study. Annual publication and citation patterns, as well as prominent nations, institutions, journals, and publishers, are among these criteria.

5.2 Publication characteristics

Analysing the number of publications and citations in a certain subject is a typical method for determining the relevance of a technology within that sector. The publication and citation history are shown in Figure 2 in chronological order. The illustration displays a growing number of citations and publications. The number of publications is expected to rise further until 2023, continuing a trend that started in 2015. According to this study, computer vision technologies are revolutionising piled raft analysis.

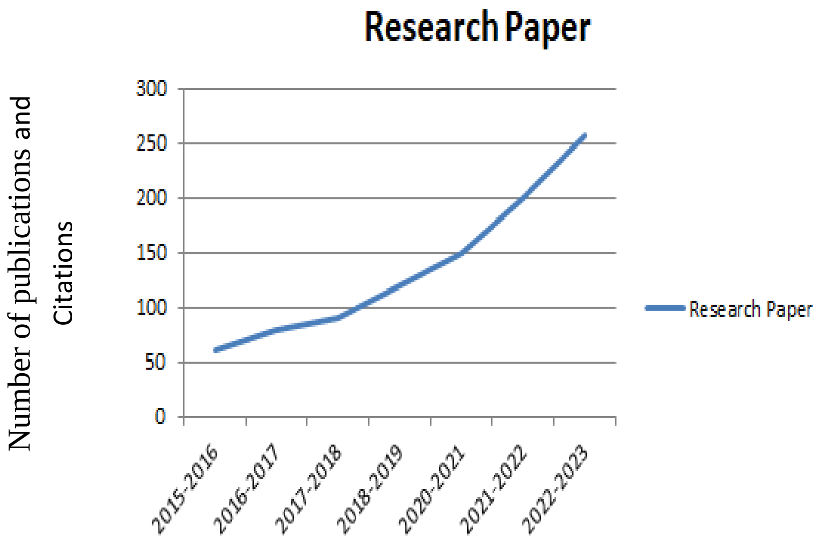

Fig. 2. Shows a trend in terms of the number of publications and citations as a function of year

Citation analysis was used to build the network map of country ties shown in Figure 3. A "node" represents each nation. The number of publications in each country determines the size of the node. Connections between nodes establish links to nations. The link width determines the strength of citation relationships. Geographic proximity is what determines national affinity. Citations are classified by the colour of a country.

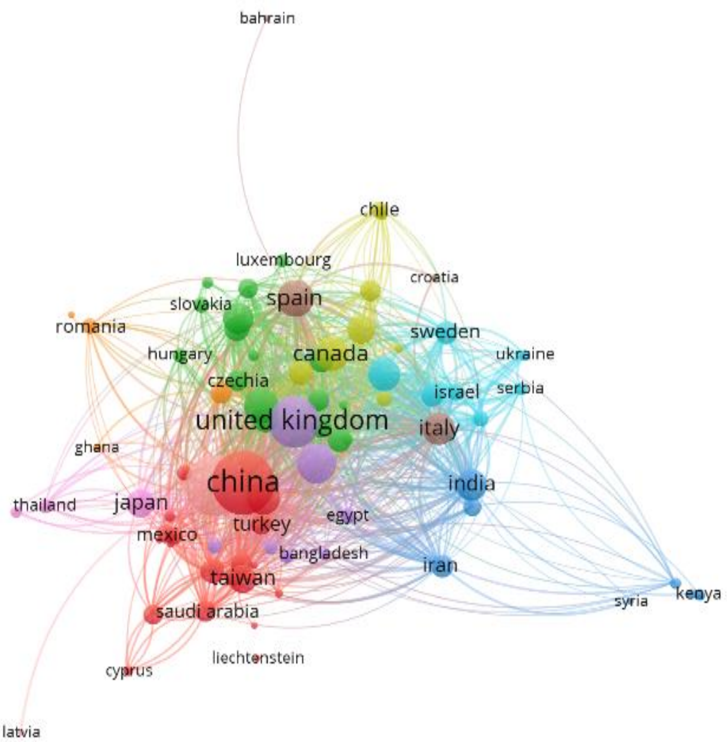

Figure 3 Network map of countries

6 Software used for analysis of piled raft foundation

There are several pieces of software available for analysing PRF, which are a kind of building support system that uses both piles and rafts. These approaches evaluate foundation behaviour by taking into consideration the interaction of the pile, raft, and soil. The following are some popular pile-raft foundation analysis programmes:

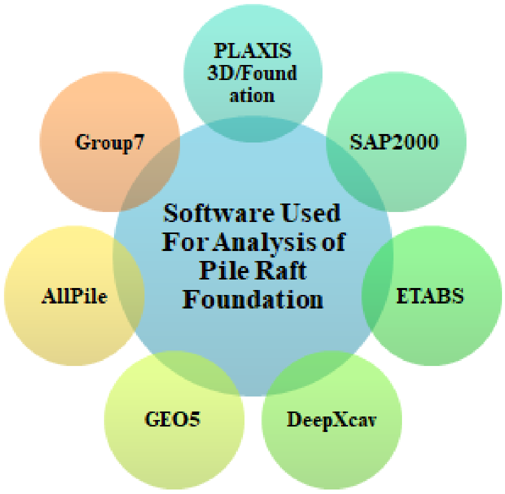

Fig. 7. Software used for analysis PRF

1. **PLAXIS 3D/Foundation:** PLAXIS is a widely used finite element analysis (FEA) software that includes modules for geotechnical engineering. PLAXIS 3D/Foundation is specifically designed for analysing pile foundations and raft systems [36].

2. **SAP2000:** SAP2000 is a structural analysis and design software that can be used for pile-raft foundation analysis. It's a versatile tool that allows for the modelling and analysis of complex structures, including those with pile foundations [49].

3. **ETABS:** Similar to SAP2000, ETABS is another structural analysis and design software that can be used for analysing pile-raft foundations. It's particularly useful for modelling and analysing buildings with irregular shapes and configurations [50].

4. **SAFE:** Safe is specialized software for the analysis of piles, and it includes features for considering the interaction between piles and raft foundations. It's focused on the analysis of pile groups.

5. **GEO5:** GEO5 is a suite of geotechnical software tools that includes various modules for analysing different aspects of geotechnical engineering, including foundation design. The Pile program within GEO5 can be used for pile-raft foundation analysis [51].

Finite element analysis (FEA) and other simulation methods better depict the intricate interactions between the foundation, piles, and soil layers. This combination of advanced modelling methods optimises piled raft foundation designs and balances cost and structural performance.

6.1 Finite Element Analysis PRF analysis

Finite Element Analysis (FEA) is a powerful numerical method widely used in geotechnical engineering to analyse complex structures like PRF. When it comes to PRF analysis using FEA, several key steps and considerations are involved:

1. Geometry and meshing: The first step in FEA involves creating a geometric model of the piled raft foundation. This model includes the piles, raft, and the underlying soil. The geometry is then discretized into smaller elements, forming a mesh. The meshing process is crucial, and finer meshes are often required near areas of high stress or strain.

2. Material properties: Assigning appropriate material properties is essential. This includes properties for the piles, raft, and soil. Pile properties may involve considering nonlinear behaviour, such as pile-soil interaction. Soil properties, including shear modulus and Poisson's ratio, play a significant role in accurately representing the behaviour of the foundation system.

3. Boundary conditions: Applying realistic boundary conditions is critical for obtaining meaningful results. This involves constraining certain degrees of freedom at appropriate locations to simulate the real-world constraints. The boundary conditions influence the response of the foundation under loading.

4. Loading conditions: Defining the loading conditions is a key aspect. Various load cases, such as vertical loads, lateral loads, and moments, should be considered. Additionally, time-dependent loading or staged construction loads can be simulated to capture the transient behaviour of the foundation.

5. **Pile-Soil interaction models:** Pile-soil interaction is a complex phenomenon that needs to be accurately represented. Various models, such as p-y curves for lateral analysis and t-z curves for axial analysis, can be employed to simulate the interaction between the piles and surrounding soil.

6. **Analysis types:** Different types of analyses may be performed depending on the objectives. Static analyses are common for evaluating the foundation under steady-state loading, while dynamic analyses may be necessary for considering the effects of dynamic loads or seismic events.

7. **Consideration of nonlinearities:** Nonlinearities, such as soil yielding, pile-soil interaction, and large deformations, should be considered where applicable. Nonlinear FEA allows for a more realistic representation of the actual behaviour of the piled raft foundation.

8. **Post-Processing and interpretation:** After completing the analysis, post-processing involves interpreting the results. This includes evaluating settlements, stresses, and deformations to assess the performance of the piled raft foundation under different loading conditions.

9. **Sensitivity analysis and optimization:** Sensitivity analysis can be conducted to understand how variations in input parameters affect the response. This information is valuable for optimizing the design parameters for better performance.

In finite element analysis is a versatile tool that enables engineers to simulate and understand the complex behaviour of PRF. It provides valuable insights into the interaction between structural elements and the underlying soil, helping engineers make informed decisions during the design process.

6.2 Piled Raft design parameters on load-Settlement

The design parameters of PRF have a profound impact on the load-settlement behaviour of the foundation system. Several key parameters influence how the structure responds to vertical loads and settles over time:

1. **Pile spacing and arrangement:** The spacing and arrangement of piles within the raft directly affect load distribution. Properly spaced and arranged piles help to minimize differential settlements by ensuring a more uniform transfer of loads to the underlying soil. Optimal spacing prevents excessive settlements in localized areas, contributing to a more stable foundation.

2. **Pile length and diameter:** The length and diameter of the piles are critical factors. Longer piles extend into deeper, more stable soil layers, providing enhanced support and reducing overall settlement. Larger diameter piles contribute to increased load-bearing capacity, affecting the load-settlement characteristics of the foundation.

3. **Raft stiffness:** The stiffness of the raft influences how loads are distributed across the foundation. A stiffer raft tends to reduce settlements by spreading the loads more efficiently. However, the interaction between the stiffness of the raft and the piles must be carefully considered to achieve the desired load-settlement response.

4. **Soil-structure interaction:** Understanding the interaction between the foundation and the underlying soil is crucial. Soil properties, such as shear strength and compressibility, play a significant role in determining the settlement behaviour. Advanced geotechnical analysis, including finite element analysis, helps model the complex interaction between the piled raft and the soil.

5. **Load magnitude and distribution:** The magnitude and distribution of applied loads influence the settlement response. Varying load patterns and magnitudes can result in differential settlements. The design must account for different loading scenarios to ensure the foundation performs adequately under various conditions.

6. **Construction sequence and timing:** The construction sequence and timing also impact the load-settlement behaviour. Rapid loading or uneven construction can lead to uneven settlements. Implementing appropriate

construction sequences and allowing for sufficient time for consolidation are essential considerations.

7. **Foundation shape and size:** The overall shape and size of the foundation, as well as the location of piles, can affect settlements. Irregularly shaped foundations may experience uneven settlements, emphasizing the importance of a well-balanced design.

The careful consideration and optimization of these piled raft design parameters are essential for achieving the desired load-settlement performance. Engineers must employ a holistic approach that takes into account soil characteristics, structural elements, and loading conditions to ensure the foundation's stability and minimize settlements over time. Advanced analysis methods and thorough site investigations are integral parts of the design process to accurately predict and control settlement behaviour.

6.3 Finite Element Analysis by simulating piled-raft in the plaxis-3D

Performing a finite element analysis (FEA) of a piled-raft system using Plaxis-3D involves several steps. Plaxis 3D is a specialized geotechnical software designed for 3D analysis of soil-structure interaction problems. Here's a generalized step-by-step guide:

1. **Geometry and Model Setup:** Define the geometric layout of the piled raft, including the location and properties of piles and the raft. Set up the dimensions and elevations accordingly.
2. **Mesh generation:** Create a finite element mesh for the soil, piles, and raft. Adjust the mesh density based on the anticipated stress concentrations and areas of interest. Plaxis 3D allows for both structured and unstructured meshing.
3. **Material properties:** Assign material properties to the soil, piles, and raft. Include geotechnical parameters such as soil stiffness, cohesion, friction angles, and pile properties like Young's modulus, Poisson's ratio, and interface properties for pile-soil interaction.
4. **Boundary conditions:** Apply appropriate boundary conditions to the model. This includes constraints and supports to simulate the realistic behaviour of the foundation under loading conditions.
5. **Loading conditions:** Define the loading conditions for the analysis. This could include vertical loads, lateral loads, moments, or any combination of these. Account for staged construction or time-dependent loading if applicable.
6. **Pile-Soil interaction Models:** Implement pile-soil interaction models available in Plaxis 3D. This may involve defining p-y curves for lateral analysis, t-z curves for axial analysis, and considering the non-linear behaviour of the soil.
7. **Analysis type:** Choose the appropriate analysis type based on your objectives. Plaxis 3D supports various analysis types, including static, dynamic, and consolidation analyses. Select the appropriate analysis settings and options.
8. **Run the analysis:** Execute the analysis and monitor the convergence. Plaxis 3D will solve the equilibrium equations and provide results for displacements, stresses, and other relevant parameters.
9. **Post-processing:** After the analysis, review and interpret the results using the post-processing tools in Plaxis 3D. This includes visualizing settlements, stress distributions, and deformations.
10. **Validation and Sensitivity Analysis:** Validate the results by comparing them with available analytical solutions or field data. Perform sensitivity analyses to understand the impact of variations in input parameters on the response of the piled-raft system.
11. **Optimization:** Based on the results and sensitivity analysis, optimize the design parameters for better performance if necessary. This may involve adjusting pile spacing, length, or other relevant factors.

6.4 Effect of piled raft design parameters on load-settlement and load-sharing response

Load-settlement and load-sharing on pile raft foundations have an impact on structural performance and safety. Many design elements influence these emotions. First, the spacing and arrangement of raft foundation piles impact load-settlement behaviour. Well-placed piles distribute loads uniformly, which reduces settling. Load-

sharing between adjacent piles and the raft has an influence on how the foundation bears vertical loads. Load-sharing is improved, and structure-wide settling is reduced with proper pile spacing and design.
Second, pile length and diameter are important. Longer piles may help to stabilise and decrease settling by reaching deeper soil layers. Larger-diameter piles improve load-bearing capabilities, resulting in a shift in foundation load-sharing. To accomplish load-settlement and load-sharing performance, these features must be addressed during design. The stiffness of the raft and piles also has an impact on foundation response. Stiffer piles and rafts reduce settling while improving load transfer and distribution. For successful load-settlement and load-sharing, the raft and pile stiffness must be balanced.

Shear strength, compressibility, and soil properties all have an impact on foundation reactivity. Understanding the soil-structure interaction is required for predicting load-settlement and load-sharing processes. Advanced analytical tools, like finite element analysis, can explain these interactions and assess the impact of design parameters on foundation reactions. Pile spacing, arrangement, length, diameter, raft stiffness, and soil conditions all have an impact on load-settlement and load-sharing. These characteristics must be carefully examined during design to ensure the foundation's optimal performance and long-term stability under various loading conditions.

7. Conclusion

The review article on PRF on silty sand soil beds finishes with a discussion of the complexities and challenges of this geotechnical engineering technology. As this detailed overview of studies and methodologies indicates, taking soil-structure interaction into consideration during design is critical. According to the literature, PRF may improve load-bearing capacity and minimise settlement in silty sand soils; however, pile spacing, length, and arrangement, as well as soil conditions, must be carefully examined. As shown by the synthesis of past research, further empirical studies and field investigations are required to better understand the long-term performance and behaviour of PRF in a variety of geotechnical conditions.

Furthermore, the research emphasises the need to use numerical models and advanced analytical tools throughout the design and analysis stages. Finite element analysis (FEA) and other modelling tools may be used to better depict the delicate interaction between the base, piles, and subsoil layers. The integration of modern modelling approaches in piled-raft foundation designs makes it simpler to achieve a compromise between cost-effectiveness and structural performance. Finally, this review study is a wonderful resource for academics, professionals, and engineers that analyse and build PRF on silty sand soil beds. This study contributes to best practices in geotechnical engineering by integrating existing knowledge and highlighting areas that need further exploration in order to promote safer and more robust foundation solutions for building projects in challenging soil conditions. Using Vos viewer is to find research trends, authors, countries, and organisations. In view of the current situation, this article discusses how to continue with development projects.

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