Examining the potential of Semi Deep foundations as an alternative to Shallow foundations in the foundation design of urban settlements

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Islamabad, Pakistan

(2024)

This is to certify that the Final Year Project Titled

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has been accepted towards the requirements
for the undergraduate degree

in

(BS Civil Engineering)

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DEDICATION

We extend our heartfelt dedication to our parents, teachers, our institution NUST, and all our friends for their unwavering support and encouragement throughout our academic journey. With unwavering commitment and determination, we have undertaken this task, applying our utmost diligence and expertise to fulfill our responsibilities.

DECLARATION

We solemnly affirm and attest that the content presented in this thesis is original and exclusively authored by us. Furthermore, we confirm that this work has not been previously submitted, in its entirety or in part, for any academic qualification at any other institution. Any references or citations to the work of other individuals or institutions have been duly acknowledged and appropriately cited in accordance with academic standards and integrity.

ACKNOWLEDGEMENTS

In the name of Allah, the Most Beneficent, the Most Merciful as well as peace and blessings be upon Prophet Muhammad, His servant, and final messenger.

We extend our heartfelt acknowledgments to the esteemed guidance of **Dr. Abbas Haider,** whose unwavering support, encouragement, and insightful mentorship have been instrumental in the successful execution of this research endeavor. Our gratitude also extends to the dedicated staff of the Geotechnical lab, whose cooperation and assistance during laboratory testing were invaluable to the progress of this project.

Additionally, we are indebted to the support and influence of our esteemed teachers, as well as the unwavering encouragement of our friends and family, whose unwavering support has been a constant source of inspiration throughout this journey. Finally, we express our sincere gratitude to the National University of Sciences and Technology (NUST) for providing an enabling environment that has facilitated our academic and personal growth, empowering us to contribute meaningfully to the advancement of knowledge and the betterment of humanity.

Contents

ABSTRACT

This work investigates the experimental and numerical analysis of shallow and semi-deep (skirted) foundation models on loose sand. The study employs both singly and doubly skirted models, utilizing varying skirt lengths of 0.25B, 0.5B, and 1B to comprehensively evaluate the performance of these skirted foundations under different conditions. The research aims to assess the feasibility of semi-deep foundations as an alternative to traditional deep foundations, with a focus on their application in soils with a relative density of 30%. The experimental setup involves systematically varying the skirt lengths and observing the resultant changes in bearing capacity. Concurrently, numerical simulations are performed to corroborate the experimental findings and provide deeper insights into the underlying mechanisms. Both sets of results consistently indicate that skirted foundations significantly enhance bearing capacity, with the bearing capacity increasing proportionally to the skirt length in both singly and doubly skirted foundations. Notably, doubly skirted foundations exhibit a more substantial improvement in bearing capacity compared to their singly skirted counterparts, suggesting a potential for greater efficiency and stability in practical applications. This comprehensive study highlights the advantages of using skirted foundations in geotechnical engineering, providing a robust alternative to deep foundations and paving the way for more cost-effective and efficient foundation design solutions.

Chapter-1 Introduction

1.1 Introduction

Designing foundations on loose soil strata, such as loose sand, poses significant challenges for engineers due to the insufficient bearing capacity of the soil. When shallow foundations fail to meet the required bearing capacity, the traditional solution has been to resort to deep foundations. However, deep foundations introduce a range of complexities, including the need for driving sheet piles, managing noise pollution and vibrations, and utilizing heavy machinery, which must often be transported to the site. These logistical challenges add significant costs to the project, making deep foundations an expensive option. Although various soil stabilization methods have been developed, they also tend to be costly and come with their own set of complexities.

Skirted foundations offer a promising alternative, particularly in terms of load-carrying capacity and cost-effectiveness. These foundations are relatively straightforward to design and do not require heavy machinery, making them easier and more economical to implement. Skirted foundations are particularly effective in loose soil strata, where they can significantly reduce costs while maintaining structural integrity. They can be designed in various shapes, including square, rectangular, pentagonal, hexagonal, and octagonal, to suit different engineering requirements.

The design of skirted foundations involves adding skirts to existing shallow foundations. These skirts enhance the foundation's stability and bearing capacity by trapping soil between them, which behaves like a stiff material. This trapped soil not only increases the bearing capacity but also provides protection against issues such as water scouring and piping. By mitigating these problems, skirted foundations offer an additional layer of safety and reliability.

This study represents the first comprehensive analysis of semi-deep foundations in Pakistan, focusing on the load-settlement behavior of shallow, square skirted semi-deep foundations with varying skirt lengths. The research includes both numerical simulations and experimental investigations of singly and doubly skirted foundation models. The skirt lengths studied include 0.25B, 0.5B, and 1B, where B represents the breadth of the foundation. Through these varied skirt lengths, the study aims to understand the relationship between skirt length and bearing capacity.

In addition to experimental methods, numerical simulations provide deeper insights into the performance of these foundations under different conditions. While deep foundations are also analyzed in this study, this analysis is conducted solely through numerical simulations due to the impracticality of extensive experimental testing within the constraints of the study.

Overall, this research aims to highlight the advantages of skirted foundations in geotechnical engineering, demonstrating their potential as a viable and cost-effective alternative to deep foundations. By providing a detailed analysis of their load-bearing capacity and settlement behavior, the study seeks to contribute valuable knowledge to the field and pave the way for more efficient foundation design solutions in the future.

1.2 Background

Recent studies have examined the effectiveness of various types of semi-deep skirted foundations, including square, pentagonal, and hexagonal configurations. These investigations consistently demonstrate that semi-deep foundations perform well in loose soil conditions. Typically, the testing in these studies is conducted on soil with a relative density of 30%. Additionally, various parameters, such as skirt size and skirt roughness, have been analyzed to determine their impact on foundation performance. [1] [2]

The findings from these investigations indicate several key points:

- The bearing capacity of skirted foundations increases with greater skirt depth.
- Enhancing the roughness of the skirts also leads to an increase in bearing capacity.
- Skirted foundations exhibit better performance in loose soil strata compared to medium or dense states.

Prior to this study, no similar research had been conducted in Pakistan. This study fills that gap by presenting both experimental and numerical results for semi-deep foundations, specifically tailored to the local sand conditions found in Pakistan. It includes a comparative analysis of shallow, semi-deep, and deep foundations, emphasizing their performance in the locally available sand. By proposing semi-deep foundations as a viable alternative to deep foundations, this research aims to provide a cost-effective and efficient solution for improving bearing capacity in loose soil conditions. The study's comprehensive approach not only advances understanding of skirted foundation behavior but also offers practical insights for geotechnical engineering applications in Pakistan.

1.3 Problem Statement:

The problem statement revolves around advocating for the adoption of semi-deep foundations as a viable alternative to deep foundations. This proposition stems from the recognition of challenges inherent in conventional deep foundation methods and the potential benefits offered by semi-deep foundations. By proposing this alternative, the objective is to address issues such as high costs, lengthy installation times, and environmental concerns associated with deep foundations. The focus is on promoting the use of semi-deep foundations, which offer a balance between depth and accessibility, providing enhanced load-bearing capacity while minimizing excavation and equipment requirements. This shift aims to leverage the advantages of semi-deep foundations in optimizing foundation design, thereby mitigating implementation obstacles and offering a more cost-effective and sustainable solution for supporting structures in construction projects. Ultimately, the problem statement seeks to catalyze innovation in foundation engineering practices, encouraging the adoption of novel approaches to enhance structural stability and resilience in the built environment.

1.4 Aim and Objectives:

The primary aim of this study is to thoroughly investigate the potential of semi-deep foundations as a strategic alternative to traditional shallow foundations, addressing the need for more efficient and cost-effective solutions in foundation engineering.

This investigation is designed to encompass a comprehensive comparative analysis between shallow and semi-deep foundations, meticulously examining their respective advantages and limitations. By doing so, the study seeks to illuminate the circumstances under which semi-deep foundations may offer superior performance, especially in terms of stability, load-bearing capacity, and adaptability to varying soil conditions.

Additionally, a significant focus will be placed on the exploration of the impact of the depth-to-breadth (D/B) ratio on the bearing capacity of semi-deep foundations. This aspect of the research aims to uncover how variations in the D/B ratio influence the overall performance and reliability of semi-deep foundations, thereby providing crucial insights for their optimal design and implementation. Through these objectives, the study aspires to contribute valuable knowledge to the field of geotechnical engineering, promoting the adoption of innovative foundation solutions that balance cost, efficiency, and structural integrity.

1.5 Expected Outcomes:

The expected results entail advancements tailored specifically to foundation engineering practices in urban settings. These enhancements are anticipated to concentrate on refining the design and implementation processes within urban centers. By improving foundation engineering practices, the objective is to tackle the distinct challenges posed by urban construction, including the significant excavation required for deep foundations, noise pollution associated with driving sheet piles, and cost considerations. This could involve adopting innovative approaches like semi-deep foundations to effectively address these challenges in urban environments.

Chapter-2 Literature Review

2.1 Shallow foundation:

Shallow foundations represent a ubiquitous form of footing distinguished by their characteristic feature: an embedment depth typically lesser than their width. In essence, they serve as fundamental supports for various structures, yet their application is often constrained by inherent limitations. One such limitation pertains to their incapacity to furnish adequate bearing capacity, especially in the context of significant construction endeavors. Their shallow nature renders them ill-equipped to withstand the immense loads and forces exerted by large-scale projects, thereby necessitating alternative foundation solutions for optimal structural integrity. Moreover, shallow foundations are prone to experiencing non-uniform settlement when subjected to substantial pressures and forces, a phenomenon that can detrimentally affect the stability and longevity of the supported structures. Consequently, while shallow foundations may suffice for smaller-scale constructions or lighter loads, their viability diminishes in the face of formidable engineering challenges. It is imperative for engineers and architects to carefully assess the suitability of shallow foundations vis-à-vis the specific requirements and demands of a given project, recognizing their inherent limitations and potential consequences on structural performance and stability.

2.2 Deep foundation:

In contrast to shallow foundations, deep foundations, also known as piles, emerge as highly suitable alternatives for substantial projects due to their ability to penetrate the soil to depths exceeding ten times their width. However, despite their evident advantages, deep foundations also present several drawbacks. Notably, they incur considerable expenses, primarily attributable to the sophisticated equipment required for their installation and reinforcement. Moreover, the process of installing and fortifying piles is notably time-intensive, posing challenges in meeting tight project timelines. Despite these drawbacks, piles remain the preferred choice for heavy, tall, and critical structures where their robust load-bearing capabilities are indispensable. Nonetheless, the widespread adoption of deep foundations is impeded by various factors, including the substantial costs involved, protracted installation periods, and environmental concerns associated with activities such as drilled shafts and pile driving. As such, while deep foundations offer unparalleled support for monumental projects, their widespread utilization is curtailed by practical considerations and logistical constraints.

2.3 Semi-deep foundation:

Following an exhaustive review of foundation research literature, our final year project introduces the innovative concept of semi-deep foundations as a compelling solution to address structural support challenges. Semi-deep foundations represent a distinct category within the realm of foundation engineering, distinguished by their performance characteristics and growing significance as an optimal alternative to traditional deep foundations. These foundations offer a unique balance between depth and accessibility, making them particularly well-suited for supporting structures within reachable depth ranges.

Unlike shallow foundations, which are limited in their depth, and deep foundations, which penetrate the soil to much greater extents, semi-deep foundations strike a middle ground. They have the capability to penetrate into the soil up to four times their width, thereby significantly enhancing bearing capacity while maintaining a level of accessibility that is often impractical with deep foundations. This feature makes them versatile and adaptable for various construction scenarios, offering improved load-bearing capabilities without the need for extensive excavation or specialized equipment.

One of the key advantages of semi-deep foundations lies in their ability to optimize foundation design while minimizing costs and implementation complexities. Unlike conventional deep foundation methods, which often entail significant expenses and logistical challenges, semi-deep foundations present a more streamlined and cost-effective solution. By reducing the need for extensive excavation and specialized equipment, they offer a practical alternative that is more accessible to a wider range of construction projects.

Moreover, the implementation of semi-deep foundations is accompanied by fewer restrictions in terms of allowable costs and implementation obstacles. This makes them a particularly attractive option for projects with budgetary constraints or time-sensitive requirements. By offering a balance between performance, accessibility, and cost-effectiveness, semi-deep foundations emerge as a promising avenue for addressing foundational needs across a diverse array of construction projects. [1] [2]

2.4 Assembly of semi-deep foundations:

The assembly of semi-deep foundations involves the incorporation of skirted foundations, a term denoting shallow foundations augmented with skirts affixed around their circumference. These skirts serve a crucial function by creating an enclosed space within which the soil is tightly confined, effectively transforming the foundation and skirt combination into a unified system. This arrangement facilitates the transfer of the entire structural load to the soil primarily at the level of the skirt tip. Skirts can be deployed in various geometric configurations, including circular, rectangular, strip, and square shapes, and can be applied to both new constructions and existing shallow foundations. Beyond their primary role in enhancing load-bearing capacity, circumferential skirts also serve additional purposes. They contribute to improving piping and scouring safety, thereby safeguarding the integrity of the foundation against potential erosion risks. Moreover, the inclusion of a peripheral skirt can prevent soil displacement beneath the foundation, mitigating the risk of damage resulting from nearby construction activities. In essence, the assembly of semi-deep foundations through the integration of skirted foundations represents a comprehensive approach to bolstering structural support and ensuring long-term stability in diverse construction environments. [1]

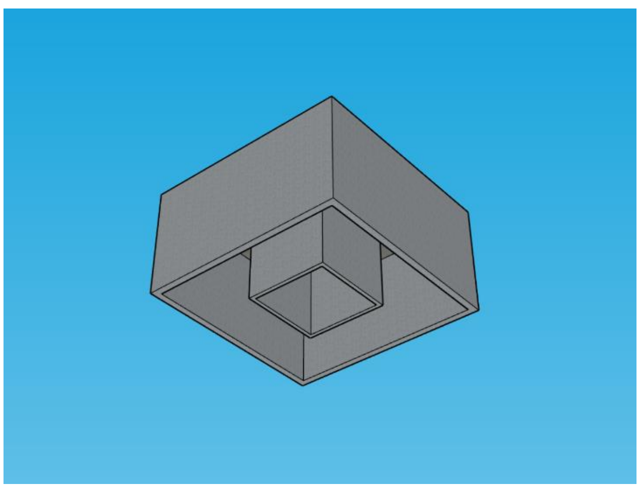


Fig1 showing 3D assembly of double skirted foundation from side

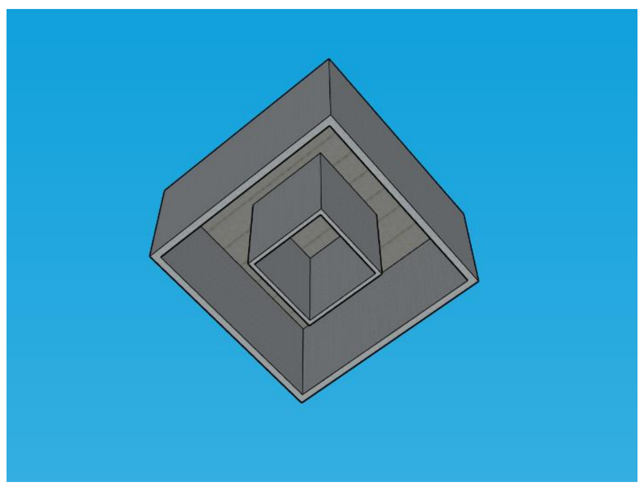
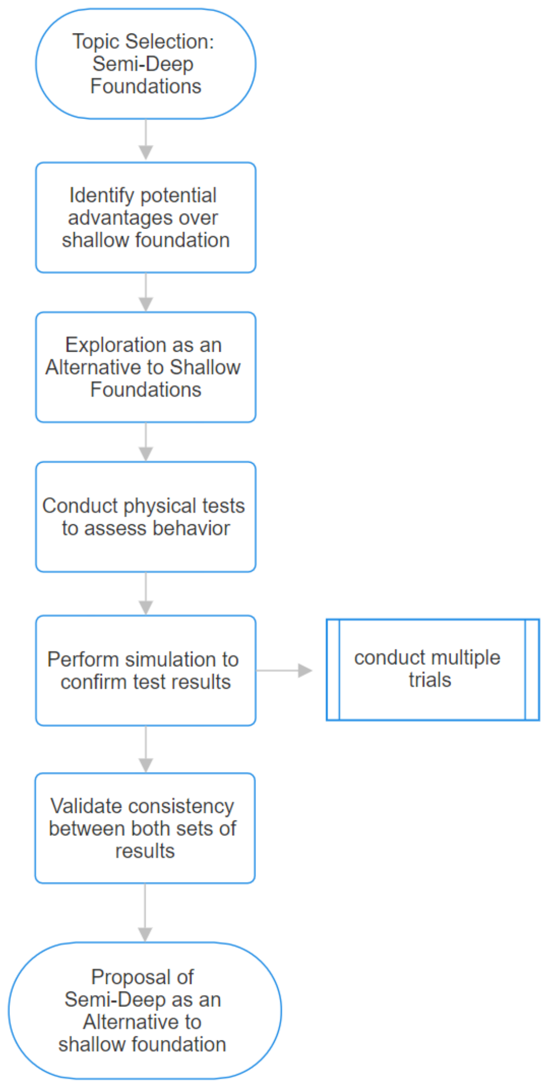


Fig 2 showing assembly of double skirted deep foundation from bottom

Chapter-3 Methodology

3.1 Flow Chart:



Materials and Experimental Methods Used

3.2 Experimental Study:

Due to the prohibitive costs associated with conducting field tests to study the load-settlement behavior of semi-deep foundations, a small-scale experimental setup was devised to facilitate this research. This setup allowed for a controlled and cost-effective means to investigate the performance of these foundations. The small-scale models were meticulously designed to replicate the conditions and behaviors of semi-deep foundations in a manageable and replicable environment.

The experimental apparatus consisted of several key components. A test tank was used to contain the soil and foundation models, providing a controlled environment for the experiments. Small-scale shallow and semi-deep foundation models were constructed to mimic the actual foundations' behavior under load. A proving ring was employed to accurately measure the applied loads, ensuring precise and reliable data collection. To apply these loads, a manually operated hydraulic jack was utilized, allowing for controlled and incremental loading. A settlement gauge was included to monitor the displacement of the foundation models under load, providing essential data on their performance.

Locally available Lawrencepur sand was chosen as the testing medium due to its representative properties and availability, ensuring the results would be applicable to real-world conditions in the region. The entire testing procedure was carried out at the NICE structure warehouse, which provided the necessary facilities and space for the experimental setup. [3]

3.3 Test Tank:

The test tank used in the experiment had dimensions of 760mm in length, 760mm in width, and 600mm in depth. Constructed from steel, the tank was reinforced with proper bracing to ensure it could withstand heavy loads without failing. [4]

Fig 3 Showing Test Tank Used for this Test.

To facilitate the accurate placement and compaction of the sand, the entire depth of the tank was divided into six equal sections, each 100mm deep. Lines were drawn inside the tank at these 100mm intervals. This segmentation allowed for systematic and uniform layering of the sand, ensuring that each layer could be placed and compacted to achieve the desired relative density of 30%.

The careful layering was essential to replicate the loose soil conditions accurately and to maintain consistency across different tests.

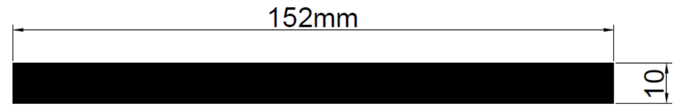
Additionally, a steel beam was mounted on the test tank to support the loading apparatus, ensuring stability and precision during the testing process.

3.4 Model footings:

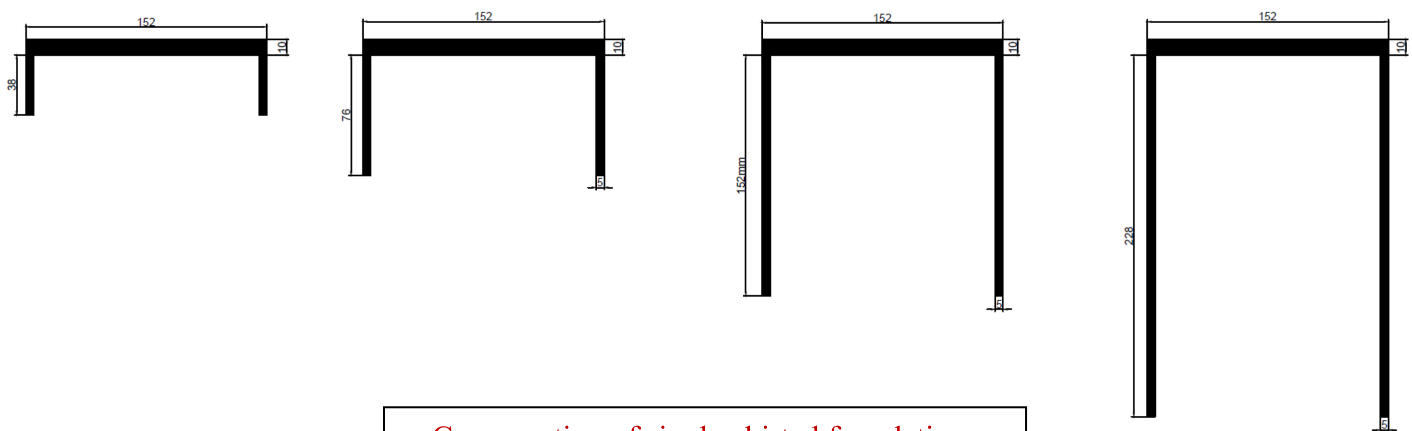
The footings were intricately designed to match the dimensions of the test tank, ensuring the prevention of any boundary effects. Extensive analysis of boundary effects was carried out before determining the footing sizes. [5], [6] Each shallow foundation was meticulously crafted with dimensions of 152mm in length, 152mm in width, and 10mm in thickness. [7]

Four models of singly skirted and four models of doubly skirted foundations were meticulously fabricated, with varying skirt lengths at 0.25B, 0.5B, 1B, and 1.5B, where 'B' represents a characteristic dimension.

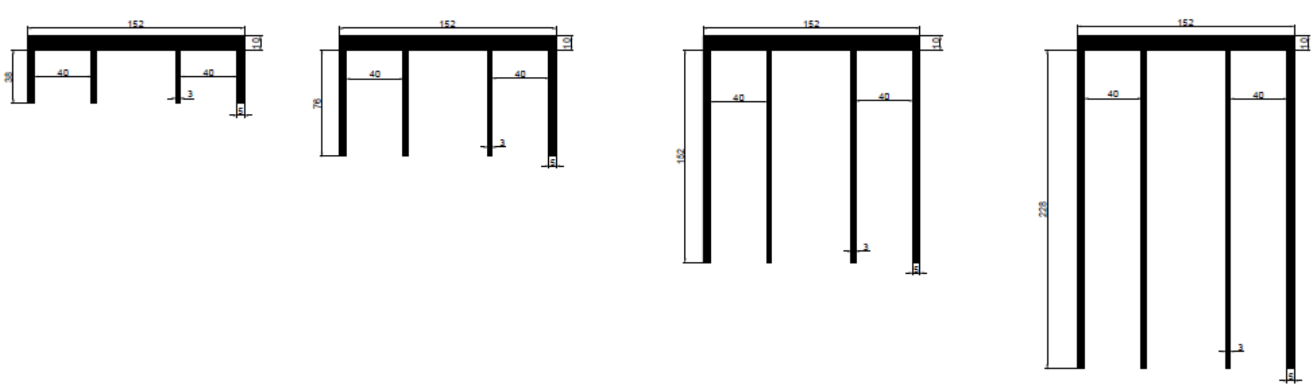
Mild steel was chosen as the foundation material, with outer skirts measuring 5mm in thickness and inner skirts 3mm thick. This methodical approach ensured precise experimentation and reliable results in the study of foundation behavior.



Shallow foundation



Cross section of singly skirted foundations



Cross section of doubly skirted foundations

3.5 Laboratory Soil Testing:

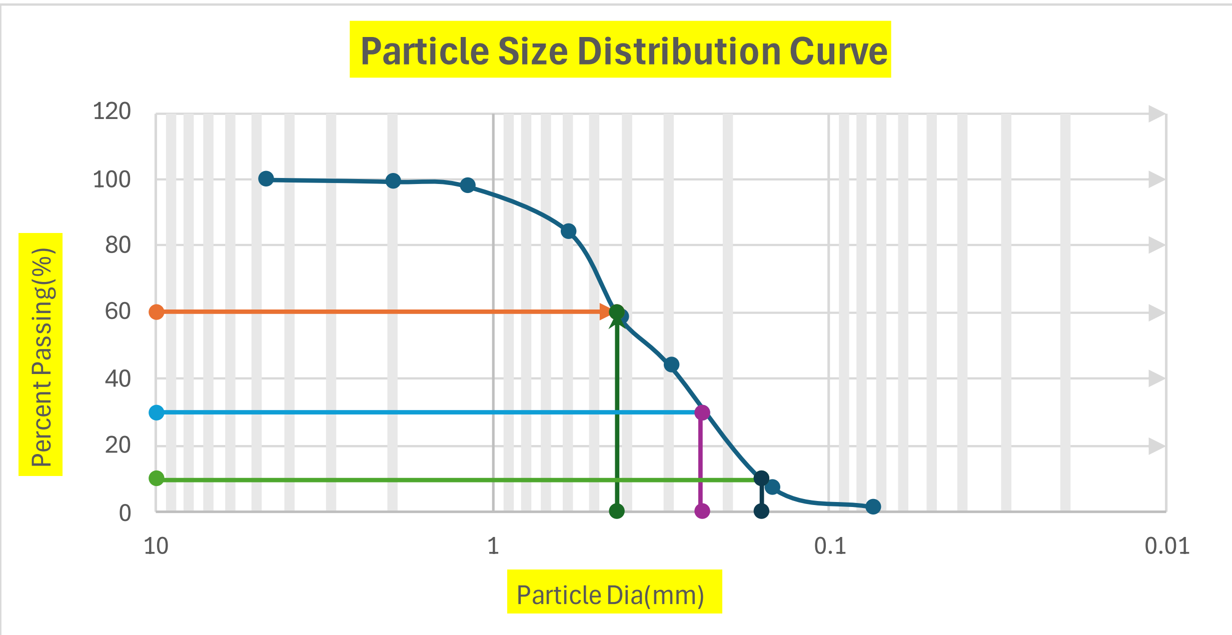
In the lab, several soil tests were conducted to assess the properties of the sand.

- A sieve analysis was performed to determine the soil's particle size distribution.
- The moisture content was measured using the oven drying method.
- Speedy moisture test provided a rapid assessment of the moisture content.
- Additionally, a standard Proctor test was conducted to establish the optimal moisture content and maximum dry density for soil compaction.

Fig 4 Showing preparation of test mold and test samples for Performing Proctor test.

3.6 Sand:

Locally available Lawrencepur sand was selected for this study. Sieve analysis revealed a fine to medium grained sand with a grain size ranging from 0.075 mm to 2.0 mm. Key grain diameters were determined to be 0.1587 mm for D10 (effective diameter), 0.2400 mm for D30, and 0.4294 mm for D60. Calculated coefficients indicated a poorly graded sand with a uniformity coefficient (Cu) of 2.70 and a curvature coefficient (Cc) of 0.8452. [8]



Graph Between Percent Passing (%) and Particle Size (mm) for Sieve Analysis

Property	Value
Grain Size Range	0.075 mm to 2.0 mm (fine to medium)
D10 (Effective Diameter)	0.1587 mm
D30	0.2400 mm
D60	0.4294 mm

Uniformity Coefficient (Cu)	2.7
Curvature Coefficient (Cc)	0.8452
Gradation	Poorly graded

Results of Sieve Analysis Performed in Lab

3.7 Geotechnical properties of the sand:

The geotechnical properties of the sand sample are characterized by an optimum moisture content (OMC) of 9.98% and a maximum dry density (MDD) of 1780 kg/m^3. The sand exhibits a stiffness of 10 MPa, indicating its resistance to deformation under applied stress. The internal friction angle (θ) is measured at 30°, reflecting the sand's shear strength and stability. [9]

The test was carried out with the sand at a relative density of 30%, representing a loose state. This condition was selected to simulate the behavior of semi-deep foundations in loose soil environments. In such settings, shallow foundations are unsuitable, making deep foundations the only viable option. The dry unit weight of the sand at 30% relative density was determined using the specified formula.

$$D_r = \frac{\gamma_{d\max}}{\gamma_d}\left(\frac{\gamma_d - \gamma_{d\min}}{\gamma_{d\max} - \gamma_{d\min}}\right)$$

3.8 Relative density test

The relative density test, conducted in accordance with ASTM D4254, was performed to determine the maximum and minimum densities of the soil, essential for calculating the unit weight of the soil at 30% relative density. The test involved two main steps: determining the minimum density by placing a known volume of dry soil into a cylindrical mold in a loose condition and measuring its weight and determining the maximum density by compacting the soil in the mold to its maximum possible density. For the maximum density, the relative density machine was turned on at a frequency of 60 Hz for 10 minutes, after which the reduced volume of the soil was calculated. The maximum density was found to be 1784 kg/m³, and the minimum density was 1532 kg/m³.

Fig 5 Showing preparation of test mold and test samples for Performing Relative density test.

Fig 6 ***Relative Density Instrument in Use for Maximum Density***

Minimum Density:

Property	**Value**
Mass of empty mold (m1), g	3778
Mass of empty mold + sand (m2), g	7838
Mass of sand (m=m2-m1)	4060
Dia of mold (cm)	15
Depth of mold (cm)	15
Vol of empty mold (v)	2651.0625
Min density (m/v), g/cm^3	1.531461442
Min density (m/v), kg/m^3	**1531.461442**

Minimum density results (ASTM D4254)

Minimum Density:

Property	**Value**
Average top height (cm)	0.82
thickness of base plate (cm)	1.3
reduced height of sand (cm)	12.88
reduced volume of sand (v), cc	2276.379
Max density (m/v), g/cm^3	1.783534288
Max density (m/v), kg/m^3	**1783.534288**

Maximum density results (ASTM D4254)

These values were utilized to calculate the required weight of soil for our tank at 30% relative density. By determining the maximum and minimum densities, we were able to accurately compute the soil weight needed to achieve the specified relative density, ensuring optimal compaction and stability for our project requirements.

3.9 A Typical Test

A typical test to assess the behavior of sand under load involved a meticulous process of preparing and executing the experiment. Initially, the sand was placed in a test tank in layers to ensure uniformity and consistency throughout the test. The test tank was divided into six distinct layers, with each layer receiving a calculated amount of sand to achieve a relative density of 30%, representing a loose state of compaction. The sand was carefully poured from a close range to prevent it from compacting more than the desired value. This step was crucial to maintain the integrity of the test conditions. Each layer was carefully balanced using a water balance to ensure homogeneous placement and uniform density.

Once the sand was properly layered and compacted to the specified relative density, the next step involved placing the model foundation. The model foundation was carefully positioned at the center of the tank, ensuring precise alignment with pre-marked signs. This alignment was essential for accurate results. The foundation was then leveled using a water balance to guarantee an even surface, which is critical for the consistency of the loading process and the validity of the test results

With the foundation in place, the loading setup was prepared. A hydraulic jack was positioned directly above the foundation to apply the load. A proving ring was then placed on top of the hydraulic jack to measure the applied load accurately. Before beginning the loading process,

Fig 7 showing load being applied on foundation resting on sand through hydraulic jack.

settlement gauges were installed to measure the displacement of the foundation. These gauges were carefully reset to zero to ensure accurate measurement of settlement from the start of the test.

The loading process commenced with the manual operation of the hydraulic jack. Load was gradually applied, and the proving ring gauge readings were taken after each 5 mm increment of settlement [10]. This step-by-step loading continued until the foundation reached a total settlement of 30 mm. The incremental approach allowed for precise monitoring of the foundation's behavior under load, providing valuable data on its performance.

After the foundation reached the desired settlement, the test was concluded, and the setup was carefully disassembled. To prepare for the next test, the upper layers of sand were removed and replaced with sand compacted to the initial relative density of 30%. This step was necessary to avoid any over-compaction that could skew the results of subsequent tests. Each of the nine foundation models underwent this detailed and consistent testing procedure to ensure reliability and comparability of the results across all tests. [11], [12]

Chapter-4 NUMERICAL MODELLING

4.1 Introduction

Following the experimental testing of our seven foundations, each placed separately on sand within a test tank, it was essential to verify our results. For this purpose, we selected Plaxis 3D, a widely used software for geotechnical analysis. This software enabled us to conduct a three-dimensional finite element analysis (FEA) to validate our experimental model and to examine the load-settlement behavior of the foundations on sand. [13]

4.2 Model Scaling and Simulation

Given the small scale of our experimental model, direct replication in Plaxis 3D was problematic due to soil collapse issues, indicated by Software Error 101. To address this, we decided to scale up our model by a factor of five. This scaling included enlarging both the size of the test tank and the depth of the soil layer by five times, thereby maintaining an identical environment. Scaling up was also necessary to mitigate boundary effects due to confinement within the box, ensuring the validity of our readings.

4.3 Model Setup

The geometry of the foundation was proportionally increased to match the scaled-up test tank dimensions. Each foundation was numerically simulated separately to ensure effective and efficient analysis. The sequence of simulations progressed from the shallow foundation to single skirted foundations at depths of 0.25B, 0.5B, and 1B, and then to double skirted foundations at the same depths.

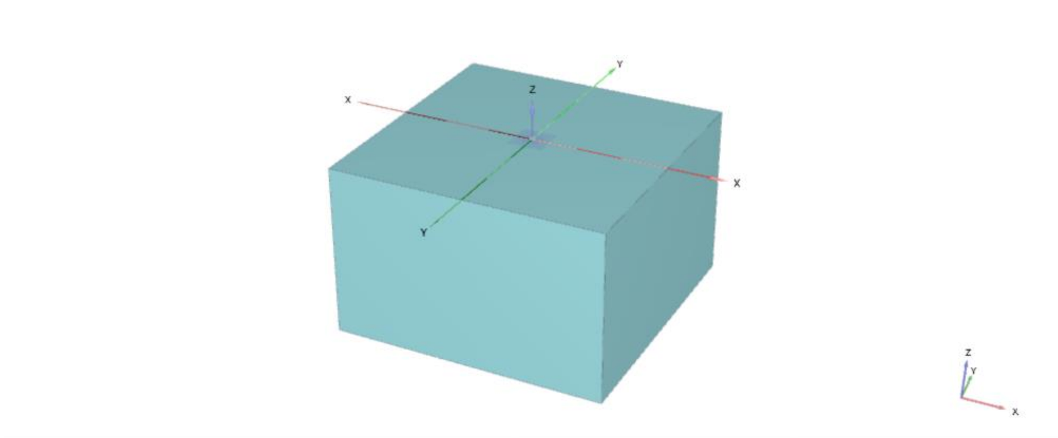


Fig 8 showing numerical modelling of foundation in Plaxis 3D

4.4 Finite Element Analysis Methodology

For the finite element analysis, both elastic and plastic behaviors of the soil were modeled. While elastic behavior was handled using elastic models within the program, the plastic behavior was modeled using various plasticity models such as the Mohr-Coulomb (MC) model. The MC model was selected to accurately reflect the soil properties and experimental conditions, incorporating five key parameters: modulus of elasticity (E), Poisson's ratio (υ), cohesion (c), internal friction angle (φ), and dilatation angle (ψ).

By scaling up our experimental model and employing the Mohr-Coulomb model in Plaxis 3D, we were able to effectively simulate and analyze the load-settlement behavior of our foundations. This numerical validation provided robust support for our experimental findings and ensured the reliability of our results. [14], [1], [11]

4.5 Comprehensive Procedure Using Plaxis 3D

4.6 Overview

In our modelling of foundations, we simulated load-settlement behavior by predefining settlement and then calculating the corresponding load. After defining all relevant soil parameters and the depth of the soil layer, we proceeded to define our structural model.

4.7 Defining the Structure

To simulate the foundation, we created a material as a plate made of steel, assigning properties such as unit weight, elastic modulus, Poisson's ratio, and thickness. These properties are detailed in the following table. It is important to note that steel is considered an isotropic material, meaning its properties remain constant throughout the cross-section.

Property	**Value**
Unit Weight (kN/m^3)	78.5
Elastic Modulus (GPa)	210
Poisson's Ratio	0.3

Properties Used in Plaxis 3D For Performing Numerical Modelling

4.8 Creating the Foundation Model

After defining the properties, we created the foundation surface with dimensions of 0.75 x 0.75 mm. The visualization settings were adjusted to 0.125 mm to accurately model the foundation dimensions. A predefined settlement of 25 mm was then applied to the center of the foundation to determine the maximum load it could support. This approach allowed us to compare the results with our experimental data.

4.9 Meshing

Positive interfaces were made to ensure accurate simulation of results. The mesh type was selected based on the desired balance between accuracy and computation time. Coarser meshes provide faster results but can be less accurate, whereas finer meshes offer higher accuracy with longer computation times. We chose a finer mesh for our analysis and used the default settings of Plaxis 3D.

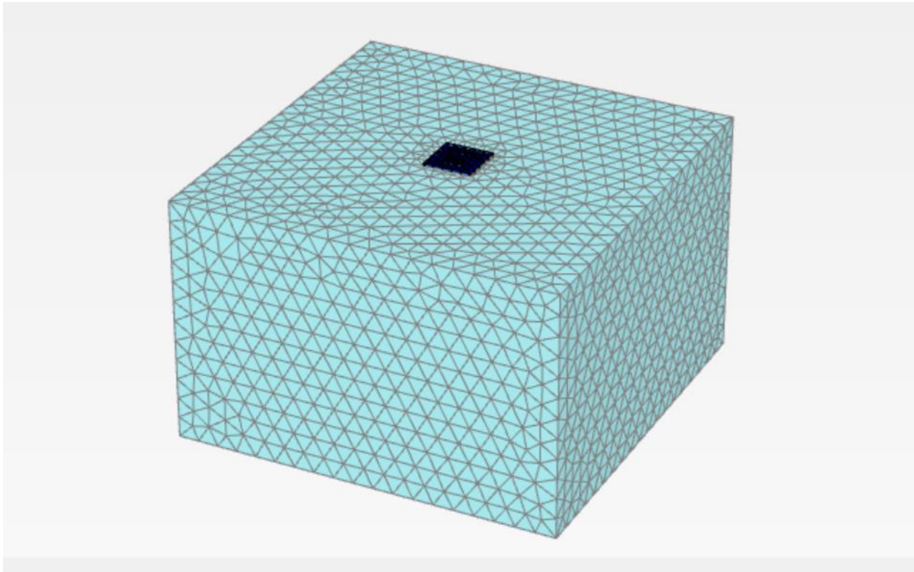


Fig 9 showing meshing used in numerical modeling

4.10 Phases in Staged Construction

To analyze displacements and stresses induced at every point, we defined three phases in staged construction:

4.10.1. Initial Phase

In the Initial Phase, the primary focus is on establishing the baseline conditions of the site. At this stage, only the soil model is in place. This means that the geometry and physical properties of the soil are fully defined and activated within the analytical model. Other critical parameters, such as the foundation elements and any displacement forces, remain inactive. By isolating the soil model in this phase, we can accurately assess the inherent characteristics and behavior of the soil without interference from additional structural elements. This initial assessment is crucial for understanding the natural conditions and potential challenges that might arise once construction progresses.

4.10.2 Installing the Foundation

The second phase involves the integration of the foundation into the existing soil model. During the Installing the Foundation phase, both the soil and the foundation geometry are turned on. This means that the model now includes the physical dimensions and material properties of the foundation, which is superimposed onto the soil model established in the initial phase. At this point, point displacement parameters are still turned off. This is done to focus solely on how the foundation interacts with the soil without considering any external forces or settlements. By doing this, we can study the stress distribution and potential displacement that occur as the foundation settles into the soil, providing insights into the stability and suitability of the foundation design under ideal, undisturbed conditions.

4.10.3 Applying Settlement and Measuring Load

In the final phase, Applying Settlement and Measuring Load, all parameters are activated to simulate real-world conditions. This includes turning on point displacements and interface elements, which are crucial for simulating the actual physical interactions that occur once the structure is subjected to real loads and settlements. At this stage, the model reflects the full complexity of the construction environment, accounting for the loads applied by the structure, the resulting settlements, and the interaction between the soil and the foundation. By doing this, we can measure the actual displacements and stresses experienced by the foundation and the surrounding soil. This comprehensive simulation allows for the assessment of the structural integrity and performance under realistic conditions, providing valuable data for making any necessary adjustments to the construction process or design.

4.11 Running Simulations and Obtaining Results

After specifying all phases, we ran our simulations. Results were obtained via a data log table, specifying nodes at the center of the foundation to calculate load relative to settlement. The process was repeated for single and double skirted foundations, only changing the skirt depth and scaling the model to five times the original dimensions while keeping soil parameters constant.

Chapter-5 Results

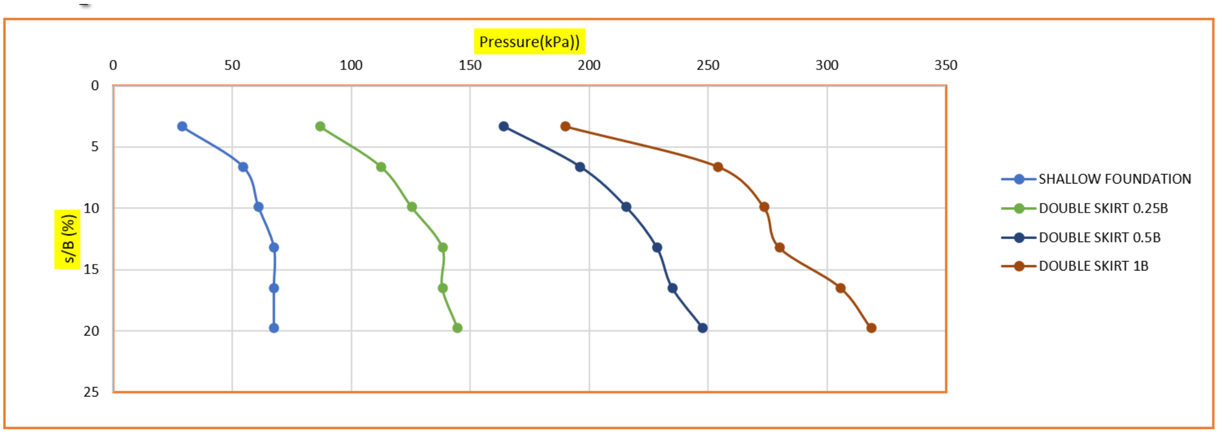
5.1 Experimental Results

5.1.1 Experimental Load-Settlement behavior of Shallow and Singly Skirted Square Footings:

The study investigated the load-settlement behavior of both shallow and singly skirted square footings, particularly focusing on their performance on sand. Experimental data was collected for various skirt depths, including 0B, 0.25B, 0.5B, and 1B, where 'B' represents the width of the footing.

The analysis included calculating the bearing capacity using a 10% s/B ratio. Initially, the bearing capacity for a shallow square footing was determined to be 1.34kN. However, as the skirt depth increased, significant improvements were observed in the bearing capacity. Specifically, for skirt depths of 0.25B, 0.5B, and 1B, the bearing capacity increased to 112kPa (84% improvement), 131kPa (114.7% improvement), and 215kPa (252% improvement) respectively.

These findings highlight the notable enhancement in bearing capacity achieved through the addition of skirts to the square footings, underscoring the effectiveness of skirted footings in improving load-settlement behavior, particularly in sandy soil conditions.



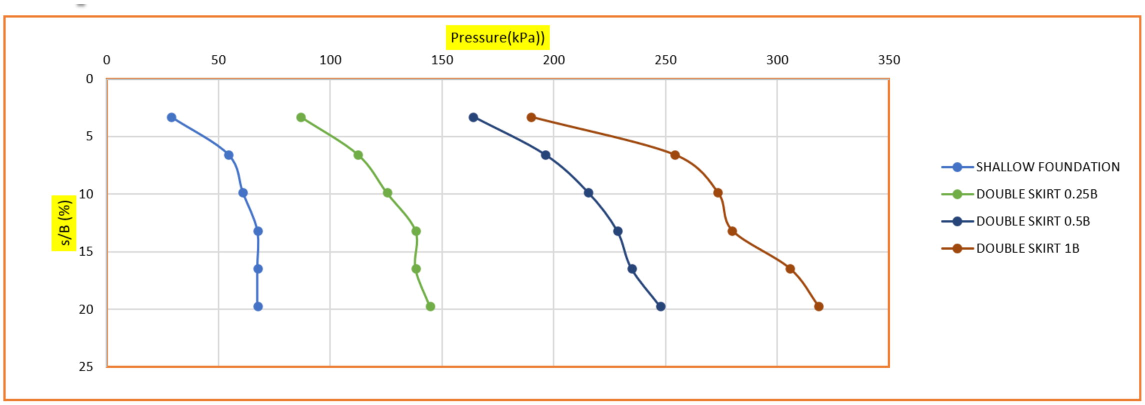
Graph Between Pressure and s/B(%) of shallow and skirted foundations for physical testing.

5.1.2 Experimental Load-Settlement behavior of Shallow and Doubly Skirted Square Footings:

The experimental investigation delved into the intricate load-settlement dynamics of shallow square footings, juxtaposed against those fortified with double skirts, elucidating their performance across varying depths.

Initially, the study established a baseline bearing capacity for the shallow square footing, pegged at 1.34kN. However, the inclusion of double skirts ushered in remarkable improvements in load-bearing capabilities. As the skirts' depth increased incrementally to 0.25B, 0.5B, and 1B, the bearing capacity exhibited substantial augmentation, soaring to 125kPa (a notable 104.9% enhancement), 215kPa (a remarkable 252% improvement), and 273kPa (an astonishing 347% increase) respectively.

These findings not only underscore the efficacy of double skirts in fortifying square footings but also highlight their progressive reinforcement as the skirt depth amplifies. Such revelations unveil the potential of double skirts to significantly bolster load-settlement behavior, showcasing their versatility and efficacy across a spectrum of depths. This comprehensive understanding provides valuable insights into optimizing foundation design strategies, particularly in scenarios where robust load-bearing capacities are paramount, propelling advancements in structural engineering practices and fortifying urban infrastructure against diverse challenges.



Graph Between Pressure and s/B(%) of shallow and skirted foundations for Numerical Modelling.

% Increase Relative to Shallow Foundations			
S. No.	**Skirt Length**	**SS**	**DS**
1	0.25B	84%	104.9%
2	0.5B	114.7%	252%
3	1B	252%	347%

5.2 Simulation Results

Results Comparison:

The comparison reveals results obtained from experimental testing and numerical modeling of shallow foundations, suggesting a congruence between the two datasets. This correspondence confirms the reliability of both experimental findings and numerical simulations.

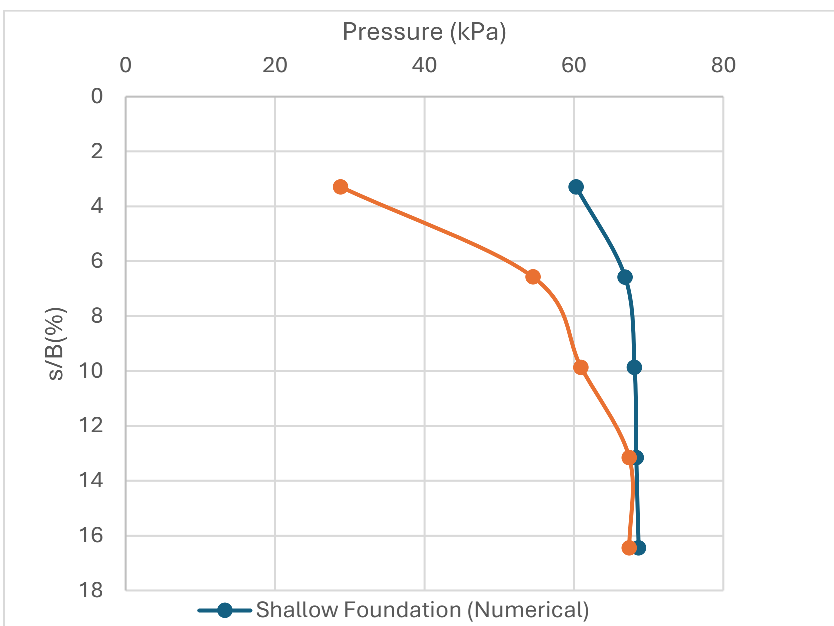
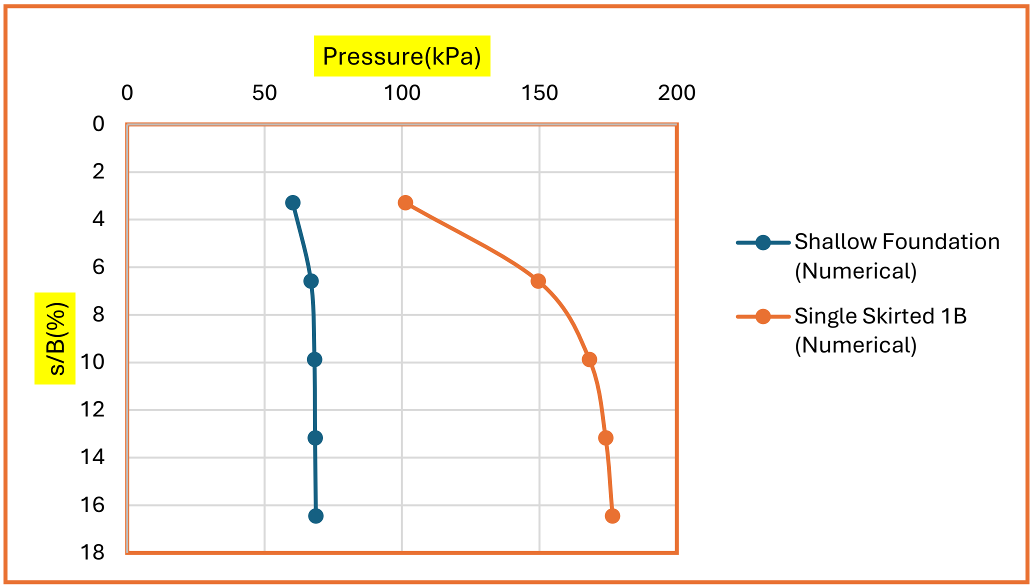
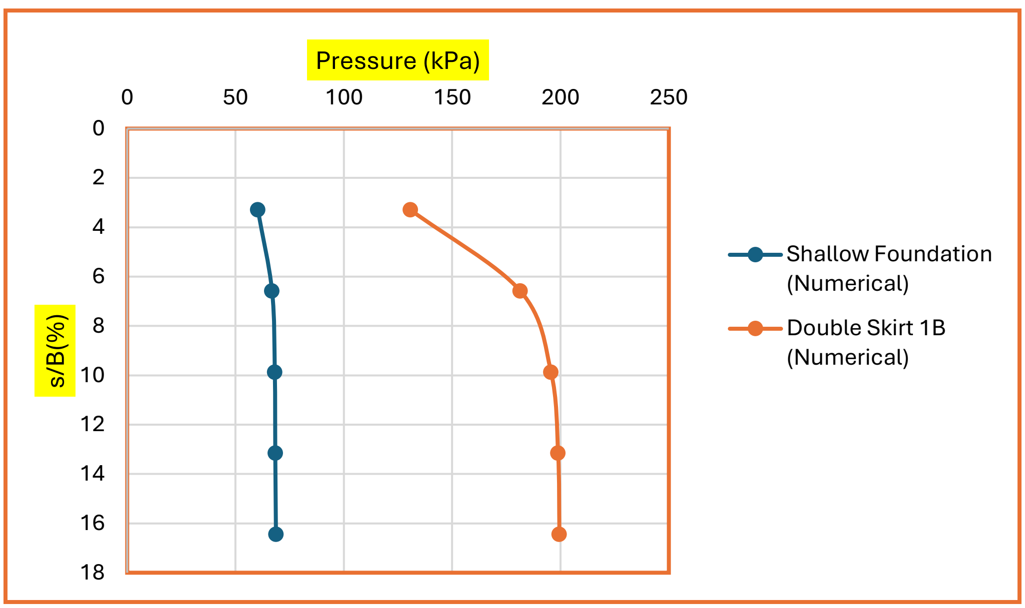


Fig 8 showing numerical and experimental results identical to each other

Skirted vs. Shallow: Results



Shallow vs. singly skirted foundation with skirt length 1B



Shallow vs. Doubly skirted foundation with skirt length 1B

Chapter-6 Conclusion

6.1 Significance & Applications:

The significance and practical applications of skirted foundations are multifaceted. Firstly, they offer superior load-bearing capacity in loose soils compared to traditional shallow foundations, a benefit that further escalates with increased skirt depth.

Secondly, in loose soil conditions, skirted foundations present a viable alternative to deep foundations, negating the necessity for complex structural solutions. This not only streamlines construction processes but also potentially reduces overall project costs due to simplified design requirements.

Additionally, the installation of skirted foundations is typically swifter than that of deep foundations, contributing to reduced construction timelines. Moreover, their minimal material requirements and expedited installation further contribute to a diminished environmental footprint, aligning with sustainability objectives in construction practices.

Overall, skirted foundations emerge as a versatile and cost-effective solution, offering improved load-bearing capabilities, expedited construction timelines, and reduced environmental impact, particularly in loose soil conditions.

6.2 Further Prospects:

Looking ahead, there are promising avenues for skirted foundations in various domains. Firstly, the inclusion of peripheral skirts presents an opportunity to bolster safety measures by providing added protection against issues like piping and scouring.

Moreover, skirted foundations play a crucial role in maintaining soil stability, preventing soil displacement and shielding against potential damage from nearby excavation activities. In offshore settings, these foundations have already gained traction due to their efficacy in supporting structures amidst challenging marine conditions.

Looking to the future, there is potential for wider adoption across industries, with opportunities to engage construction firms and advocate for the broader implementation of skirted foundations. By tapping into these further prospects, skirted foundations can continue to enhance safety standards, ensure soil stability, and find applications across a diverse range of construction projects.

6.3 Limitations:

Several challenges may hinder the adoption of skirted foundations, including reluctance towards embracing new technologies within the construction sector, upfront expenses associated with research and development, and the complexities of obtaining regulatory clearance for novel foundation systems. To overcome these obstacles, our strategy involves showcasing the economic advantages and environmental merits of skirted foundations through pilot initiatives. Additionally, we aim to proactively collaborate with regulatory authorities from the outset to navigate approval processes effectively. Moreover, garnering support from industry leaders and stakeholders will be pivotal in building confidence and fostering acceptance of skirted foundations as a viable solution within the construction industry.

6.4 Conclusion:

In conclusion, the application of skirted foundations as an alternative to deep foundations in loose soil conditions signifies a significant advancement in foundation engineering practices. These foundations offer a myriad of benefits, including heightened load-bearing capacity, streamlined construction processes, and improved cost-effectiveness. Unlike traditional deep foundations, which often entail extensive excavation and complex structural arrangements, skirted foundations provide a simpler yet equally effective solution for supporting structures in challenging soil environments.

Furthermore, skirted foundations contribute to enhancing safety measures by offering increased protection against common issues like piping and scouring. The addition of peripheral skirts helps to confine the soil effectively, preventing soil displacement and potential damage from nearby excavation activities. This aspect not only ensures the stability and integrity of the foundation but also mitigates risks associated with soil instability, thereby enhancing overall safety standards in construction projects.

Moreover, the versatility of skirted foundations extends beyond terrestrial applications, finding relevance in offshore structures as well. Their robust load-bearing capabilities and stability make them well-suited for supporting offshore platforms and structures in marine environments. This diversification of applications underscores the adaptability and resilience of skirted foundations across various construction settings, further solidifying their appeal as a viable foundation solution.

Looking ahead, future research endeavors should prioritize exploring the long-term performance of skirted foundations, conducting comprehensive cost-benefit analyses, and assessing their environmental impact. This will help to provide a more nuanced understanding of the efficacy and sustainability of skirted foundation models, guiding their implementation in future construction projects. Collaborative efforts with industry stakeholders will be essential in advocating for the broader adoption of skirted foundations, facilitating knowledge exchange, and driving innovation in foundation engineering practices. Through strategic partnerships and ongoing research initiatives, skirted foundations have the potential to revolutionize the construction industry, advancing safety standards, ensuring soil stability, and promoting sustainable building practices on a global scale.

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