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Evaluating Differences in Foundation Depth Planning and Implementation for Building Structure Safety

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A B S T R A C T

Kediri has been named the Most Sustainable City. To support this, Kadiri University also contributed by building lecture buildings. In its implementation, there is a difference in the depth of the foundation from the initial plan. This causes the need for evaluation to ensure the safety of the building structure. This research aims to identify (Cone Penetration Test) CPT distances, depth differences, negative skin friction, settlement, and empirical bearing capacity calculations on the safety of building structures on sandy soil. The direct observation method was used to obtain data. The analysis includes a comparison of depth, negative skin friction values, settlement, and bearing capacity. The research results show that the average CPT distance is 18.22 m, which can result in inaccurate CPT data because differences in soil structure can occur. A depth difference of 22% from the plan can be considered safe for the structure. This is validated by a field settlement of 2 mm lower than the maximum settlement limit and a Negative skin friction value of 0, indicating no additional settlement. These parameters indicate that the structure is safe. The modified Meyerhoff and Trofimankove methods are suitable for planning foundations with sandy soil because they can meet the load received. This research can add empirical evidence in evaluating structural safety for different depths of foundation planning and implementation in sandy soil-based projects, as well as reducing the potential risk of structural failure in the long term.

1. Introduction

Kediri City is one of the cities in East Java. Kediri was crowned as the 1st Most Sustainable City [1]. Based on the Ministry of Communication and Information, Kediri's smart

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city index achievement in 2022 is 3.31, or an increase of 0.25 from the previous year's achievement. This achievement brought the City of Kediri to 4th place in East Java and 22nd place nationally [2]. To support the city government, Kadiri University, the oldest private university in the Kediri Residency, is also participating by building lecture buildings to increase the effectiveness of teaching and learning activities. So that it can create graduates from Kediri City who can compete in the world of work. The lecture building will have a system connected to the Internet for energy efficiency, security, and comfort [3]. Resources such as electricity, water, and lighting are optimized [4]. It is also equipped with advanced security features such as a video surveillance system [5].

The construction must consider building structure rules to avoid failure [6]. One of the keys to achieving this is proper and accurate foundation planning [7]. Proper foundation planning depends on the Cone Penetration Test (CPT) results, which help to evaluate the soil characteristics in the construction area and determine the optimal depth for the foundation [8]. However, in its implementation, the foundation erection experienced a difference in depth from the initial plan that had been made.

Differences in foundation depth can affect the strength and stability of the building structure [9]. In addition, a foundation depth that is not according to plan allows excessive settlement to occur due to the reduced bearing capacity of the foundation [10]. These discrepancies result in the need for evaluation because they can impact the building's safety, stability and overall quality. Evaluation is needed to identify safety and can be the basis for further planning to minimize potential problems [6]. The importance of this evaluation does not only apply to this lecture building construction project but is also relevant for many other locations that may face similar problems [11].

The difference in foundation depth between planning and implementation is caused by various factors, including the CPT distance. The CPT distance plays an important role in determining the depth of the pile foundation [12]. Apart from that, negative skin friction (NSF) is also an indicator [13]. Settlement is another indicator of structural safety [14],[15],[16]. It has been revealed that the difference between the depth of the foundation plan and its implementation in the field on sandy soils has significant variations in various locations worldwide. In Chongqing, China, the difference in design depth was 14%, with the sandy soil type resulting in damage to the structure after construction [17]. A similar incident also occurred in the Gyeonggi region, South Korea, with depth differences reaching 20% from the plan, indicating that kinematic forces from slopes can cause differences in soil and pile phases [18].

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In addition, in the Bhin Duong area, Vietnam, a difference of up to 29% in sandy soil causes a reduction in the bearing capacity of the foundation, and the potential for settlement increases. This can cause damage to the building structure, causing the building to crack [19]. This fact differs from the results of research from continental Europe, specifically in Katzenbach, Germany, which revealed that a 33% difference with sandy clay soil types did not cause structural failure [20]. Also, a similar study revealed that a 48% difference in sand soil type did not cause structural failure [21]. Based on previous research, it shows that there are inconsistencies in justifying whether differences in the depth of foundation planning and implementation affect the safety of structures on sandy soil. For this reason, comprehensive research is needed to evaluate structural safety due to differences in the depth of planning and implementation of foundations on sandy soil.

This research aims to identify CPT distances, depth differences, negative skin friction, settlement, and calculation of bearing capacity for the safety of building structures on sandy soil. It is hoped that the research results will add empirical evidence in evaluating structural safety based on differences in depth of foundation planning and implementation in sandy soil-based projects, as well as reducing the potential risk of structural failure in the future.

2. Research Method

The research methods used were field observations and empirical calculations. Observations were carried out to collect data in the form of distance from the CPT to the planting point, depth, settlement, and dimensions of the pile foundation. Apart from that, CPT and Driving Report data were also collected. Depth comparison analysis was conducted to determine the foundation depth difference for planning and implementation. Next, an empirical calculation of the NSF value is carried out. When the NFS value has been obtained, empirical calculations are carried out to determine the settlement value. In addition, a settlement in the field was observed for approximately three months. The settlement value obtained from empirical calculations is then compared with the settlement value in the field. When the observed settlement is close to or even the same value as the planned settlement, it is declared safe. Next, empirical calculations are carried out to determine the bearing capacity that each pile can support. The bearing capacity is calculated using several methods (Meyerhoff, Modified Meyerhoff, Begemann, and Trofimankove) and then compared with the planned load. Empirical calculations using several methods determine the most efficient method for estimating bearing capacity.

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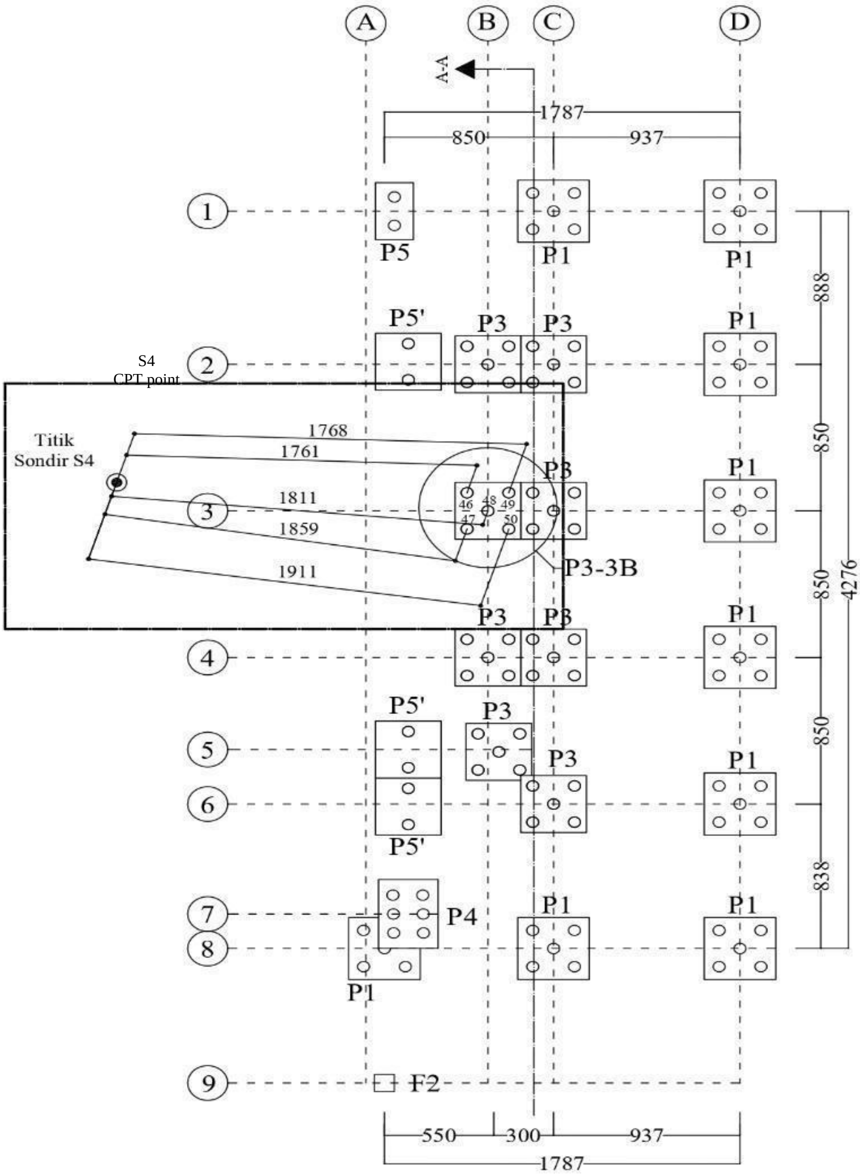
3. Results and Discussions

3.1 Distance from CPT Point to Pile

The following is an image of the foundation plan for building construction at Kadiri University, one of which is the P3 foundation point, which consists of 5 piles equipped with the distance between the CPT points and each pile.



Source: Plan Drawing.

Figure 1. Distance of CPT Point to Pile

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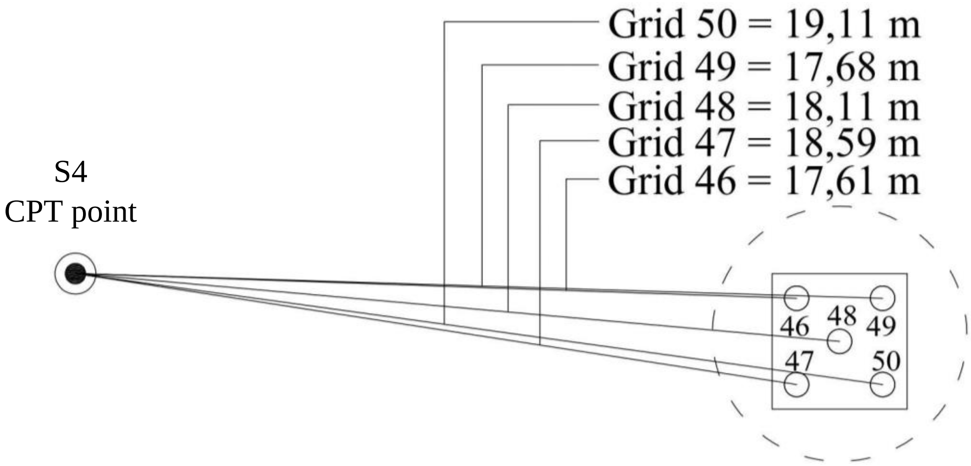

Source: Plan Drawing.

Figure 2. Details Distance of CPT Point to Pile

Figure 2 is the distance from the CPT point to the erection point, so that an average distance of 18.22 meters is obtained. At the CPT test point, it should be noted that it is taken outside the construction area. So, that results in a lack of accuracy of the data obtained. The lack of accuracy of CPT data is due to differences in soil characteristics in the area where the CPT point and the erection point are taken. Thus, differences in pile depth during planning and implementation may occur [12].

3.2 Pile Foundation Depth

A comparison of the depth of the pile foundation embedded in the field with the plan is shown in **Table 1**.

Table 1. Pile Foundation Depth Plan and Implementation.

Grid	46	47	48	49	50
Depth of Implementation Based on Driving Report (m)	8,60	9,30	9,60	9,50	9,00
Planning Depth Based on CPT Data (m)	11,80	11,80	11,80	11,80	11,80
Difference (%)	27,1	21,2	18,6	19,5	23,7

Source: Field Data (2023).

Table 1 shows the difference between the planned depth and the depth of the piles implemented in the field, with an average difference of 22%. The 22% difference in soil was identified as not endangering the structure. This is based on similar cases in several countries, one of which was in the Binh Duong area, Vietnam, where the planning and implementation of pile foundations showed a difference in the depth of the driving report with the depth of the CPT data of 29%. Even though there are differences, the pile foundation is guaranteed to be

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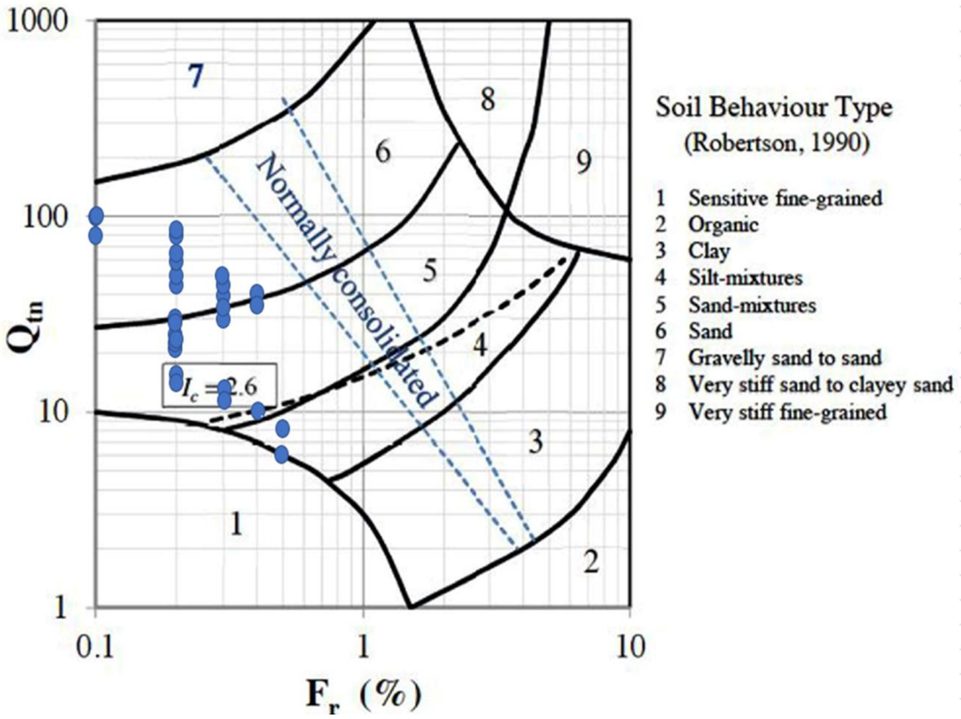
safe to support the load on it [19][20]. Even though it is declared safe, regular supervision and monitoring must be done to detect potential problems and take appropriate preventive steps.

3.3 Negative Skin Friction

Below is a picture of soil classification using the Soil Behavior Type (SBT) graph.



Source: Robertson (1990).

Figure 3. CPT-based SBT Graph

Table 2. Soil Type Classification.

Grid	Depth	Group	Soil Type
46	8,6	6	Sand
47	9,3	6	Sand
48	9,6	6	Sand
49	9,5	6	Sand
50	9	6	Sand-mixture

Source: Author Data Processing.

Based on the classification of soil types using the SBT graph with an Fr value of 0.30% and a Qtn of 50, it shows that group 6 is a type of sandy soil. The results of empirical calculations show that the negative skin friction value is 0.

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Negative skin friction has a value of 0, meaning changes or shifts in the soil do not produce friction opposite to the structure's direction of movement [22]. As a result, the load received by the pile is reduced, and no additional settlement occurs due to negative skin friction [23]. In this way, the structure is safe from impacts that may occur due to negative skin friction.

3.4 Settlement

Based on the calculation results, the maximum planned pile group settlement value is 16.58 mm. However, after field observations, the decrease that occurred was only 2 mm, not exceeding the planned calculations, as proven by the figure in **Figure 4**.

(a) (b)

Source: Field Data.

Figure 4. (a) Observation of the First Month’s Settlement, (b) Observation of the Third Month's Decline

The actual settlement in the field does not exceed the planned value. This shows the safety of the structure [24][25]. Conformity of settlement values with plan limits and structural safety standards indicates success and reduces the possibility of problems occurring due to settlement [26]. Although settlement values tend to be low, regular monitoring and maintenance are still required to ensure the long-term performance and sustainability of the structure.

3.5 Comparison of Bearing Capacity

Based on the CPT data obtained, the bearing capacity results of several methods are presented below.

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Table 3. Comparison of Bearing Capacity.

Grid	46	47	48	49	50	Pile Grup
Eg	0,915	0,915	0,915	0,915	0,915	-
Meyerhoff	86,60	87,08	84,07	84,15	76,15	382,587
Meyerhoff Modifikasi	209,715	241,431	250,888	250,888	222,481	1075,667
Begemann	128,177	146,82	154,498	154,50	136,13	659,016
Trofimankove	168,6808	194,2247	202,1846	202,1846	178,3049	865,346
CPT Data	62,51	70,99	76,83	76,83	59,3	346,46

Source: Data Processing (2023).

Based on **Table 3**, with a planned load received by the column of 700 tons, two methods can be met: Modified Meyerhoff and Trofimankove. Both methods tend to have high bearing capacity values because they take into account the influence of lateral loads on the piles [27]. A sandy type of soil also supports it, so its properties provide better support for the piles [28]. Meanwhile, the results of the Meyerhoff and Begemann methods are unsuitable because both methods were developed to calculate the bearing capacity of cohesive soils such as clay [29].

So, when planning a pile foundation with sandy soil conditions, it is recommended to use the Modified Meyerhoff and Trofimankove methods by considering all relevant factors, such as soil characteristics [28]. By using the right method, pile foundations can be built safely.

4. Conclusion

The evaluation results show that the difference in the depth of the planned and implemented foundations is 22% in buildings with sandy soil, indicating that they are in a safe condition. So, there is little chance of structural failure in the building. This is shown by the average CPT distance of 18.22 meters, which makes the CPT data less accurate because differences in soil structure can occur. Apart from that, the field settlement of 2 mm is lower than the maximum settlement limit, and a negative skin friction value of 0 indicates no additional settlement. This parameter indicates the structure is in safe condition. For calculating bearing capacity, the Modified Meyerhoff and Trofimankove methods are suitable for planning foundations on sandy soil because they can meet the load received. The results of this research can add empirical evidence in evaluating structural safety based on differences in depth of foundation planning and implementation in sandy soil-based projects, as well as reducing the potential risk of structural failure in the future.

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