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Design Analysis of Triangular Minipile for Cohesive Soil: A Study Case

Mila Kusuma W. [1a*], M.Ferdaus N.A[2a], Arintha IDS.[b], Febiana P[c]

[a,b,c] Institut Teknologi Adhitama Surabaya, Indonesia

Abstract. Triangular minipile foundations are still rarely encountered in construction even though they are still being produced. The use of minipile foundations can be considered in the design of foundations with soft soil depth of < 10 m. This study was conducted to design for a triangular minipile on soft soil by considering the bearing capacity of either the foundation or the material, settlement, as well as the implementation method and cost budget. The soil data used is NSPT data with a soft soil depth of up to 8 m with a 2-storey shophouse building load. The recommended results are given when using a minipile of 28x28x28 cm compared to 32x32x32 cm, the need for a minipile is different from 3 to 6 piles at a depth of 6 m with a load of 40.37 tons. A triangular minipile with dimensions of 28 x 28 x 28 cm has total settlement of 6.02 cm. A triangular minipile with dimensions of 32 x 32 x 32 cm has total settlement of 3.87 cm. The minipile foundation implementation method using the "press in pile" Driving is carried out using an HSPD machine with a capacity of 120 tons. Costs calculated in meters include material costs, work wages and heavy equipment used. The cost used in the 32x32x32 triangular minipile is 10% cheaper than the 28x28x28 m dimension.

Keywords: triangular minipile, cohesive soil, bearing capacity, settlement, budget
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1. Introduction

The foundation design in Geotechnical Science will be based on soil data and the function of the building to be carried out. If a structure has an increase in load, the existing building would be threatened by excessive settlement [1], [2]. Basically, foundation design can be divided into deep foundation design and shallow foundation design. Soil conditions in the foundation design as the basis for the selection and for the analysis calculation results. In composite soils such as a mixture of fine-grained soil and coarse-grained soil with properties that need to be improved on the compaction, permeability, and shear strength of the mixed soil. The shear strength of the composite is low and needs to be increased, composite soil reinforced with a foundation requires a strong platform [3]. Shear strength on composite soils as shallow foundations can be carried out using a direct shear test with the concept of Tabari investigation [4], in shallow foundation designs when there is an eccentric load, the bearing capacity parameter is determined by determining the lower limit value of lateral soil stress. This value can use a minimum size equal to the width of the foundation [1], [3], [5].

In soft soil conditions in Indonesia, a foundation design that is suitable for the working load is important. One type of foundation applied in Indonesia to soft soil at medium layer to deep layer depth is micropile. Mini piles or micro piles are drilled deep foundation systems with high-capacity which transfers the structural load through soil layers. Mini piles can be made of materials such as concrete, bamboo, wood, etc. Besides being used as deep foundations, mini piles can also be used as slope stability reinforcement [6] and improvement of soft soil and liquefaction soil [7], [8].

A study once conducted a study on triangular mini piles using pile caps in office buildings showing the results that with a triangular mini pile of 32x32x32 cm, variations in the number of piles were obtained. From the number of piles analyzed, it was found that the number of mini piles was 6 pieces with a depth of 17 m [9]. Some studies in the mechanism of load transfer from the superstructure to the sub-foundation supported by micropiles [2]. Several experimental experiments and theoretical approaches were developed to analyze the loading behavior with the carrying capacity of the micropile including the centrifuge modelling [10], [11]. The use of a load-bearing micropile configuration shows that the optimum distance is 3-4 times the diameter with a length of 10 to 30 m depending on the soil conditions [12].

One of the two-story shophouse buildings in Gresik district has NSPT test results as deep as 20 m. From the results of soil testing, the dominant type of subgrade is clay with very soft clay consistency at a depth of 1-4 m and at a depth of 5-8 m, the NSPT value of 10-12 is medium clay consistency. Based on the existing conditions, it is recommended to use minipiles.

The purpose of this study is to determine the need for minipile design in clay soils with simple buildings. The design carried out includes bearing capacity calculations, settlement control and knowing the implementation method and costs. This study still uses one case example in a two-story shophouse building. It is hoped that this study will become a reference in the design for minipile users as an alternative foundation for light buildings with medium soft soil conditions.

* Corresponding author: milakusuma@itats.ac.id

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2. Materials and Methods

The minipile type A and B used in the construction of a two-story shophouse is based on the BEP pile brochure with a triangular shape as shown in Figure 1 and 2. The triangular minipile has a thickness of 3.5 cm concrete decking, with 3 pieces of D13 deformed bars as the main reinforcement, 3 m to 6 m length, and K-450 of concrete quality.

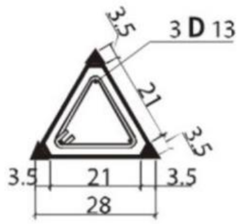

Figure 1. Type A Minipile, size 28x28x28

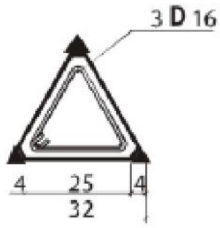

Figure 2. Type B Minipile, size 32x32x32

The loading calculation on each column affects the bearing capacity of the foundation and the number in the pile group. Based on calculation using SAP2000 with loading combination of 1.2D + 1.6L, the load acting on the column that the largest load is on column K5 of 81.9 tons, while the minimum load is focused on the K3 column of 31.07 tons.
The injected pile (high pressure) method of driving was obtained in planning of the two-storey shophouse building with HSPD (Hydraulic Static Pile Driver) so that the calculation of the Luciano Decourt method bearing capacity required parameter values α and β according to the type of soil planned for silty clay [13]. Table 1 show the coeffiecient of pile base (α) and the coefficient of pile skin friction (β) based on the soil type for injected pile (high pressure). The Luciano Decourt method uses the N_P value of the average N-SPT 4B above and 4B below the embedded pile, and the N_S value is obtained from the average NSPT of a number of pile depths. The implementation of the field penetration test with the SPT is carried out based on the SNI guidelines [14].

Table 1. Coeffiecient of pile base (α) and the coefficient of pile skin friction (β) for injected pile (high pressure).

Soil Type	α	β
Clay	1	3
Intermediate Soils	1	3
Sands	1	3

Unstructured interview questionnaires were conducted as supporting data that the author will use as a reference and advice in the selection of foundation forms and driving methods. The minipile driving method was chosen based on interview questionnaires to several people who have experience of foundation work in the field. Figure 3 shows the source of the profile data that has been obtained.

Keterangan				
Respondent's Job Title	Project Manager	Site Manager	Engineer	Project Executor
Respondent's Education	SMK	S1	S2	
Respondent's Age	17 – 25	26 – 35	36 – 45	46 – 55
Respondent's Work Experience	1 – 5 years	6 – 10 years	11 – 15 years	> 16 years

Figure 3. Source profile of the unstructured interview of this study

3. Results and Discussion

3.1 Load Calculation

The calculated load is a building consisting of reinforced concrete and the substructure in the form of a minipile. The column load itself has a different value at each column point. In a combination of loads which is also called a factored load, each type of load has its own load factor which is then added up to obtain a factored load. The live load is determined to be 250 kg/m² based on the Indonesian loading regulations for buildings (PPIUG 1983). The largest load is obtained at a combined loading of 1,D +1L, because it displaysthe most critical design condition or the greatest load of the load combination. The value of the axial load for each column is given in Table 2.

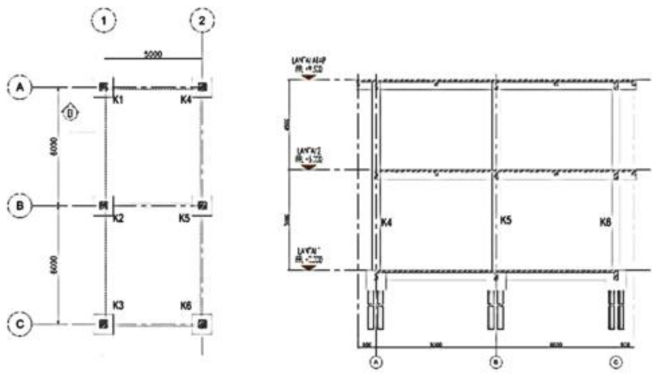

Figure 4. 2D design plan and sectoions

Table 1. Load analysis calculation results

No.	Coloumn	P (ton)	Mx (ton)	My (ton)
1	K1	45.390	0.87	0.652
2	K2	54.086	-0.001	1.070
3	K3	31.075	-2.52	1.882
4	K4	49.688	0.0005	3.629
5	K5	81.902	0.001	-0.04
6	K6	49.688	-3.63	-0.003

3.2 Single Pile Bearing Capacity Calculation

The final depth of soil testing 8 meters deep, it is known that a square minipile measuring 25 x 25 cm has the highest carrying capacity is 32.48 tons, then the next highest order is triangular shape with a size of 32 x 32 x 32 cm with a value of 29.85 tons, next minipile triangular shape size 28 x 28 x 28 has a carrying capacity value of 25.71 tons, then a square minipile measuring 20 x 20 cm with a value of 25.13 tons. From the minipile form, the bearing capacity of the foundation does not change the magnitude of the bearing capacity of the foundation.

The results of carrying capacity when using other soil data such as sondir indicate that the static analysis calculation method is better when using the modeling results with FEM. Another study conducted by [15], [16] dan [17] showed that the static analysis carried out by comparing several carrying capacity formulas was only 6.65% different. So that the carrying capacity when using the NSPT value using the Luciano Decourt method is sufficient in the analysis in this plan.. Figure 5 shows the NSPT value and the calculation results of the minipile bearing capacity.

3.3 Analysis Foundation Depth

The strength of the material is calculated as a reference value for determining the depth of the foundation. The bearing capacity of the material is calculated using the concrete quality parameters obtained from the brochure K-450 pile specification BEP = fc' 37.35 Mpa = 42 kg/cm The bearing capacity of the material is calculated using concrete quality and minipile surface area. From the calculation of the strength of the material obtained a value of 29,097 tons which is seen as more than the allowable compression value in the pile brochure, which is 30 tons, then this value is sufficient. The results of the calculation show the need for the number of minipiles with an embedded foundation of 6 m long, that in 1 building need 25 pieces of type A minipiles, while type B requires 23 minipiles, but the number of each point the column has different variations according to the axial load supported between 3 - 6 piles.

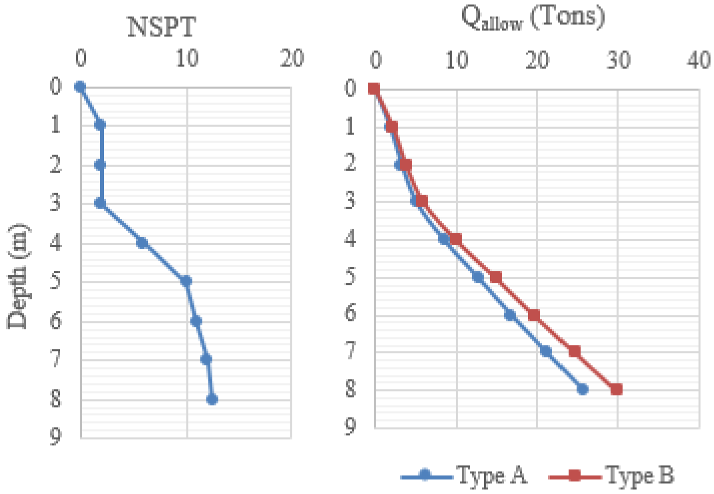

Figure 5. N-SPT value and the allowable bearing capacity Luciano Decourt method

3.4 Minipile Settlement

In the foundation design according to [18], one of the safe requirements is to meet the permit reduction limit. from the results of the calculation of the depth and the number of minipile needs, it can be carried out analysis of group foundation settlement. The pile group settlement is generally greater than that of the single pile which influenced by the stress in the wider and deeper area around the pile. The total settlement is the sum of the immediate settlement and the consolidation settlement as illustrated by Figure 5. Table 2 shows the results of the total settlement calculation

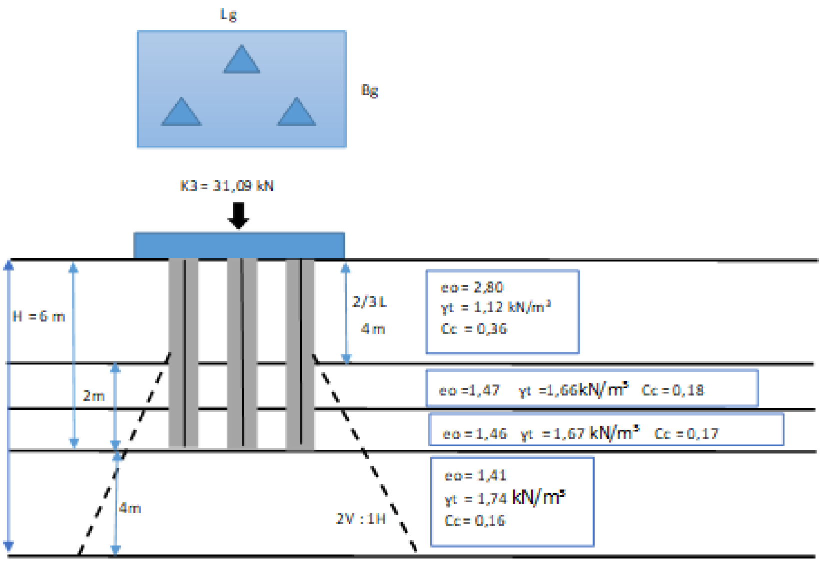

Figure 6. Illustration of Consolidation Settlement

the largest total Settlement in the pile group was 7.58 cm at column K5 axial load 81.90 and the number of piles is 5 with a triangular minipile size 32 x 32 x 32 cm. The smallest Settlement is in K3 with a load of 31.08 tons the number of poles in one group is 3 pieces with a square size of 20 x 20 cm and the decrease that occurs is 2.5 cm. Thus the total Settlement is said meet the maximum reduction limit for high-rise buildings, namely SNI 8460:2017 The total settlement meets the maximum reduction limit for high-rise buildings according to SNI 8460:2017 Geotechnical Design Requirements < 15 cm.

Table 3. Triangular Minipile Group Settlement

Column Point	Type A		Type B	
(tons)	Number of Piles	Total Settlement	Number of Piles	Total Settlement
K1 = 45.39	4	6.02	3	3.87
K2 = 54.09	4	5.22	4	5.04
K3 = 31.08	3	2.6	2	5.36
K4 = 49.69	4	5.12	4	4.96
K5 = 81.90	6	5.78	6	5.78
K6 = 49.69	4	5.12	4	4.96

3.5 Minipile Driving Method

The results of the interview shows that most of the interviewees had encountered and used a minipile foundation with a triangular shape in their work. Choosing minipiles as a construction project foundation is a pretty good choice, but the use of a minipile as a foundation tends to be more expensive in the implementation process and the material procurement process is quite difficult, especially the minipile with a triangular shape. The procurement of triangular minipiles is a factor causing the infrequent use of triangular minipiles in construction projects. In addition, any type of soil can be planned using a minipile foundation. Calculation analysis can help to determine the selection of the foundation both from the shape of the cross section, minipile diameter and the right implementation method to use.

3.5.1. Preparatory Work and Soil Improvement

In preparatory work, improvement of surface soil stability aims to stabilize the footing of heavy equipment during the driving process so that the alignment of the minipile foundation can be maintained. After that, a marker is made at each point to be planted, then the minipile is moved next to the driving machine, the final set planning and the driving sequence are very necessary for the mobilization of heavy equipment, then it will stop briefly before connecting the piles to the design depth, the driving can be stopped if the pile is felt reaches hard ground, the last cut will be done at the specified level.

3.5.2. Driving Process

The process of lifting and pressing the pile with the load need to be considered to minimize damage to the minipile. The driving process starts from where the minipile stock piles up, the pile is lifted on the hydraulic machine then it will clamp the center of the minipile and press it with a capacity of 120 tons.

3.5.3. Quality Control

At this stage, checks must be carried out carefully to find out cracks and the slope of the minipile. Checking the pile surface, cracks and other damage is carried out periodically during the driving process, whether it is tilted and marking every half meter on the pile body. Inspection of the pile during the driving process must be careful to avoid the risk of cracking and breaking the pile during driving process.

3.6 Cost Analysis

Calculation of the cost of the driving work on the two-story shophouse construction plan is determined from the work location, soil data, and the layout of the pile driving point. Driving is carried out using an HSPD machine with a capacity of 120 tons. Costs calculated in meters include material costs, work wages and heavy equipment used. The results of the foundation calculation per meter can be seen in Table 3.

Table 4. Calculation results of Minipile Driving Cost.

Type	Size (cm)	Pile Requirement (pcs)	Total of Pile Length (m)	Total cost of minipile driving
A	28x28x28	25	150	Rp43.162.200
B	32x32x32	23	138	Rp39.036.198

3.7 Productivity of Piling Process Analysis

In general 'Press in Pile' technology reduces environmental problems, is more practical, faster and more economical. Good piling will produce the expected productivity value. The pile driving process with a jack-in system using a Hydraulic Static Pile Driver (HSPD) in the building showed the highest productivity (0.509 m/min) and the lowest (0.406 m/min) [19]. The productivity value depends on the length of the pile and the unit of time in terms of the duration of piling process. Table 4 shows the results of the minipile piling process productivity based on the calculation for each column point.

Table 5. Productivity of the minipile piling process.

Column Point	Type A		Type B	
(tons)	Length (m)	Productivity (m/min)	Length (m)	Productivity (m/min)
K1	24	11.16	18	8.37
K2	24	11.16	24	11.16
K3	18	8.37	12	5.58
K4	24	11.16	24	11.16
K5	36	16.74	36	16.74
K6	24	11.16	24	11.16

4. Conclusion

The shape of the minipile used in the 2-storey shophouse design is a triangular shape at 6 m depth. When using a minipile size of 28x28x28 cm it is 25 minipile while when using a minipile size of 32x32x32 cm it is 23 minipile. The difference in the number of minipile needs based on that size with a working load of 3-6 piles. A triangular minipile with dimensions of 28 x 28 x 28 cm has total settlement of 6.02 cm. A triangular minipile with dimensions of 32 x 32 x 32 cm has total settlement of 3.87 cm.

The minipile foundation implementation method is based on the interview results using the "press in pile" method of the Hydraulic Static Pile driver machine. Driving is carried out using an HSPD machine with a capacity of 120 tons. Costs calculated in meters include material costs, work wages and heavy equipment used. The cost used in the 32x32x32 triangular minipile is 10% cheaper than the 28x28x28 m dimension. Further studies need to compare designs on other simple buildings using a rectangular minipile on the same ground. In addition, it can be considered the use of minipile on sandy soil.

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