Mini Pile Foundation Construction Design on Soft Soil Due to Box Traffic Loads based on Standard Penetration Test

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Keywords: Box Traffic Loads, Mini Pile Foundation, Foundation Construction Design.

Abstract: Box traffic is an underpass structure in the form of a tunnel under the ground that functions as a transverse road under other roads that serves as a liaison between separate areas due to the construction of toll roads. The construction of Padang – Sicincin Toll Road has separated several surrounding areas so that public access is limited. To solving this problem, a traffic box is built at STA 2+175. Based on the Standard Penetration Test (SPT) data, the location has deep soft soil, so that it cannot support the loads. This paper discusses the used of mini pile foundations to increase the bearing capacity of the soil. The foundation was used with a size of 0.25 m x 0.25 m, the distance between the piles (s) 1m, with variations in the penetration depth of 10m, 12m, and 14m. Bearing capacity analysis was carried out based on SPT data. The analysis results show that the sub-grade settlement without using a mini pile foundation is 0.34 m – 0.35 m BH-01 and 0.59 m – 0.62 m on BH-02, where the settlement exceeds the allowable settlement limit. While, by using a mini pile foundation with a depth of 10 m, the settlement is 0.02 – 0.05 cm. This settlement is smaller than the allowable settlement for pile foundation. The bearing capacity of the mini pile group foundation increases with increasing pile penetration depth, but it does not apply to single piles.

1 INTRODUCTION

Pile foundation is one of the important aspects of road construction. It functions as a successor to the load that works on it and is channeled to the subgrade. Pile foundations are generally divided into two sizes, namely large size (maxi pile) and small size (mini pile)(Yu & Wang, 2019). The foundation must withstand the loads that work on it (Yu & Wang, 2019), (Purwanto, 2019). One of these loads can be a box traffic load.

Box traffic is an underpass structure in a tunnel under the ground that functioned as a transverse road under the road (Desai & Desai, 2017). In its role as an underpass, this traffic box carries both gravity and lateral loads. The gravity load includes dead loads and live loads. In comparison, the lateral load includes earth pressure and earthquake loads (Wrana, 2015), (de Sanctis et al., 2021). Carry out the working load needs the subgrade must have allowable bearing capacity to withstand the load.

In the construction of the Padang-Sicincin Toll Road, there is a location with soft soil that is quite deep based on the Standard Penetration Test results (SPT). This condition leads to the soil not being able to withstand the load, such as box traffic. Therefore, efforts are needed to increase the bearing capacity of the soil.

This paper discusses a mini pile foundation design due to box traffic load to solve the problem. This foundation design will strengthen the subgrade of the structure. Thus, it has sufficient permit-bearing capacity to withstand the load.

This paper is organized as follows: In Section 2, the proposed construction design is explained. Section 3 contains the results and discussion of the methods that have been implemented. Lastly, section 4 concludes the paper.

2 METHODS

2.1 Data Collection

The mini pile foundation construction design is built from secondary data, i.e., the soil data from field and laboratory tests, box traffic structure specification, and mini pile specification data.

Liliwarti, ., Archenita, D. and Faurina, S.
Mini Pile Foundation Construction Design on Soft Soil Due to Box Traffic Loads based on Standard Penetration Test.
DOI: 10.5220/0010945800003260
In *Proceedings of the 4th International Conference on Applied Science and Technology on Engineering Science (iCAST-ES 2021)*, pages 358-364
ISBN: 978-989-758-615-6; ISSN: 2975-8246

2.1.1 Soil Data

- Field testing: boring and SPT tests of two drilling points (BH-01 and BH-02) with a depth of 50 m
- Laboratory test: from 4 undisturbed sample (UDS1 to UDS4) which varies in-depth, as shown in Table 1.

Table 1: Undisturbed Samples for Soil Laboratory Test.

Sample ID	Depth
UDS1	5 m and 13 m
UDS2	19 m and 29 m
UDS3	39 m
UDS4	49 m

2.1.2 Box Traffic Specification

The traffic box specifications used are shown in Table 2. With concrete quality, the density of concrete and steel quality is 20 MPa, 24 kN/ m^3, and 390 MPa.

Table 2: Box Traffic Specification.

Dimension	
Length	32,70 m
Width	970 or 974 m (skew)
Height	6.95 m
Top plate thickness	0.80 m
Wall plate thickness	0.85 m
Bottom plate thickness	0.95 m
Materials	
Concrete quality	20 MPa
Density of concrete	24 kN/ m^3
Steel quality	390 MPa

2.1.3 Mini Pile Specification

The mini pile is 0.25x 0.25 m in size. It is calculated with the condition of the head of the pile being pinched. It is because the thickness of the bottom plate of the box is directly used as a pile cap.

2.2 Box Traffic Loads

The box traffic load for the foundation construction design is shown in Table 3. While R_A is reaction at point A, R_D is reaction at point B, and Q is load.

Table 3: Box Traffic Load.

R_A		**R_D**		**Q (kN)**
Vertical (kN)	**Horizontal (kN)**	**Vertical (kN)**	**Horizontal (kN)**	
6927.51	-3.02	8109.50	0	15037.01

Figure 1: Box Traffic.

Figure 2: The points reviewed on the box traffic.

2.3 Mini Pile Foundation Construction Design

The mini pile foundation is designed with a direct foundation plate like a pile cap from the pile head (foundation with a box traffic monolith structure) (Yu & Wang, 2019). Thus, the head of the foundation is in a clamped condition. It means that it can withstand the moment or overturn in the structure or the moment on the structure=0. Manual calculations carry out this foundation design for the axial bearing capacity of the pile foundation and the bearing capacity of the group pile foundation. At the same time, the lateral bearing capacity of pile foundations and pile foundation settlement is modeled using structure analysis software.

The calculations of three factors can determine the number of piles, i.e. (1) the distance between the piles (s) following the box traffic structure; (2) the implementation of pile driving in the field; (3) the efficiency of the pile group (de Sanctis et al., 2021),(Feicheng & Jianjing, 2017). Based on these factors, the distance between the piles is 1 m with the pile group efficiency is 0.75 for cohesive soils based on the group pile efficiency factor in cohesive soils While for non-cohesive soils is 1. Thus, the number of piles (n) that will be used is 279 piles and the cross-section as shown in Fig.3.

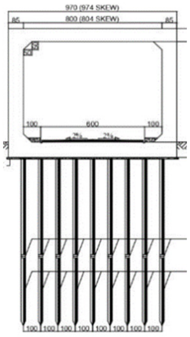

Figure 3: Mini pile foundation design based on the distance between the piles (s) is 1.

2.3.1 Loads on Foundation

- Total loads on pile group (P_{total}), is calculated by the Eq 1.

$$P_{total} = R_A + R_D \quad (1)$$

While,
R_A = Reaction at point A (kN)
R_D = Reaction at point D (kN)

- The loads on each pile (P_{single}), is calculated from the P_{total} divided by the number of pile (n), as shown in Eq.2.

$$P_{single} = \frac{P_{total}}{n} \quad (2)$$

These calculations give P_{total} = 15037.01 kN, and P_{single} = 53.89kN.

2.3.2 Axial Bearing Capacity of Pile Foundation

The axial bearing capacity of the pile foundation is calculated based on the strength of the material and soil conditions around the foundation (Liliwarti, 2019). The calculations is done at a depth of 10 m, 12 m, and 14 m. This aims to determine whether the pile is able to withstand the loads both internally and externally

- Axial bearing capacity of pile foundation based on SPT

The axial bearing capacity of the pile foundation from the SPT data is calculated using an equation based on the Meyerhof 1956 method (Hardiyatmo, 2011).

a. End Bearing Pile
   - End Bearing Pile in cohesive soil

$$Q_p = 9 \, x \, c_u \, x \, A_p \quad (3)$$

   - End Bearing Pile in cohesive soil

$$Q_p = 40 \text{ x } N_{SPT} \text{ x} \frac{L}{d} \text{ x } A_p \leq 400 \text{ x } A_p \text{ x } N_{SPT} \quad (4)$$

b. Friction pile
   - cohesive soil

$$Q_s = \alpha \text{ x } c_u \text{ x p x } L_i \quad (5)$$

   - Non cohesive soil

$$Q_s = 2 \text{ x } N_{SPT} \text{ x p x } L_i \quad (6)$$

   - Total Bearing Capacity

$$Q_u = Qp + Qs \quad (7)$$

Where

Q_p: friction pile (kN)
N_{SPT} : N- SPT
c_u : undrained cohesion (kN/m^2)
L : dept of pile (m)
d : diameter of pile (m)
A_p: area of pile (m^2)
Q_s: tahanan gesek tiang (kN)
α : coeficient adhesi soil and pile
p : perimeter of pile (m)
L_i : dept of soil layer (m)

2.3.3 Lateral Bearing Capacity of Pile Foundation

Pile foundation in the box traffic is designed with the condition of the pile head pinched (Hardiyatmo, 2011). Thus, it can withstand the moment that will occur (moment = 0). Lateral load on the foundation based on structural mechanics is analyzed by using analyzing software. It gives the result of 3.02 kN (H = 3.02 kN). Furthermore, the lateral bearing capacity of the pile foundation against the load is calculated based on variations in the depth of pile penetration, i.e., 10 m, 12 m, and 14 m.

The type of soil at the tip of the pile in each variation of penetration depth in BH-01 and BH-02 includes silt and/or sandy soil. Therefore, based on Broms's (1964) method in calculating the lateral bearing capacity of the pile, the formula used is a formula that is suitable for the type of soil at the end of the pile, i.e., silt and or sand. The lateral bearing capacity of the pile is calculated based on the pile deflection and the ultimate lateral load-bearing capacity that the pile can withstand (Hardiyatmo, 2011).

The ultimate lateral load of the pile is calculated based on Broms method (1964) (Hardiyatmo, 2011). Calculation of the pile type obtained from the previous calculation pile vertical deflection and the type of soil at the tip of the pile in BH-01 and BH-02. The calculations result are shown in Table 4.

Table 4: The ultimate lateral load-bearing capacity of the pile on BH-01 and BH-02.

No.	Depth	Soil type	My (kN-m)	Hu (kN)
		BH-01		
1	10 m	Silt	25.34	22.52
2	12 m	Sandy silt	-173.39	-127.26
3	14 m	Sandy silt	-250.17	-158.84
		BH-02		
1	10 m	Silt sand	1492.05	799.32
2	12 m	Sandy silt	-278.62	-201.54
3	14 m	Sandy silt	-311.37	-196.14

Hardiyatmo (2011),(Hardiyatmo, 2011) states that the maximum deflection for buildings, bridges, and similar structures is 6 mm to 18 mm. Vertical pile deflection from the analysis is shown in Table 5.

Table 5: Vertical pile deflection on BH-01 and BH-02.

No.	Penetration depth	Soil types	yo (m)	
			Cohesive	Granular
		BH-01		
1	10 m	Silt	0.00169	-
2	12 m	Sandy silt	0.00143	-
3	14 m	Sandy silt	0.00125	-
		BH-02		
1	10 m	Silt sand	-	8E-05
2	12 m	Sandy silt	0.00111	-
3	14 m	Sandy silt	0.00101	-

2.3.4 Pile Settlement

The total settlement that occurs in the pile foundation is calculated based on the elasticity of the pile material itself and the axial bearing capacity of the pile (Wang et al., 2019), (Hardiyatmo, 2011). The axial bearing capacity of the pile under review is the carrying capacity based on SPT data on BH-01 and BH-02. So that the pile settlement will be calculated based on these two indicators, in addition, pile settlement will also be calculated for each variation of pile penetration depth on BH-01 and BH-02. The settlement on the pile was calculated based on the Vesic method (1977) according to the magnitude of the axial bearing capacity of the pile based on SPT data. The calculations result are shown in Table 6.

Table 6. The Total Pile Group Settlement on BH-01 and BH-02.

Depth	Soil type	S_1 (cm)	S_2 (cm)	S_3 (cm)	s (cm)	$S_{g(e)}$ (cm)
		BH-01				
10 m	Silt	0.01	0.00	0.00	0.01	0.04
12 m	Sandy silt	0.01	0.00	0.00	0.01	0.04
14 m	Sandy silt	0.01	0.00	0.00	0.01	0.05
		BH-02				
10 m	Silt sand	0.01	0.00	0.00	0.01	0.05
12 m	Sandy silt	0.01	0.00	0.00	0.01	0.05
14 m	Sandy silt	0.01	0.00	0.00	0.01	0.05

3 RESULT AND DISCUSSION

Based on the previous calculation, the result of the 0.25 x 0.25 m mini pile foundation construction design is obtained, as shown in Fig. 2 to Fig. 9.

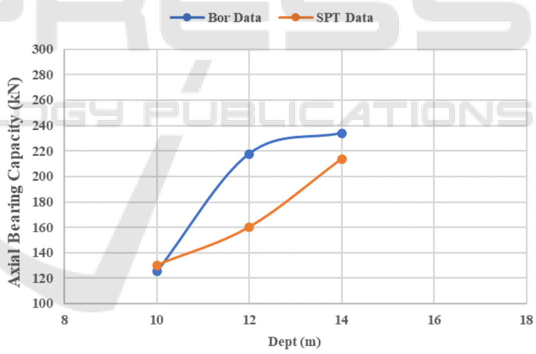

Figure 4: Axial bearing capacity single pile on BH-01.

Bearing capacity on BH-01 increases with the dept of the pile, showing the deeper the pile driving, the greater the bearing capacity of the soil.

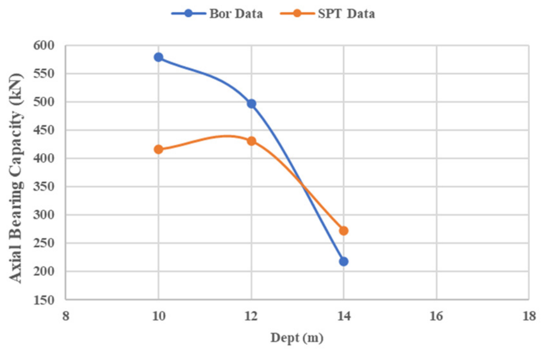

Figure 5: Axial bearing capacity single pile on BH-02.

Bearing capacity on BH-02 decreases with the dept of the pile, showing the deeper the pile driving the lower bearing capacity of the soil. This is because of the condition of the soil layer at a depth of 12 and 14 m in soft soil.

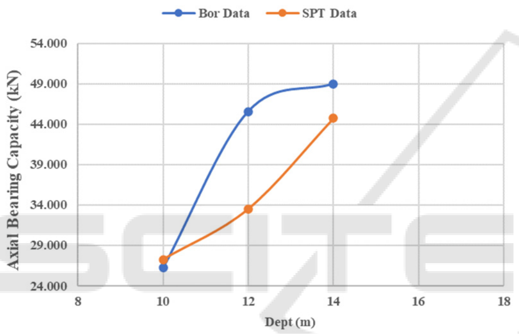

Figure 6: Bearing capacity of the pile group on BH-01.

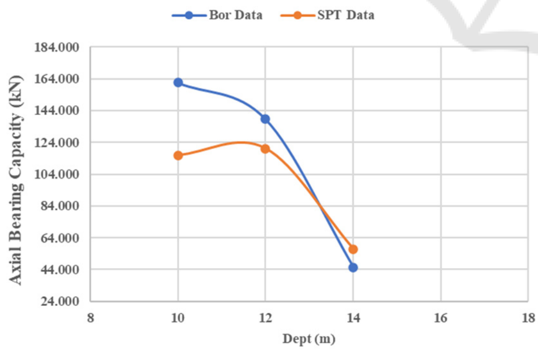

Figure 7: Bearing capacity of the pile group on BH-02.

Bearing capacity for single piles and group piles shows the same behavior in BH01 and BH 02.

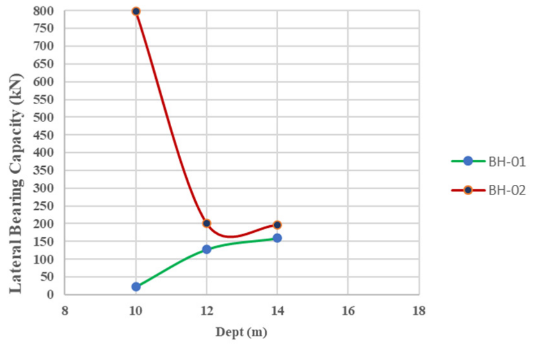

Figure 8: Lateral load capacity on BH-01 and BH-02.

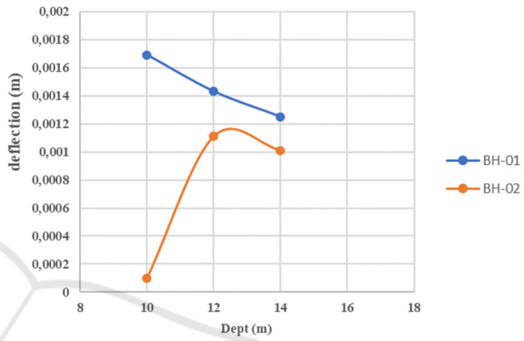

Figure 9: Maximum pile deflection on BH-01 and BH-02.

At BH01, the pile deflection decreases with increasing depth of the pile, but otherwise for BH 02.

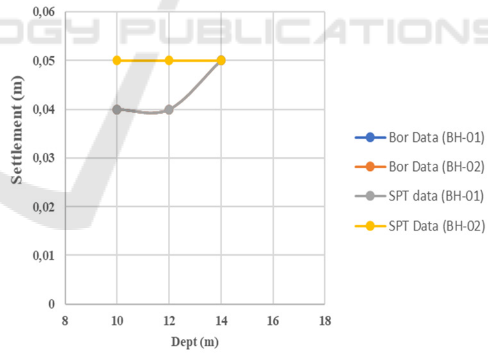

Figure 10: Pile settlement on BH-01 & BH-02.

Pile settlement BH 01 and BH02 showed the same results in analysis with bor data. If analyzed with SPT data, there was an increase in the value of pile settlement, but still below the allowable settlement.

Based on the design calculations that have been carried out, the mini pile foundation is planned with a pile penetration depth (L) of 10 m, the distance between piles (s) of 1 m, and the number of pile foundation points (n) as many as 279 piles. It is obtained based on the calculation output of the permitted axial bearing capacity, group bearing

Table 7: The final result design of the mini pile foundation varies in-depth on BH-01 and BH-02.

	Loads Acting on the Foundation			**Pile Axial allowable Bearing Capacity (Q_{all}) (kN)**	**Pile Group allowable Bearing Capacity (Q_{ag}) (kN)**	**Ultimate Lateral Load (Hu) (kN)**	**Pile Deflection (yo) (m)**	**Settlement of Pile ($S_{g(e)}$) (cm)**
	P_{total} (kN)	**$P_{tunggal}$ (kN)**	**H (kN)**					
BH-01								
Depth of Pile 10 m	15037.01	53.89	3.02	130.27	27258.6	22.52	0.002	0.04
Safety Factor				2.5	2.5	2.5	0.025	6.5
				Safe	Safe	Safe	Safe	Safe
BH-02								
Depth of Pile 10 m	15037.01	53.89	3.02	415.64	115963.6	799.32	0.0001	0.05
Safety Factor				2.5	2.5	2.5	0.025	4.0
				Safe	Safe	Safe	Safe	Safe

capacity, lateral bearing capacity, and pile settlement at a depth of 10 m based on SPT data that can withstand the load that will work. The final result in a mini pile foundation design for the traffic box is shown in Table 7.

4 CONCLUSION

Based on the calculations that have been carried out, the mini pile foundation is planned with a pile penetration depth (L) of 10 m, a distance between piles (s) of 1 m, and the number of pile foundation points (n) as many as 279 piles. It is obtained based on the calculation results of the permit axial bearing capacity, group bearing capacity, lateral bearing capacity, and pile settlement at a depth of 10 m based on SPT data. It has been able to withstand the load, and the load on the single pile (P_{single}) and the pile group (P_{total}) is 53.89 kN and 15037.01 kN. The magnitude of the decrease in the pile group that occurs is 0.02 – 0.05 cm. It shows that the settlement is safe for the structure because it does not exceed the maximum pile settlement limit, which is 6.5 cm for piles in clay and 4.0 cm for piles in the sand (SNI 8460:2017).

In further research, the calculation of the load on the subgrade originating from the box traffic structure load is expected to be closer to the original conditions in the field so that the subgrade settlement due to the working structure load can be calculated more accurately. complete again so that the calculation of settlement and foundation design can run smoothly and have more accurate results.

ACKNOWLEDGMENTS

This research was fully funded by DIPA of Politeknik Negeri Padang.

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