

Construction Cost Analysis of Spun Pile and Bored Pile Foundations for Aqueduct C of the Raw Water Supply Supplemental Project in Aceh Province

Ghufran Helmi Aziz^{1*}, Andi Patriadi², Esti Wulandari³

Universitas 17 Agustus 1945 Surabaya, Indonesia^{1,2,3}

Email: ghufranelmi@gmail.com*, andipatriadi@untag-sby.ac.id,
wulandariesti@untagsby.ac.id

Abstract

Selecting the optimal deep foundation system is a critical task in major infrastructure projects, requiring a balance between structural performance, geotechnical constraints, and economic viability, as foundation costs typically represent a significant portion of the total budget. Bored piles and spun piles are two widely adopted deep foundation types, each offering distinct advantages in terms of capacity, installation speed, and environmental impact. Given the necessity for cost optimization in the Raw Water Supply Supplemental Project in Aceh Province, this study focuses on comparing the construction costs of these two foundation types for Aqueduct C. The foundation plan for Aqueduct C requires a total pile length of 2,870 meters with a diameter of 60 cm. The analysis uses unit cost data based on the Ministerial Regulation's Unit Price Analysis (AHSP) tables. The calculation results show that the total cost for the bored pile foundation is Rp2,847,074,353.90, while the total cost for the spun pile foundation is Rp3,205,844,730.90. This indicates that the bored pile foundation is more cost-effective for this specific project by approximately Rp358,770,377.00. The structural capacity analysis confirmed that the designed foundation group safely supports the axial load transferred by the piers.

Keywords: deep foundations, cost analysis, bored piles, spun piles, aqueduct construction

Corresponding Author: Ghufran Helmi Aziz
E-mail: ghufranelmi@gmail.com



Introduction

Bridges and other large infrastructures rely on foundation systems capable of safely transferring loads from the superstructure to competent soil or rock layers (Li, 2020; Magar, 2020). Foundations are therefore critical structural components whose performance directly influences the safety, serviceability, and long-term durability of the entire system (Rafidatul Hildayani, 2024; Putri, 2024). Inadequate bearing capacity or excessive settlement can trigger severe structural damage, including catastrophic failure (Fajarsari, 2020). Globally, foundation-related issues account for approximately 10–15% of total infrastructure repair costs, with inappropriate foundation selection being a leading cause of premature structural deterioration and project budget overruns (Alsanabani, 2023). In large-scale water infrastructure projects, optimizing foundation costs while maintaining structural integrity remains a universal challenge, particularly in regions with

complex geological conditions where foundation expenses can escalate significantly (Lifshitz Sherzer et al., 2024; McCall, 2024; Sun et al., 2025). Consequently, foundation planning requires careful evaluation of load-transfer mechanisms, soil characteristics, and deformation limits to ensure acceptable safety and performance under working conditions (Melchior Filho, 2020; Ardiansyah, 2024).

Deep foundations—particularly bored piles and spun (prestressed hollow concrete) piles—are widely adopted when shallow soils cannot provide sufficient bearing resistance (Amal, 2023; Ardana, 2022). Bored piles are cast in situ after drilling the ground to the designed depth and are favored for their high bearing capacity, low noise, and minimal vibration during construction (Yonamastuti, 2022; Wang, 2023). However, their performance is strongly influenced by soil disturbance, installation effects, and drilling fluids such as bentonite, which may reduce shaft resistance through filter-cake formation (Bulathsinhala, 2024). Accurate prediction of bored-pile settlement remains complex due to uncertainties in soil behavior, construction quality, and load-transfer mechanisms (Al-Kinani, 2020; Hu, 2023).

Spun piles—also referred to as prestressed hollow concrete (PHC) piles—are commonly used in Indonesia and many other countries due to their rapid installation, high axial capacity, and cost-effectiveness (Mohamad, 2022; Jisha, 2021; Riyono, 2023). Despite these advantages, spun piles exhibit limited ductility and poor lateral performance, making them vulnerable in high-seismic regions (Fajar, 2021; Ren, 2021). In Indonesia, design codes such as SNI 8460 still impose elastic behavior requirements for spun piles due to repair limitations and increased seismic demand (Callista, 2022).

Selecting between bored piles and spun piles requires balancing geotechnical conditions, structural performance, environmental considerations, and economic constraints (Sari, 2021; Alsanabani, 2023). Foundation costs typically account for 10–15% of the total project budget, and optimizing foundation type can significantly reduce overall expenditures (Alsanabani, 2023). In regions with complex geological conditions—such as Aceh Province—uncertainty in soil stratigraphy further complicates foundation selection, influencing both technical feasibility and cost efficiency (Qu, 2024; Oluwatuyi, 2023).

The Raw Water Supply Supplemental Project in Aceh Province requires a foundation system capable of supporting substantial loading while accommodating the site's variable subsurface conditions. Despite extensive global research on deep foundations, comparative analyses of construction cost efficiency between spun piles and bored piles in Indonesian water infrastructure projects remain limited. Understanding the cost implications of each foundation type is essential for supporting effective decision-making, ensuring structural reliability, and maximizing project value.

This comparative cost analysis is particularly urgent at this stage of the project as it directly informs the procurement and tender process for Aqueduct C construction. With the project currently in the detailed engineering design phase, selecting the most cost-effective foundation system will provide substantial economic justification for budget allocation and enable more efficient resource planning. Moreover, the findings will serve

as a valuable reference for similar water infrastructure projects across Indonesia, where foundation costs constitute a major portion of total project expenditure. Therefore, this study aims to analyze and compare the construction costs of spun pile and bored pile foundations for the Raw Water Supply Supplemental Project in Aceh Province. The findings are expected to provide meaningful insights for engineers, contractors, and decision-makers in selecting the most cost-effective deep-foundation system for similar infrastructure projects.

Research Method

This study employed a quantitative approach focusing on the structural analysis and cost comparison of deep foundations. The structural analysis was conducted using data from boring logs and established geotechnical engineering principles, specifically to determine the ultimate and allowable bearing capacity of a single pile (Q_{all}) and the required capacity of the pile group (Q_g). The calculation involved determining the pile end bearing resistance (Q_p) and the skin friction resistance (Q_s), followed by calculating the group efficiency (EFF) based on the number of piles and spacing. The resulting total required foundation length (2,870 meters) for all piers in Aqueduct C served as the basis for the cost analysis. The construction cost calculation for both Bored Pile and Spun Pile foundations (diameter 60 cm) utilized the standard unit price analysis (AHSP) tables released by the Directorate General of Construction (2024) to ensure standardized and accurate costs. Finally, a comparative analysis was performed by multiplying the total required length by the respective foundation unit costs to determine the most economical option.

Result and Discussion

1. Foundation Design Parameters

The structural analysis was based on the following key parameters for a single pile:

- Pier Load (V): 3.248,68 kN
- Pile Diameter (D): 0,6 m
- Pile Length (L): 22 m
- Concrete Compressive Strength (f_c): 25 kg/cm²
- Unit Weight of Concrete (W_c): 24 kN/m³

Table 1. Boring log Data

No.	Depth		Litology	NSPT	c_u (kN/m ²)
	z_1 (m)	z_2 (m)			
1	0	2	Sandy Silt	23	138,00
2	2	4	Sandy Silt	28	168,00
3	4	6	Sandy Silt	32	192,00
4	6	8	Sandy Silt	38	228,00
5	8	10	Marl	60	360,00
6	10	12	Marl	60	360,00

No.	Depth		Litology	NSPT	c _u (kN/m ²)
	z ₁ (m)	z ₂ (m)			
7	12	14	Marl	60	360,00
8	14	16	Marl	60	360,00
9	16	18	Marl	60	360,00
10	18	20	Marl	60	360,00

2. Single Pile Bearing Capacity

The ultimate bearing capacity (Q_u) of a single pile is the sum of the end bearing resistance (Q_p) and the skin friction resistance (Q_s).

- a. Pile End Bearing Resistance (Q_p)

$$Q_p = \mu \cdot c_u \cdot N_c \cdot A_b$$

Using the ultimate undrained cohesion (c_u) of the lowest soil layer (Marl) from the boring log, c_u = 360 kN/m², and the pile's cross-sectional area A_b = 0.28 m²:

$$Q_p = 0,8 \times 360 \text{ kN/m}^2 \times 9 \times 0,28 \text{ m}^2 = 725,76 \text{ kN}$$

- b. Pile Skin Friction Resistance (Q_s)

$$Q_s = \sum (A_s \cdot \alpha \cdot c_u)$$

Table 2. Q_s calculation results

Depth		L ₁ (m)	A _s (m ²)	c _u (kN/m ²)	α _d	P _s (kN)
z ₁ (m)	z ₂ (m)					
0	2	2	3,7699	138,00	0,36	136,069
2	4	2	3,7699	168,00	0,31	147,932
4	6	2	3,7699	192,00	0,20	159,728
6	8	2	3,7699	228,00	0,20	180,494
8	10	2	3,7699	360,00	0,20	272,376
10	12	2	3,7699	360,00	0,20	272,376
12	14	2	3,7699	360,00	0,20	272,376
14	16	2	3,7699	360,00	0,20	272,376
16	18	2	3,7699	360,00	0,20	272,376
18	20	2	3,7699	360,00	0,20	272,376
20	22	2	3,7699	360,00	0,20	272,376
Q _s = ∑ (A _s × α × c _u)						2530,852

Based on the calculation results, the total skin friction resistance is:

$$Q_s = 2,530.852 \text{ kN}$$

- c. Ultimate and Allowable Bearing Capacity

$$Q_u = Q_p + Q_s = 725,76 \text{ kN} + 2.530,852 \text{ kN} = 3.256,612 \text{ kN}$$

With a Safety Factor (SF) of 3:

$$Q_{all} = Q_u / SF = 3.256,612 \text{ kN} / 3 = 1.085,537 \text{ kN}$$

The net allowable load after subtracting the pile weight (W_p = 147.84 kN) is 937.697 kN.

3. Pile Group Bearing Capacity

The number of piles required (n) for the pier load is calculated as 6. With a 3 times 2 configuration (m=3, n=2) and spacing (S) of 1,8 m, the group efficiency (EFF) is 0,76.

- a. Pile Group Bearing Capacity (Q_g)

$$Q_g = EFF \times n \times Q_{all}$$

$$Q_g = 0,76 \times 6 \times 937,697 \text{ kN} = 4.275,898 \text{ kN}$$

Since $4.275,898 \text{ kN} > 3.248,68 \text{ kN}$, the design is deemed safe.

The final design for all piers in Aqueduct C resulted in a total required pile length of 2.870 meters.

Table 3. Results of Calculation of Bearing Capacity on Aqueduct C

Pier Number	Foundation Depth	Number of Foundations	Total Foundation Length	Qp (kN)	Qs (kN)	SF Single Foundation	Q group (kN)	P axial (Kn)	SF group
1	22	6	132	732,87	1.846,15	3	3.243,74	3.248,68	1
2	20	9	180	732,87	1.665,66	3	4.342,53	4.331,57	1
3	26	16	416	732,87	2.207,14	3	8.906,80	8.799,29	1,01
4	26	12	312	732,87	2.207,14	3	6.844,70	6.770,60	1,01
5	28	9	252	732,87	2.387,63	3	5.561,78	5.499,56	1,01
6	30	12	360	610,73	3.316,85	3	9.417,47	8.799,29	1,07
7	24	12	288	610,73	2.630,35	3	7.815,12	7.447,66	1,05
8	30	9	270	610,73	3.316,85	3	7.232,96	6.770,60	1,07
9	28	12	336	732,87	3.380,99	3	10.061,99	9.899,20	1,02
10	24	6	144	732,87	2.836,24	3	4.688,74	4.331,57	1,08
11	30	6	180	732,87	3.653,37	3	5.746,54	5.499,56	1,04
Total	288	109	2870						

4. Construction Cost Analysis

The construction cost analysis utilized the Unit Price Analysis (AHSP) tables released by the Directorate General of Construction (2024).

a. Bored Pile Foundation Cost (Diameter 60 cm)

Table 4. Cost of Drilling Bored Piles with a Diameter of 60 cm per Meter

No.	Description	Code	Unit	Coefficient	Unit Price (Rp)	Total Price (Rp)
1	2	3	4	5	6	7
A	Labor					
1	Worker	L.01	OJ	0.1305	21,428.57	2,797.09
2	Craftsman	L.02	OJ	0.1305	27,142.86	3,542.98
3	Foreman	L.04	OJ	0.0131	32,142.86	421.07
					Total Labor Cost	6,761.15
B	Materials					
					Total Materials Cost	
C	Equipment					
1	Bored Pile Machine (Hydraulic) Auger ϕ 30 - 60 cm	E.06.a	Hour	0.1805	273,102.74	35,648.36
					Total Equipment Cost	35,648.36
D	Total Cost of Labor, Materials and Equipment (A+B+C)					42,409.51
E	Overhead and Profit (10% - 15%) x D				15% x D	6,361.43
F	Unit Price per m3 (D+E)					48,770.94

Source: Directorate General of Construction (2024)

Table 5. Cost of Reinforcement and Casting Work for Bored Piles with a Diameter of 60 cm per Meter

No.	Description	Code	Unit	Coefficient	Unit Price (Rp)	Total Price (Rp)
1	2	3	4	5	6	7

A Labor							
1	Worker	L.01	OJ	0.5955	21,428.57	12,760.71	
2	Craftsman	L.02	OJ	0.0992	27,142.86	2,692.57	
3	Foreman	L.04	OJ	0.0596	32,142.86	1,915.71	
						Total Labor Cost	17,369.00
B Materials							
1	Steel Reinforcement for Foundation Pile 100 kg	B.06. a.1	kg	28.2743	16,922	478,457.70	
2	Medium Grade Concrete $f_c = 25$ Mpa, Slump (10+-2.5)	B.06. a.2	m3	0.2883	1,058,902.43	305,281.57	
						Total Materials Cost	783,739.28
C Equipment							
1	Concrete Vibrator, 52 mm, 3.5 m3/hour, 1 HP	To.39 .1	Hour	0.0992	26,841.82	2,662.71	
2	Crane Truck 5 ton, Winch 8 Ton	E.11. p	Hour	0.0496	331,423.37	16,438.60	
						Total Equipment Cost	19,101.31
D Total Cost of Labor, Materials, and Equipment							820,209.58
E Overhead					15%		123,031.44
F Unit Price per m							943,241.02

Source: Directorate General of Construction (2024)

The total cost per meter for the Bored Pile foundation is the sum of the drilling cost and the reinforcement/concreting cost.

1. Drilling Cost per meter: Rp 48.770,95
2. Reinforcement & Concreting Cost per meter: Rp 943.241,02 (calculated from the source data)
3. Total Cost per meter: Rp 48.770,95 + Rp 943.241,02 = Rp 992.011,97

For the total required length of 2.870 meters:

$$\text{Total Cost} = \text{Rp } 992.011,97/\text{m} \times 2.870 \text{ m} = \text{Rp } 2.847.074.353,90$$

- b. Spun Pile Foundation Cost (Diameter 60 cm)

Table 6. Cost of Piling a 60 cm Diameter Spun Pile Per Meter

No.	Description	Code	Unit	Coefficient	Unit Price (Rp)	Total Price (Rp)	
1	2	3	4	5	6	7	
A Labor							
1	Worker	L.01	OJ	0.1147	21,428.57	2,457.86	
2	Craftsman	L.02	OJ	0.1147	27,142.86	3,113.29	
3	Foreman	L.04	OJ	0.0114	32,142.86	366.43	
						Total Labor Cost	5,937.57
B Materials							
1	Spunpile dia 60 cm type B		m	1.0000	885,000.00	885,000.00	
						Total Materials Cost	885,000.00
C Equipment							
1	Crawler Crane 10 Ton + Leader 14 m	E.11.b	Hour	0.1147	431,545.25	49,498.24	
2	Diesel Hammer 2 ton	E.01.e	Hour	0.1147	269,268.68	30,885.12	
						Total Equipment Cost	80,383.36
D Total Cost of Labor, Materials, and Equipment							971,320.93

E	Overhead	15%	145,698.14
F	Unit Price per m		1,117,019.07

Source: Directorate General of Construction (2024)

The cost for the Spun Pile foundation includes the procurement and driving cost per meter.

- Total Cost per meter (Procurement & Driving): Rp 1.117.019,07
For the total required length of 2.870 meters:
Total Cost = Rp 1.117.019,07/m x 2.870 m = Rp 3.205.844.730,90

5. Cost Comparison Analysis

The results of the cost analysis are summarized as follows:

Table 7. The results of the cost analysis

Foundation Type	Total Length Required (m)	Total Cost (Rp)
Bored Pile	2,870	2,847,074,353.90
Spun Pile	2,870	3,205,844,730.90

The Bored Pile foundation is the more economical choice for Aqueduct C, with a cost saving of Rp 358.770.377,00 compared to the Spun Pile foundation. This difference primarily stems from the lower unit cost per meter for the Bored Pile method, especially considering the specific unit price analysis used. Both foundation types, if properly executed to the required depth and quantity, are structurally adequate to support the pier loads.

Conclusion

The structural analysis verified that the final deep foundation design for Aqueduct C, spanning 2,870 meters, satisfies safety requirements by ensuring pier loads meet the condition $Q_g > V$. The construction cost comparison between 60 cm diameter Bored Pile and Spun Pile foundations identified Bored Piles as the most cost-effective option, with a total estimated cost of Rp 2,847,074,353.90. Future research could expand this analysis by conducting long-term field monitoring of Bored Pile performance under Aceh's seismic and soil variability conditions to validate cost savings against actual maintenance and durability outcomes.

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