PRACTICAL INSIGHTS INTO COST REDUCTION USING SAND PILES IN GEOTECHNICAL PROJECTS: A COMPARISON WITH CONVENTIONAL PILING METHODS

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ABSTRACT

Foundation systems in geotechnical design are very central to structural stability and cost savings in construction projects. The research discusses the effectiveness and cost benefits of sand piles as a ground improvement method compared to conventional foundation systems such as precast and cast-in-situ concrete piles. Technical performance and economic viability are subjects of study that are being represented in context to verifying data collected from case histories of structures constructed in soft soil conditions. The research compares key parameters like the load-carrying capacity, installation time, equipment requirements, and cost estimates. Results determine that even though sand piles overall have lower load-carrying capacity compared to precast and cast-in-place piles, they are highly efficient in improving ground conditions to a satisfactory level suitable for light to moderate loads like low-rise buildings. Besides, sand pile installation requires simpler equipment and labor-saving techniques, significantly reducing mobilization and operating expenses. A cost comparison based on actual project experience reveals that sand pile systems save 20–25% of the cost of cast-in-situ piles and 35–40% of the cost of precast piles, depending on site conditions and project size. Sand piles also create faster installation, saving up to 15-40% of the total project time of substructure, which translates into indirect cost savings for project management and equipment rental expenses. However, the study also reveals some of the limitations of sand piles, for example, their unsuitability to high-load situations or where strict settlement requirements have to be met. In this manner, sand piles are thus recommended to be employed in projects involving average loading needs and good quality ground, where cost reduction is the primary objective. In summary, the findings indicate that sand piles are a viable and cost-effective alternative to conventional piling methods in favorable geotechnical conditions. The study provides field experience for structural engineers and project managers in selecting foundation systems that balance performance with cost-effectiveness.

Keywords: *Sand Piles, Ground Improvement, Geotechnical Engineering, Cost Comparison, Foundation Systems*

1. INTRODUCTION

Soil plays a crucial role in carrying the loads transferred from superstructures. The primary objective of structural engineering is to ensure that these loads are transmitted to the ground through an optimal and stable path, considering various foundation design methods.

Soft soils—also referred to as weak or compressible soils—represent a common geotechnical challenge in construction projects around the world. These soils are characterized by low shear strength, high compressibility, and high water content, which make them susceptible to excessive settlement and deformation under applied loads (Naseer et al., 2020). Soft soils are typically found in clayey deposits, silts, and organic formations. They generally exhibit low bearing capacity, poor drainage characteristics, and high sensitivity to variations in moisture content and loading conditions.

When the competent or stable soil layer lies at a high depth, the foundation design must ensure that the load from the superstructure is effectively transmitted to that deeper, stronger layer. In such cases, pile foundations are followed to achieve adequate load transfer. However, as the depth of the foundation increases, the cost of construction also rises significantly (Salas & Yepes, 2020). If the load from the superstructure is relatively low, ground improvement techniques can be adopted to enhance the bearing capacity of the existing soil and thereby minimize construction costs (Sánchez-Garrido et al., 2022).

Besides that, the environmental costs associated with RCC pile foundations are generally higher due to the extensive use of construction materials such as cement and steel, as well as the energy consumed during installation (Li et al., 2019). These environmental costs need to be minimized. Therefore, it is essential to adopt techniques that can simultaneously reduce both the financial and environmental impacts of foundation construction while improving the engineering properties of the subsoil.

There are various concepts and methods available for soil improvement worldwide. Over time, several well-established techniques have been refined for use in construction projects. These include the installation of micro piles (Mollaali et al., 2014), pressurized cement grouting using jet-grouting systems (Makovetskiy & Zuev, 2016), and the formation of soil–cement columns(Dao & Pham, 2018). Additionally, unstable or weak soils can be stabilized by incorporating industrial by-products such as fly ash (Baqir et al., 2020), which is effective for very soft clay soils, or glass dust residues (Blayi et al., 2020), which enhance the strength of expansive soils.

In Bangladesh, among various soft soil improvement techniques(Hore & Ansary, 2020), the Sand Compaction Pile (SCP) method is considered user friendly and widely applicable, even in rural areas. This technique effectively increases the Standard Penetration Test (SPT) values of soft soils, indicating improved strength and density(Yi et al., 2013). Moreover, since Bangladesh lies within a high seismic risk zone, the SCP method may offer additional benefits by enhancing ground stability and mitigating the impact of intense, long-duration earthquakes.(Kinoshita, 2011).

2. METHODOLOGY

2.1 Project Description and Location

The project involves the construction of a four-storied academic building with a four-storied foundation at a madrasa located in South Surma Upazila, Sylhet. The project is being implemented by the Education Engineering Department (EED). The construction contract was awarded to M/s. Chowdhury Enterprise by e-gp system for executing the building and foundation works, including soil improvement through the Sand Compaction Pile (SCP) method. The SCP work has been carried out by the subcontractor Contemporary Engineering Limited. According to the design specifications, the building has an overall length of 34.2 meters and a width of 10.0 meters as per Figure 1.

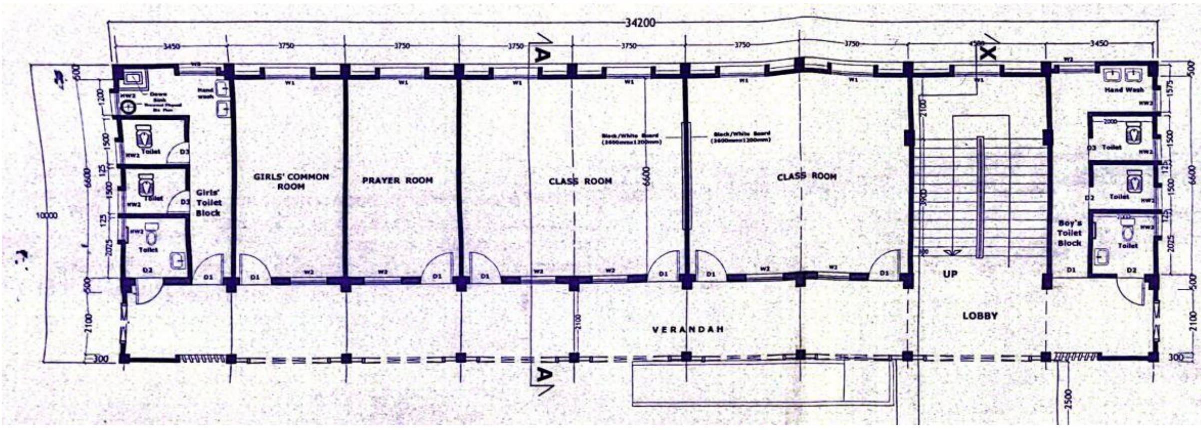

Figure 1: Typical Floor Plan

2.2 Soil Condition before SCP

The soil conditions at the project site were determined through Standard Penetration Tests (SPT) conducted at three borehole locations, as presented in Table 1. The groundwater table was observed at a depth of approximately 1.5 meters below the existing ground level. Based on the borehole data, the subsurface soil was identified predominantly as clay up-to a depth of about 16.5 meters. The average moisture content of the soil samples collected from different depths across the three boreholes was found to be 41%, while the average specific gravity of the soil was found to be 2.65.

Bore Hole 1			Bore Hole 2			Bore Hole 3		
Depth(m)	Soil Type	Field SPT N Value	Depth(m)	Soil Type	Field SPT N Value	Depth(m)	Soil Type	Field SPT N Value
1.5	Clay	2	1.5	Clay	1	1.5	Clay	1
3	Clay	1	3	Clay	1	3	Clay	1
4.5	Clay	2	4.5	Clay	2	4.5	Clay	2
6	Clay	3	6	Clay	3	6	Clay	2
7.5	Clay	4	7.5	Clay	4	7.5	Clay	5
9	Clay	6	9	Clay	4	9	Clay	6
10.5	Clay	7	10.5	Clay	5	10.5	Clay	6
12	Clay	8	12	Clay	4	12	Clay	6
13.5	Clay	12	13.5	Clay	7	13.5	Clay	8
15	Sand	15	15	Clay	8	15	Clay	10
16.5	Sand	36	16.5	Sand	32	16.5	Sand	28
18	Sand	38	18	Sand	25	18	Sand	26
19.5	Sand	42	19.5	Sand	28	19.5	Sand	26

Table 1: Bore Hole Data Before SCP

2.3 Load from the Super Structure

After considering all relevant design criteria for an educational building as per BNBC 2020 (BNBC, 2020), the summation of dead and live loads was determined to be 220 kips, 320 kips, 175 kips, 150 kips, 125 kips, and 100 kips as illustrated in Figure 2. The superstructure design of the building was carried out using the structural analysis and design software CSI ETABS.

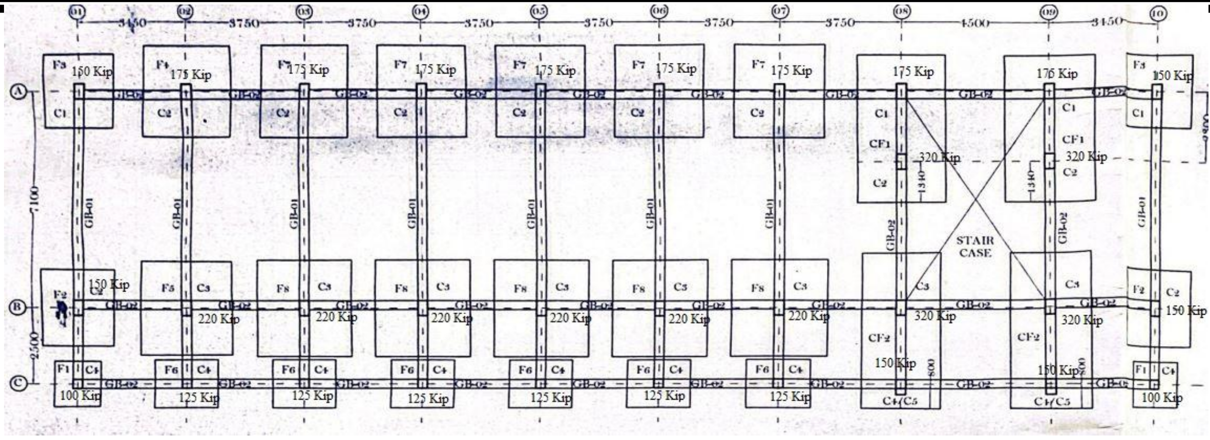

Figure 2: Foundation Layout with Load from Super Structure

2.4 SCP Method

The SCP was done using an 8 m-long pile formed within a casing pipe of 8.5 m length and 250 mm inner diameter. A drop hammer weighing 1 ton, with a diameter of 242 mm, was used for compaction. The slightly smaller diameter of the hammer allowed it to move freely within the casing pipe. Initially, a shallow hole (50–100 mm deep) was created at each pile location by dropping the hammer from 1.5m height. The casing pipe was then positioned vertically at the same location using a tripod stand and wire rope to ensure a 90° vertical alignment.

The sand used for the SCP was tested before and maintained a fineness modulus (F.M.) of 2.2. Sand was poured into the casing pipe up to a height of 1 m, and the hammer was dropped from a height of 1.5 m to compact the sand. The dropping process was continued until the hammer toe reached the design depth of 8 m, corresponding to the required pile length. During driving, the casing pipe penetrated the ground together with the hammer until it rested at the desired depth.

After reaching the full depth, the casing pipe was withdrawn upward by approximately 300 mm. Sand was then poured into the pipe up to a height of 600 mm. Then the compaction of sand was done again using the drop hammer from a height of 1.5 m. Once compaction was completed, the casing pipe was again up-warded by 300 mm, and another 600 mm layer of sand was added and compacted. This step-by-step process of sand pouring, casing withdrawal, and compaction was repeated continuously up to the ground surface to ensure full pile length and uniform compaction. This installation procedure is illustrated in Figure 3, while the pile layout is shown in Figure 4. A total of 1,190 sand compaction piles were constructed following this method considering 2 ft centre to centre spacing from one another. *Figure 5* shows the ongoing sand compaction pile work on site. There were installed some well points to pump out the water contained in that wells.

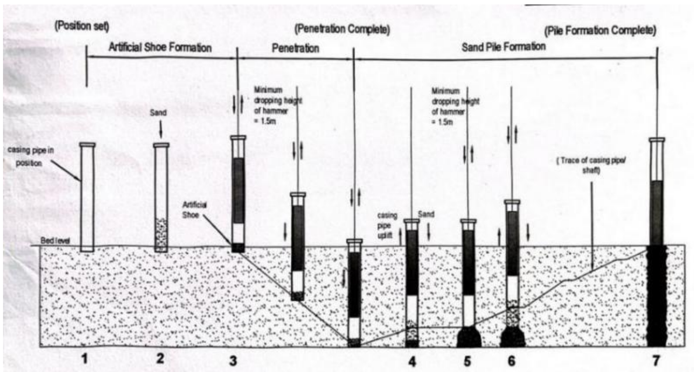

Figure 3: Steps of Sand Compaction Pile

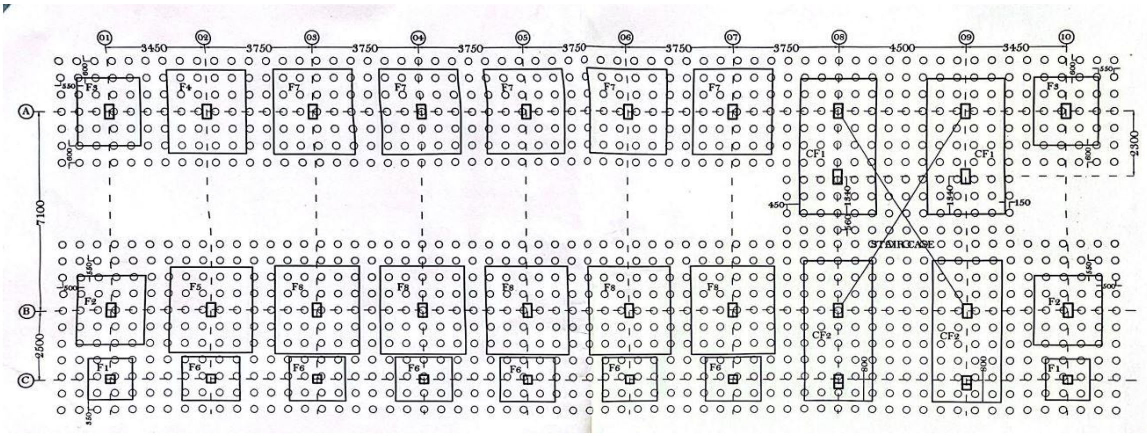

Figure 4: Footing and Pile Layout

Figure 5: Sand Compaction Pile Work

2.5 Precast Pile Design

The allowable load-carrying capacity of the R.C.C. precast pile was determined using the modified Meyerhof (Bowles) formula with a factor of safety 2.5. Based on the design calculations, the required precast pile length was found to be 18 m, and the pile cross-section was designed as 360 mm × 360 mm. From the total structural load and the allowable pile capacity, the number of piles required was calculated to be 70. The reinforcement design for each pile consisted of four 16 mm diameter bars and four 20 mm diameter bars as longitudinal reinforcement, with lateral ties provided at an average spacing of 100 mm centre to centre. This reinforcement configuration was adopted to ensure adequate strength, stability, and durability of the pile during handling, driving, and service conditions.

2.6 Cast in Situ Pile Design

The allowable bearing capacity of the R.C.C. cast-in-situ pile was designed using the modified Meyerhof (Bowles) formula with a factor of safety of 2.5. Based on the design calculations, the required pile length was found to be 16.5 m, and the pile diameter was designed as 500 mm. From the total structural load and the allowable pile capacity, the number of piles required was calculated to be 70. The reinforcement design for each pile consisted of eight 16 mm diameter bars as longitudinal reinforcement, with lateral ties provided at an average spacing of 100 mm.

3. ILLUSTRATIONS

3.1 SPT after SCP

After completion of the Sand Compaction Pile (SCP) works, a Standard Penetration Test (SPT) was conducted at the same locations within the construction site. The test results clearly indicated an increase in the N-values following the execution of the SCP, as presented in Table 2. The post-construction soil investigation was carried out one week after the completion of the SCP works. The average moisture content of the soil was found to be 18%, whereas it had been 41% prior to the SCP installation. This significant reduction in moisture content and corresponding increase in SPT N-values confirm the improvement in soil density and strength achieved through the sand compaction process.

Bore Hole 1				Bore Hole 2				Bore Hole 3			
Depth(m)	Soil Type	Field SPT N Value Before	Field SPT N Value After	Depth (m)	Soil Type	Field SPT N Value Before	Field SPT N Value After	Depth(m)	Soil Type	Field SPT N Value Before	Field SPT N Value After
1.5	Sand	2	8	1.5	Sand	1	6	1.5	Sand	1	7
3	Sand	1	9	3	Sand	1	8	3	Sand	1	7
4.5	Sand	2	11	4.5	Sand	2	7	4.5	Sand	2	8
6	Sand	3	9	6	Sand	3	8	6	Sand	2	10
7.5	Sand	4	10	7.5	Sand	4	7	7.5	Sand	5	11
9	Sand	6	11	9	Sand	4	9	9	Sand	6	12
10.5	Clay	7	11	10.5	Clay	5	9	10.5	Clay	6	10
12	Clay	8	10	12	Clay	4	10	12	Clay	6	11

Table 2: Bore Hole Data after SCP

3.2 Cost Comparisons of SCP, Precast and Cast in Situ Pile

The cost of the substructure was estimated based on the rate schedule of the Public Works Department (PWD) published in 2022 (*PWD Schedule of Rates(Revised)*, 2022) and the rate analysis of Education Engineering department. Minor costs that have a negligible impact on the total construction cost were not considered in the estimation. These costs include labour charges, material costs, contractor's profit, value-added tax (VAT), and other incidental expenses. Table 3 represented the cost for cast in situ pile, precast pile and sand compaction pile. Graphical representation of the cost of different pile works are shown in Figure 6.

Cast in Situ Pile						
Concrete Volume (cumec)	Rate (Tk)	Reinforcement (Kg)	Rate	Equipment Mobilization Cost (Tk)	Boring Cost Rate per m (Tk)	Total (Tk)
227.00	16842.00	23600.00	121.00	5644.00	1213.00	8085393.00
Precast Pile						
Concrete Volume (cumec)	Rate (Tk)	Reinforcement (Kg)	Rate	Equipment Mobilization Cost (TK)	Driving Cost per m (Tk)	Total (Tk)

150.00	15311.00	26640.00	121.00	186508.00	809.00	6640993.00
Sand Compaction Pile						
SCP Running Meter		Rate per Meter (Tk)		Equipment Mobilization Cost (TK)	Total (Tk)	
9520		408.52		14585.00	3903695.40	

Table 3 : Cost of Different Pile Construction

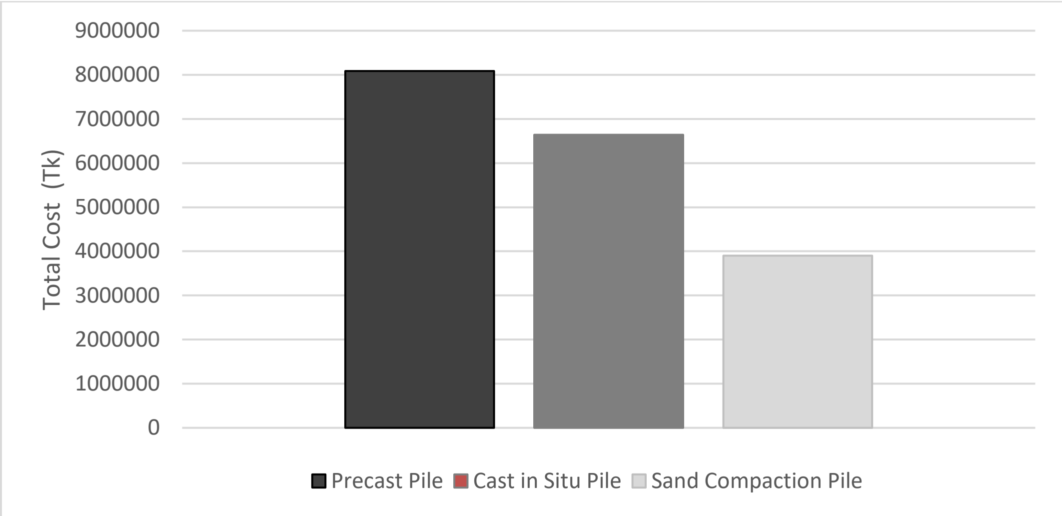

Figure 6: Graphical Representation of Cost of Different Pile Works

3.3 Time Frame and Labour Requirement for Construction

Time is a significant factor in building construction, as reducing the construction period can help lower overall costs and minimize construction-related challenges. The construction of a precast pile foundation, including the curing period, required approximately 60 days. In comparison, the construction period for a cast-in-situ pile substructure was approximately 40 days, while soil improvement using the Sand Compaction Pile (SCP) method required only about 35 days. Regarding labor requirements, the total workforce needed for precast pile construction was approximately 400 persons, for cast-in-situ piles about 350 persons, and for the SCP method around 250 persons. The construction time, expressed in days, is illustrated in Figure 7, while the manpower requirements for each method are shown in Figure 8.

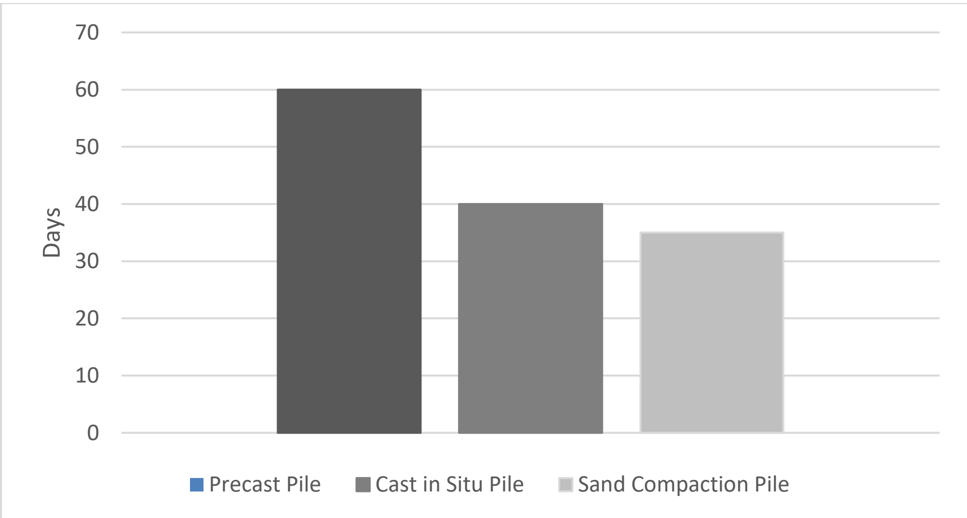

Figure 7: Time Required (in days) for Different Pile Construction

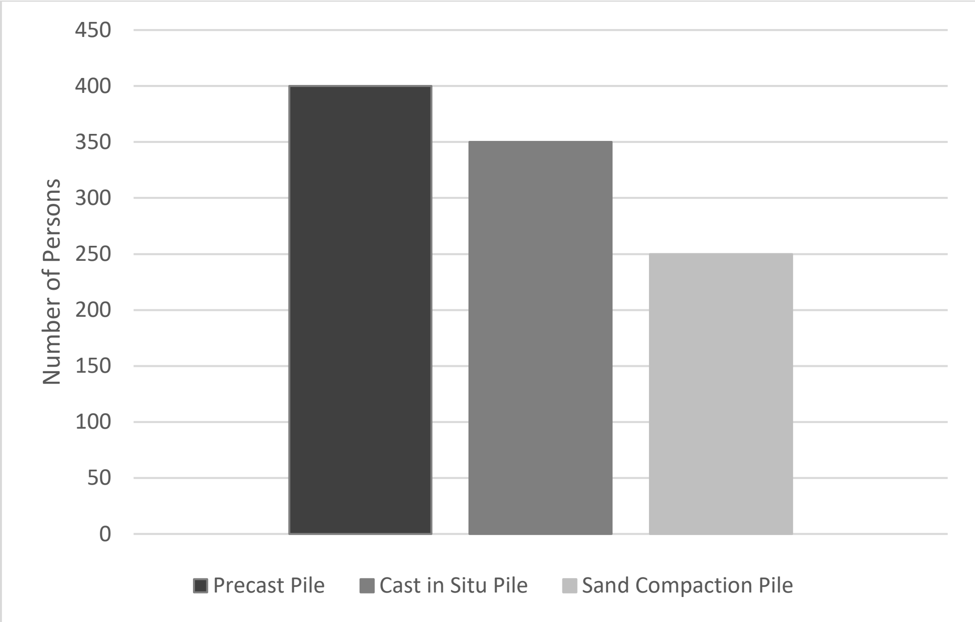

Figure 8: Man Power Required for Different Pile Construction

4. CONCLUSIONS

From the discussion above, the following conclusions can be drawn:

a. The construction period is shortest in the case of Sand Compaction Piles (SCP), with the time required being 15-40% less than that for cast-in-situ pile and precast pile.
b. The construction cost is also lowest for SCP, being approximately 20-25% less than cast-in-situ piles and 35-40% less than precast piles.
c. Labor requirements are reduced for SCP, with manpower needs being 28% to 38% lower compared to precast and cast-in-situ piles.
d. A potential drawback of the SCP method is the risk of sand being washed out beneath the foundation, which should be addressed in future research. Besides that, the existing ground level was increased up to 450mm from the initial position due to the swelling of sand but after creating some well points and pumping the water from that points, the swelled soil reduced its volume.

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DECLARATION OF USE OF AI:

AI tools were used in a limited capacity in this paper, primarily to enhance sentence clarity, coherence, and overall readability. Although the use of AI was minimal, the insights and contributions presented here are expected to be valuable for future research and beneficial to engineers working in related fields.

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