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# Productivity Analysis of Piling Work for Coastal Safety Construction in Bay Phase 6 Package 4, Jakarta, Indonesia

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**ABSTRACT**

Coastal areas are more susceptible to inundation, chiefly due to elevated sea levels and storm surges. Coastal regions, like Jakarta Bay, face escalating threats from sea-level rise and severe weather phenomena, requiring the implementation of resilient defensive infrastructures such as embankments supported by deep piling systems. During the project's execution, substantial discrepancies were noted between the anticipated and actual productivity of piling operations. This paper seeks to examine the productivity of spun pile installation utilizing the inner boring technology and to determine the principal elements leading to the variance between projected and actual outputs.. A quantitative approach was employed, combining direct field observations, video-based time studies, and secondary data analysis. Productivity was evaluated through metrics such as effective productivity (3.33 piles/day), field productivity (3.2 m/h), and contract productivity (3.59 m/h). The primary findings indicated that although the inner boring technique presents benefits such as less noise and vibration, it is still vulnerable to environmental limitations, equipment inefficiencies, and site-specific disruptions. These problems collectively led to diminished piling productivity and scheduling delays. The findings highlight the necessity of integrating real-time monitoring and adaptive planning in forthcoming coastal construction endeavors to improve operational efficiency and reduce the danger of delays.

## 1. Introduction

Coastal regions are particularly vulnerable to flooding, primarily caused by rising sea levels and storm surges. In response, significant efforts are required to protect these areas through the construction of coastal safety structures. In the case of Jakarta Bay, the National Capital Integrated Coastal Development (NCICD) project has initiated the construction of a coastal safety embankment and river estuary protection system (Figure 1). These embankment structures are critical in preventing flooding, especially as sea levels rise and extreme weather events become more frequent [1].

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One type of embankment building technology uses concrete piles (spun piles). Spun pile in the shape of a circle with a diameter of 80 cm. One of the main technologies employed in these coastal defense structures is the use of spun concrete piles (spun piles). These piles, typically cylindrical with a diameter of 80 cm, are driven into the ground to form the foundation of the embankments. While embankments utilizing spun piles have been successfully implemented in various countries, including China [2]. Their productivity in piling operations can vary significantly based on several factors, such as soil conditions, weather disturbances, and community interference.

The piling work for this project (Figure 2), which spans from February to November 2023, involves driving 363 spun piles. The project timeline, estimated at 303 days, is heavily dependent on the productivity of the piling operations. However, deviations between planned and actual productivity often occur due to factors such as equipment limitations, environmental conditions and unforeseen delays. This research focuses on analyzing the productivity levels of the spun pile installation process, identifying the reasons for any discrepancies between contract time, field productivity and effective productivity.

**Fig. 1.** Beach Safety Embankment


**Fig. 2.** Piling work Location

Calculation of the productivity level of heavy equipment needs to be done to determine how long and how much the budgeted cost is to carry out a hoisting activity. The calculation of the level of productivity of heavy equipment in road work has been carried out [3]. Added productivity related to the use of piling equipment [4–9]. From the results of this study, information was obtained that the productivity of piling differed according to the factors that affected piling.

Despite careful planning, the productivity of piling operations often falls short of the expected rates, leading to delays and increased costs in coastal safety construction projects. The deviation between contract time, actual field time and effective time is a critical issue that needs to be addressed [10,11]. Limited empirical evidence exists regarding the discrepancy between planned and actual productivity in coastal piling projects under dynamic environmental conditions, making this study crucial to fill that gap and offer practical insights for future construction planning [12]. Previous research on productivity has been done but they examined based on secondary data. In the research the data taken is real time.

The objective of this study is to provide an in-depth analysis of the productivity levels during the piling process using an inner boring system. By comparing the planned versus actual productivity, we aim to identify the key factors that contribute to time deviations and offer recommendations for improving future piling operations. The results will be useful for planning and controlling similar construction projects in different coastal regions.

### *1.1 Pile Foundation*

A pile foundation is a part of the structure that is used to receive the load of the superstructure and channel it to the supporting soil located at a certain depth. It is further stated that pile foundations have the form of columns made of concrete or sturdy steel that will strengthen the structure of the building. Generally, pile foundations are used if the soil structure to be built has the possibility of shifting.

Pile foundations are distinguished based on: material quality, and piling technique. Piles are distinguished: 1) precast piles: how to build, how to vibrate, and how to plant, 2) cast-in-place piles: how to penetrate the base, and how to dig.

Stages of piling activities with jack in pile: 1) mobilization of tools to the intended point, 2) binding of piles 3) lifting of piles, 4) removal of piles, 5) insertion of piles. 6) Pile point drilling, 7) pile pressing, 8) joint pile picking, 9) joint welding, 10) joint pile pressing, 11) ruyung picking, 12) pile pressing with the help of ruyung, and 13) cutting [13]. The types of piling tools used are 1) vibratory pile drive, 2) diesel hammer, 3) drop hammer and 3) hydraulic static pile driver (HSPD).

The advantages of pile foundation are both in bearing strength and stability. Its ability to transfer heavy loads to hard soil layers at depth makes it ideal for soft or soft soils. In addition, it minimizes building subsidence, accelerates construction time, and is relatively environmentally friendly because it reduces soil excavation. Its resistance to earthquakes and effectiveness on tall buildings make it a reliable and economical option in the long run [6].

Pile driver offers several advantages, especially in terms of minimizing disturbances to the environment. Compared to other piling methods that generate high vibration and noise, HSPD works by pressing the piling into the ground slowly and controlled using hydraulic pressure [14]. The distribution of the average level of noise decreased with the increased distance from the piling machine [15]. This makes it a better choice for construction projects in densely populated areas or close to vibration-sensitive structures [14].

### *1.2 Piling with Inner Boring*

Inner boring is a technology for installing precast foundation piles (spun pile) that combines drilling and jacking methods by drilling holes in the ground with a drill while inserting foundation piles by pressing [16]; To cut the piling, you can also use the inner boring system method (Figure 3).

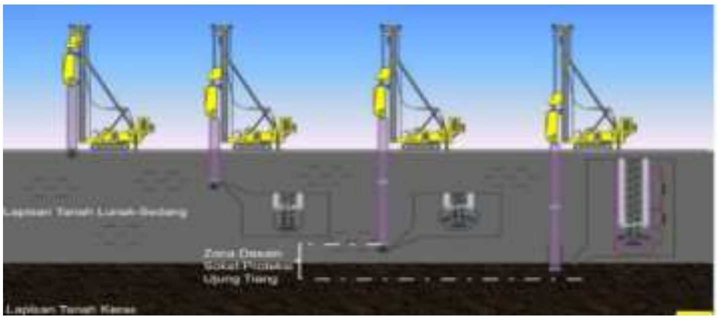

**Fig. 3.** Inner boring system method

The inner boring system has several advantages: 1) it does not cause vibration and minimizes noise pollution because it uses a hydraulic system, 2) the soil from drilling is not messy because drilling is carried out at the same time as the pile piling, 3) the quality of the pile is more guaranteed and the dimensions between the piles are uniform because it uses precast piles, and 4) the compressive strength is large because it uses a hydraulic system. However, this system also has its drawbacks, namely the cost incurred is more expensive compared to other methods of installing foundations because it requires more modern tools.

The piling process with the inner boring system method begins with the drilling of a pilot hole at a specified location. After that, a steel casing is inserted into the borehole to keep the hole wall from collapsing. Next, the diameter of the borehole is enlarged using a magnifying tool (reamer) that is pulled through the inside of the casing. Then, steel piles or precast concrete are inserted into the enlarged hole and driven into the ground using a hydraulic press. The top of the pile that is above the ground level is cast with concrete to form a foundation structure. The inner boring method allows for baking without excessive vibration or noise, making it suitable for use in congested or vibration-sensitive areas, as well as in areas that are difficult to access by conventional baking equipment.

Planting work can be done by the inner boring method. Tools used: 1) drilling equipment, 2) drill bits, 3) casings, 4) reaming equipment, 5) hydraulic presses and 6) auxiliary equipment.

### *1.3 Productivity Spun Pile Piling*

Productivity is the rate at which a job is produced by an individual or task force per unit of time. The general formula of productivity is expressed in the following Eq. (1):

$$\text{Productivity} = \frac{\text{output}}{\text{input}} \quad (1)$$

The unit of output is the unit of related work. For example, for soil excavation activities, the unit is m3. Meanwhile, the input unit is a unit that symbolizes production components such as people-hours (OJ), people-days (OH), or simply a unit of time such as hours or days. For example, the productivity of installing a brick wall by a bricklayer is expressed in $m^2$ per person per day, and the productivity of excavation by an excavator is expressed in m3/hour. Productivity level assumptions are used as a basis for estimating the cost of workers and equipment for a job.

For piling work (spun pile), namely trailer trucks, excavators, diesel hammers and crawler cranes [10]. The productivity of the inner boring method can reach 10-15 piles per day for soft soil conditions and adequate equipment and labor. Productivity drop hammer 1.2/day, jack in pile 2.19/day [4]. The productivity analysis of the bore pile machine SANY SR 155 in bore pile foundation work was obtained at 9.22 m/h (productivity of analytical calculations) and 8.74 m/h (productivity of field observation calculations) while the productivity of the bore pile machine MAITHR 130 was 1.4 m/h (productivity of analytical calculations) and 0.92 m/h (productivity of field observation calculations). The working efficiency of the KOKEN YH-01 drill tool in production drilling activities is 62.02%. The productivity value of the auger drill/drilling machine in Project A is 38.4484 $m^3$/day, while for Project B it has a value of 51.9845 $m^3$/day [9]. The overall productivity value of the 460 Ton HSPD tool is 44,437 meters/hour, while the 1000 Ton HSPD tool is 58,469 meters/hour [8]. In the work of the flood channel of the east canal 0.3 m/min [17].

In general, the productivity of piling spun piles with a diameter of 30-50 cm is 4-8 poles/hour, with a diameter of 50-80 cm: 2-5 poles/hour. The productivity of the 120-ton Hydraulic Static Pile Driver (HSPD) is 7248 seconds/30 m, lower than the productivity of a 35-ton drop hammer-mounted crane has a productivity of 3548 seconds/30 m. Jack-in-pile piling tools are more efficient than drop hammers in terms of productivity. The average productivity of jack-in-pile piling tools is 2.19, while the drop hammer tool is 1.20 [4]. HSPD requires a total time of 56 hours, while drop hammer is 119 hours with 63 hours [6]. The average HSPD productivity in the workshop construction project is 1,143 meters/minute or 68.58 meters/hour [5]. The duration required for pile work is longer than compared of a bore pile [7].

The productivity value is 0.056. So the total field index value is obtained as much as 0.1221, which has a difference of 0.0021 from the index value of pile foundation work that has been determined in the Regulation of Ministry public work No.28/PRT/M/2016, which is 0.1200 [18]. Based on the calculation above, the average productivity realized in the field is 0.995, while the average productivity of the observation results is 1.357 [19].

According to [20] auger productivity linear regression model in Eq. (2):

$$\text{Productivity} = 8{,}4174 - 0{,}0766\text{X1} + 0{,}834\text{X2 pole/day} \tag{2}$$

Where:
X1 : Pile depth
X2 : auger height

*1.4 Factors that Determine the Productivity of Spun Pile Piling Equipment*

Factors that affect the productivity of hydraulic static pile driver piling tools are late start or early quits, tool damage, worker skills, material production, material mobilization, material placement, and final set of piling [19] also 4) the operator's expertise and experience, and 5) weather conditions and the surrounding environment. The productivity of spun pile piling (80 cm) per hour can vary depending on various factors: 1) Size and length of spun pile, 2) Soil type and field conditions, 3) Type of piling tool.

Ahmad and Xu identified 8 key input factors that affect productivity levels: 1) soil conditions, 2) type of poles, 3) pile materials, 4) project size, 5) project location, 6) depth of poles, 7) number of poles and 8) number of equipment. In drilling work, productivity is affected by the material to be penetrated, the life of the drill tool, and the drilling target [21]. Project area, land limitations, and machine specifications influence heavy equipment productivity [22]. According to the invisible subsurface barriers, lack of contractor experience, site planning, piling equipment maintenance, and have already issued a model of the erection productivity equation [20].

## 2. Methodology

This research adopts a quantitative approach to analyze the productivity of spun pile installation during coastal safety construction. The primary focus is to evaluate the actual piling performance against the planned schedule using the inner boring system. Data collection was conducted through direct field observations and time tracking of the erection process for a total of 363 spun piles, each measuring 24 meters in length. The horizontal distance between the storage point (phonton) and the pile installation location was recorded as 36 meters.

Productivity levels were calculated using a standard Eq. (3), where productivity is defined as the number of piles installed per unit of time.

$$\text{Productivity} = \frac{\text{number of piling}}{\text{time}} \tag{3}$$

All the number of spun piles staked each day is recorded until all are staked. The piling duration, including working and idle days, was documented throughout the execution phase. Observations were supported by video recordings to capture detailed cycle times for each operational stage, including mobilization, connection, hoisting, hammering, welding and final placement.

Additional data such as pile specifications, planned duration (based on the S-curve schedule), and actual working days were also gathered to assess productivity indices. These indices were then compared between three categories: contract schedule (303 days), effective working days (109 days) and actual project duration (335 days). The methodology emphasizes empirical validation of recorded time data to calculate real productivity and evaluate the deviation from the theoretical cycle time, which estimated a potential productivity of 5.79 piles per day over 63 days in ideal conditions. Table 1 shows the cylinder pile length used in this work.

**Table 1**
Concrete compressive strength f'c = 52 MPa (Cube 600 kg/cm²)

| Size (mm) | Thickness Wall (t) (mm) | Cross Section (cm²) | Section Inertia (cm⁴) | Unit Weight (ton/m) | Class | Bending Moment Crack (ton.m) | Bending Moment Ultimate (ton.m) | Allowable Compression (ton) | Cylinder Pile Length (m) Single / Double* |
|---|---|---|---|---|---|---|---|---|---|
| 800 | 120 | 2563 | 1527869 | 0.64 | A | 40 | 65 | 410 | 24 / 36 |
| | | | | | B | 55 | 80 | 390 | 24 / 36 |
| | | | | | C | 65 | 120 | 370 | 30 / 42 |
| | | | | | D | 75 | 130 | 355 | 30 / 42 |
| 1000 | 140 | 3782 | 3589571 | 0.96 | A | 75 | 110 | 600 | 24/36 |
| | | | | | B | 105 | 175 | 560 | 30 / 42 |
| | | | | | C | 120 | 220 | 550 | 30 / 48 |
| | | | | | D | 135 | 245 | 530 | 36 / 48 |
| 1200 | 150 | 4948 | 6958136 | 1.24 | A | 120 | 140 | 800 | 30 / 48 |
| | | | | | B | 170 | 270 | 745 | 36 / 48 |
| | | | | | C | 200 | 310 | 710 | 36 / 54 |
| | | | | | D | 210 | 320 | 700 | 42 / 54 |
| 1500 | 170 | 7103 | 15962533 | 1.78 | A | 220 | 265 | 1140 | 30 / 48 |
| | | | | | B | 300 | 440 | 1080 | 36 / 54 |
| | | | | | C | 340 | 520 | 1040 | 42 / 60 |
| 1800 | 200 | 10053 | 32672563 | 2.51 | A | 370 | 425 | 1630 | 36 / 48 |
| | | | | | B | 450 | 580 | 1580 | 36 / 54 |
| | | | | | C | 520 | 770 | 1520 | 42 / 60 |
| 2000 | 200 | 11309 | 46369907 | 2.83 | A | 480 | 535 | 1830 | 35 / 55 |
| | | | | | B | 590 | 790 | 1770 | 40 / 60 |
| | | | | | C | 670 | 965 | 1720 | 45/65 |

## 3. Results

The research aimed to analyze the productivity of spun pile piling work in the coastal safety construction of Jakarta Bay, focusing on the actual productivity against the planned schedule. Based on Table 1, 363 spun piles were installed throughout the project. The effective time for piling work was 109 days, although the real project duration was extended to 335 days due to non-continuous workdays. The planned schedule initially estimated the piling process would be completed in 303 days. However, the piling work was completed 32 days later than expected due to delays and interruptions. The average piling rate observed was 3.33 piles per day.

**Table 2**
Time and number of piles driven (24 m) into the ground

| No. | Time Piling | Piled Per day | Total | No. | Time Piling | Piled Per day | Total |
|---|---|---|---|---|---|---|---|
| 1 | 19-4-2023 | 1 | 1 | 60 | 17 -11-2023 | 8 | 217 |
| 2 | 3 -5-2023 | 3 | 4 | 62 | 18 -11-2023 | 1 | 218 |
| 3 | 4-5- 2023 | 4 | 8 | 64 | 20-11- 2023 | 9 | 227 |
| 4 | 5-5 -2023 | 2 | 10 | 66 | 23-11- 2023 | 7 | 234 |
| 5 | 6 -5- 023 | 3 | 13 | 68 | 24-11-2023 | 3 | 237 |
| 6 | 7-5-2023 | 3 | 16 | 70 | 2 -11-2023 | 7 | 244 |
| 7 | 8-5-2023 | 4 | 20 | 72 | 26-11-2023 | 1 | 245 |
| 8 | 9-5-2023 | 4 | 24 | 73 | 20-11-2023 | 1 | 246 |
| 9 | 10-5-2023 | 5 | 29 | 74 | 21-11- 2023 | 4 | 250 |
| 10 | 11-5-2023 | 5 | 34 | 75 | 11-1-2024 | 1 | 251 |
| 11 | 12-5-2023 | 5 | 39 | 76 | 12 -1- 2024 | 2 | 253 |
| 12 | 13-5-2023 | 5 | 44 | 77 | 13 -1-2024 | 2 | 255 |
| 13 | 14-5-2023 | 3 | 47 | 78 | 14 -1- 2024 | 3 | 258 |
| 14 | 15-5-2023 | 3 | 50 | 79 | 15 -1- 2024 | 2 | 260 |
| 15 | 09-6-2023 | 4 | 54 | 80 | 16 -1-2024 | 4 | 264 |
| 16 | 10-6-2023 | 4 | 58 | 81 | 17 -1-2024 | 7 | 271 |
| 17 | 12-6-2023 | 4 | 62 | 82 | 18 -1-2024 | 7 | 278 |
| 18 | 13-6-2023 | 4 | 66 | 83 | 25 -1-2024 | 7 | 285 |
| 19 | 15-6-2023 | 4 | 70 | 84 | 28 -1-2024 | 7 | 292 |
| 20 | 17-6-2023 | 5 | 75 | 85 | 30 -1-2024 | 7 | 299 |
| 21 | 18-6-2023 | 5 | 80 | 86 | 03 -2- 2024 | 1 | 300 |
| 22 | 19-6-2023 | 3 | 83 | 87 | 04 -2- 2024 | 2 | 302 |
| 23 | 20-6-2023 | 4 | 87 | 88 | 06 -2- 2024 | 4 | 306 |
| 24 | 21-6-2023 | 4 | 91 | 89 | 08 -2- 2024 | 3 | 309 |
| 25 | 22-6-2023 | 4 | 95 | 90 | 09 -2- 2024 | 1 | 310 |
| 26 | 21-9-2023 | 1 | 96 | 91 | 16 -2- 2024 | 1 | 311 |
| 27 | 22-9-2023 | 3 | 99 | 92 | 17 -2- 2024 | 3 | 314 |
| 28 | 23-9-2023 | 2 | 101 | 93 | 18 -2- 2024 | 3 | 317 |
| 29 | 24-9-2023 | 3 | 104 | 94 | 19 -2- 2024 | 4 | 321 |
| 30 | 25-9- 2023 | 1 | 105 | 95 | 21 -2- 2024 | 3 | 324 |
| 31 | 26 -9-2023 | 4 | 109 | 96 | ,22 -2- 2024 | 2 | 326 |
| 32 | 27-9-2023 | 4 | 113 | 97 | 26 -2- 2024 | 2 | 328 |
| 33 | 8 -9-2023 | 7 | 120 | 98 | 27 -2- 2024 | 3 | 331 |
| 34 | 29-9-2023 | 4 | 124 | 99 | 08-03-2024 | 3 | 334 |
| 35 | 04-10-2023 | 7 | 131 | 100 | 10-03-2024 | 4 | 338 |
| 36 | 05-10-2023 | 6 | 137 | 101 | 11-03-2024 | 3 | 341 |
| 37 | 06-10-2023 | 8 | 145 | 102 | 12-03-2024 | 4 | 345 |
| 38 | 14-10-2023 | 1 | 146 | 103 | 16 -03-2024 | 2 | 347 |
| 39 | 15-10-2023 | 7 | 153 | 104 | 17 -03-2024 | 3 | 350 |
| 40 | 16-10-2023 | 2 | 155 | 105 | 19 -03-2024 | 2 | 352 |
| 41 | 18-10-2023 | 7 | 162 | 106 | 20 -03-2024 | 1 | 353 |
| 42 | 20-10- 2023 | 1 | 163 | 107 | ,21 -03-2024 | 3 | 356 |
| 43 | 21-10-2023 | 6 | 169 | 108 | 22 -03-024 | 5 | 361 |
| 44 | 02-11-2023 | 2 | 171 | 109 | 23 -03-024 | 2 | 363 |
| 46 | 03 -11-2023 | 8 | 179 | | | | |
| 48 | 05 -11-2023 | 2 | 181 | | | | |
| 50 | 06 -11-2023 | 8 | 189 | | | | |
| 52 | 13 -11-2023 | 8 | 197 | | | | |
| 54 | 14 -11-2023 | 1 | 198 | | | | |
| 56 | 15 -11-2023 | 3 | 201 | | | | |
| 58 | 16–11- 2023 | 8 | 209 | | | | |

Table 3 shows the time analysis based on field observations and video recordings. The total cycle time to install one spun pile was approximately 80.57 minutes. This calculation includes the time taken for mobilization, connection, lifting, hammering, welding and other related activities. Using this information, it was estimated that the piling rate should ideally be around 5.79 piles per day. Given the actual number of piles to be installed, the piling process could have been completed in approximately 63 days, had the work progressed uninterrupted and according to the cycle time.

**Table 3**
Spun pile piling time from location survey video (survey on site)

| HE Type | Categories | Description | Time (s) |
|---|---|---|---|
| Crawler crane (material mobilization) | Cycle time (move + swing) | Before lifting | 83 |
| | Cycle time (connecting + lifting) | Connecting the winch with a square pile | 143 |
| | Cycle time (swing) | After connecting, placing the pile, and Connector | 378 |
| | Material hauling | Crossing the river | 840 |
| | Cycle time (move + swing) | Before lifting | 112 |
| | Cycle time (connecting + lifting) | Connecting the winch with the square pile | 163 |
| | Cycle time (swing) | After connecting, placing the pile, and the connector | 378 |
| Inner boring rig | Bore point checking time | | 60 |
| | Equipment preparation time | | 300 |
| | Pile drive hammer connecting time | | 491 |
| | Hammer connecting to square pile | | 274 |
| | Hammering time | | 532 |
| | Welding time (connecting 2 piles) | | 721 |
| | Hammering time | | 115 |
| | Disconnecting hammer | | 244 |
| Total Cycle Time for 1 Spun pile (min) | | | 80,567 |

***Note:*** Observation with video

Table 4 presents the productivity index comparing real-time field performance with the planned contract schedule. The real field productivity index was 1.084, while the contract-based schedule expected a productivity index of 1.198. This slight discrepancy (0.114) underscores the challenges encountered during the project that resulted in delays. These productivity figures highlight the gap between theoretical expectations and real-world execution, primarily due to environmental factors and operational inefficiencies.

**Table 4**
Spun pile piling productivity index

| No. | Productivity | Sum | | Index |
|---|---|---|---|---|
| | | Day | pile | |
| 1 | Real | 335 | 363 | 1.084 |
| 2 | Contract | 303 | 363 | 1.198 |
| 3 | Deviation | 32 | | 0.114 |

Table 5 illustrates the time efficiency comparison between the real field conditions, the contract schedule, and the observed cycle times. The real field work took 335 days, with a theoretical completion time (based on observation) of 63 days. When compared to the contract plan of 303 days, the real efficiency was lower. This table emphasizes that although the piling process could have been completed more quickly in ideal conditions, the actual project was affected by delays, leading to an overall reduction in efficiency.

**Table 5**
Time efficiency compared to observation

| No. | Capacity/day | Time (Days) | Efficiency |
|---|---|---|---|
| 1 | Real | 335 | 272,331 |
| 2 | Contract | 303 | 240,331 |
| 3 | Observation | 62,669 | 0 |

The results indicate a clear deviation between planned and actual productivity, with a significant 32-day delay in piling operations. This discrepancy can be attributed to several factors that were not fully accounted for in the planning stage, such as environmental conditions, equipment malfunctions, and human resource limitations. The study's findings suggest that while the inner boring system is efficient in terms of minimizing environmental disruption (e.g., noise and vibrations), it is susceptible to delays when faced with adverse conditions.

This delay highlights a systemic gap between theoretical cycle-time productivity and actual field performance, emphasizing the need for integrating real-time operational feedback into planning to reduce discrepancies [12]**.**

A comparison with previous studies shows that the productivity of piling operations varies based on soil conditions, equipment used, and site-specific factors [13]. The hydraulic static pile driver, used in this project, generally performs better in controlled environments but tends to face challenges in dynamic conditions such as fluctuating weather and unexpected interruptions [23].

The study underscores the importance of periodic monitoring and real-time data collection to adjust schedules and resource allocation dynamically. By improving the accuracy of initial assessments and incorporating real-time data analysis during the project, future piling projects can mitigate the risk of delays and optimize productivity.

## 4. Conclusions

This study contributes significantly to the body of knowledge on the productivity of spun pile piling in coastal safety construction by utilizing the inner boring system. The primary novelty of the research lies in the detailed analysis of actual productivity versus planned productivity, providing critical insights into the deviations caused by real-world factors such as environmental conditions, equipment performance and human resource challenges. The study demonstrated that while the planned productivity rate was 3.59 m/h, the field and effective productivity were lower, at 3.2 m/h and 3.33 piles/day, respectively, leading to a delay of 32 days in project completion.

The evidence supporting the conclusions is based on direct field observations, where the cycle time for piling operations was measured through video analysis. This methodological approach offers a unique contribution by providing real-time data on productivity performance. The findings highlight the limitations of current project scheduling and resource allocation in accounting for unforeseen delays, such as adverse weather and equipment downtime.

Despite these contributions, the research encountered several limitations. The primary limitation was the variability in environmental factors, such as weather conditions, which were difficult to predict and control. Additionally, the research relied heavily on the performance of specific equipment, which may not be representative of all piling projects. Equipment malfunctions and community disruptions also contributed to delays that were challenging to quantify.

Therefore, a more adaptive scheduling strategy—one that accounts for observed inefficiencies and integrates field-validated productivity benchmarks—should be prioritized in future coastal construction projects.

Future investigations should focus on developing more robust predictive models that can account for environmental variability and equipment performance in real-time. Additionally, exploring alternative piling methods or technologies that may offer greater efficiency in challenging environments would be beneficial. Furthermore, a more detailed examination of the human resource factors, such as operator skill and workforce allocation, could provide valuable insights into optimizing productivity in similar projects.

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