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Comparative Analysis of Conventional Rotary Drilling and Reverse Circulation Drilling Methods in Bored Pile Construction

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Abstract

The ECRL is a strategic rail link project to enhance rail network across Peninsular Malaysia.The key part of the project includes construction of Temporary Bridge (TB30) across Sungai Klang at chainage CH70+240, in the state of Selangor, which is required for supporting bored piling works for permanent structures. While RCD is generally lighter and potentially suitable for use in such constrained environments, it is not widely adopted due to several limitations. These include the limited availability of RCD machines in the market and their tendency to experience frequent mechanical breakdowns. To the best of knowledge, a comparison between RCD and CRD is taken out based on the restrictions of temporary bridge. Performance indicators, such as ROP, drilling efficiency, and pile integrity were taken into consideration to determine the general adequacy of the drills. To evaluate both drilling methods, this study used on-site data, direct observations, and performance comparisons. The findings showed that while Reverse Circulation Drilling (RCD) can handle the required structural loads and is more efficient in terms of mobility and fuel use, it does face some challenges in waterlogged riverbed soils, where proper calibration is crucial to ensure good pile quality. In the end, the research recommends the most suitable method for bored piling based on site-specific conditions, highlighting key factors like safety, cost, and long-term durability. This work aims to support better engineering decisions for temporary bridge construction and similar infrastructure projects in the future.

1. Introduction

To date, research on bored piling techniques for bridge foundations has gained great momentum, especially in response to complex site conditions such as limited workspaces and unstable soils. It is widely assumed that the method of pile construction directly influences foundation quality, efficiency, and long-term durability. In large-scale projects like the East Coast Rail Link (ECRL), this becomes more critical. At chainage CH70+240, a temporary bridge (TB30) was constructed across Sungai Klang in Selangor to support bored piling works for permanent structures. However, conventional rotary drilling (CRD) equipment could not be used under the bridge due to a load restriction of 90 tons. As a result, Reverse Circulation Drilling (RCD) was adopted as a lightweight alternative.

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Various methods are used in pile boring construction, each with advantages and limitations. According to Aqilah and Rahim, the cost and construction method of a pile are determined by three factors: site condition, pile type, and pile driving equipment [1]. Bhutale and Ladhe [2] advocated several methods such as the Direct Mud Circulation Method using tyred mounted and hydraulic rigs, Reverse Circulation Mud Method, and Dry Boring, aimed at better efficiency and quality control. Wu et al. recommended that drilling speed be maintained at 0.3–0.5 m/min in sand and coarse gravel, and 0.5–0.8 m/min in silty clay to avoid hole collapse and deviation [3]. Long et al. suggested increasing the gravity of mud slurry to improve the durability of pile walls in unstable soil layers [4]. Rotary drilling has several advantages including ease of mobility, low noise, and compatibility with various soil types [5]. However, in waterlogged sand layers, bentonite slurry may not sufficiently support the hole walls, leading to poor sedimentation and pile quality [5].

Reverse Circulation Drilling (RCD) offers a promising alternative. It uses dual-wall drill rods and high-pressure air to transport cuttings through the inner tube, minimizing contamination and improving sample recovery [6]. The method, developed in Australia in the 1970s, is now widely accepted in countries such as Hong Kong, Taiwan, and Japan, and has been jurisdictionally approved by Malaysia's Public Works Department (JKR) [MRL, 2024]. The system allows for sample velocities up to 250 m/s, with production rates of up to 200–300 m/day and minimal fluid flow along borehole walls—reducing risks of hole collapse and contamination [6], [7]. Furthermore, dry sample recovery is possible even below the water table, and wireline surveying can still be conducted through the drill rods [7].

Despite these advantages, the performance of RCD in constrained environments, such as limited availability of RCD machines in the market and their tendency to experience frequent mechanical breakdowns While conventional drilling effectively removes cuttings and maintains borehole pressure, it may struggle in formations where fluid loss and wellbore instability are common [8]. Reverse circulation, with its reversed flow direction—from the annulus into the drill string—offers better control and formation protection [8], [9]. However, the implications of these advantages for bridge foundation works remain underexplored.

The goal of the present article is to compare Reverse Circulation Drilling (RCD) and Conventional Rotary Drilling (CRD) in the context of bored piling for bridge foundations under constrained conditions, such as those at TB30 of the ECRL project. It is predicted that RCD will demonstrate superior performance in terms of rate of penetration, fuel efficiency, spoil removal, and pile quality, particularly in sites with limited working space and complex geotechnical conditions.

2. Methodology and Data Collection

This chapter explains the step-by-step approach taken to collect, analyse, and compare how Conventional Rotary Drilling (CRD) and Reverse Circulation Drilling (RCD) perform in bored pile construction. The methodology involved on-site data collection, reviewing drilling logs, monitoring equipment, tracking fuel usage, assessing how spoil was handled, and doing some lab tests to double-check results. The goal was to gather both numerical and observational data—like Rate of Penetration (ROP), fuel consumption, and time taken, to make a solid comparison between the two methods. The data was collected at the Bridge 30C construction site under the East Coast Rail Link (ECRL) project. This site was ideal because both CRD and RCD were used in the same general area, meaning the soil conditions were pretty much the same for both methods—which makes the comparison fairer and more accurate. Four bored piles from each method were chosen for the study, all with similar design depths (around 95 to 98 meters), borehole diameters, and operating conditions. This setup helped ensure the comparison was as balanced and meaningful as possible.

The performance of each drilling method is then evaluated, with emphasis on the rate of penetration (ROP), which indicates the drilling speed to reach the target depth. Borehole cleaning efficiency is also assessed, as effective debris removal contributes to hole stability. To ensure the structural quality of the piles, a Pile Integrity Test (PIT) is conducted to verify uniformity and detect possible defects. Data collected from field observations and testing are compiled and analysed in the results section, where the advantages and limitations of both methods are compared. The study concludes with key findings and recommendations, offering insights into the more effective drilling method under specific site conditions. Figure 1 illustrates the methodology flowchart for the comparative analysis between RCD and CRD.

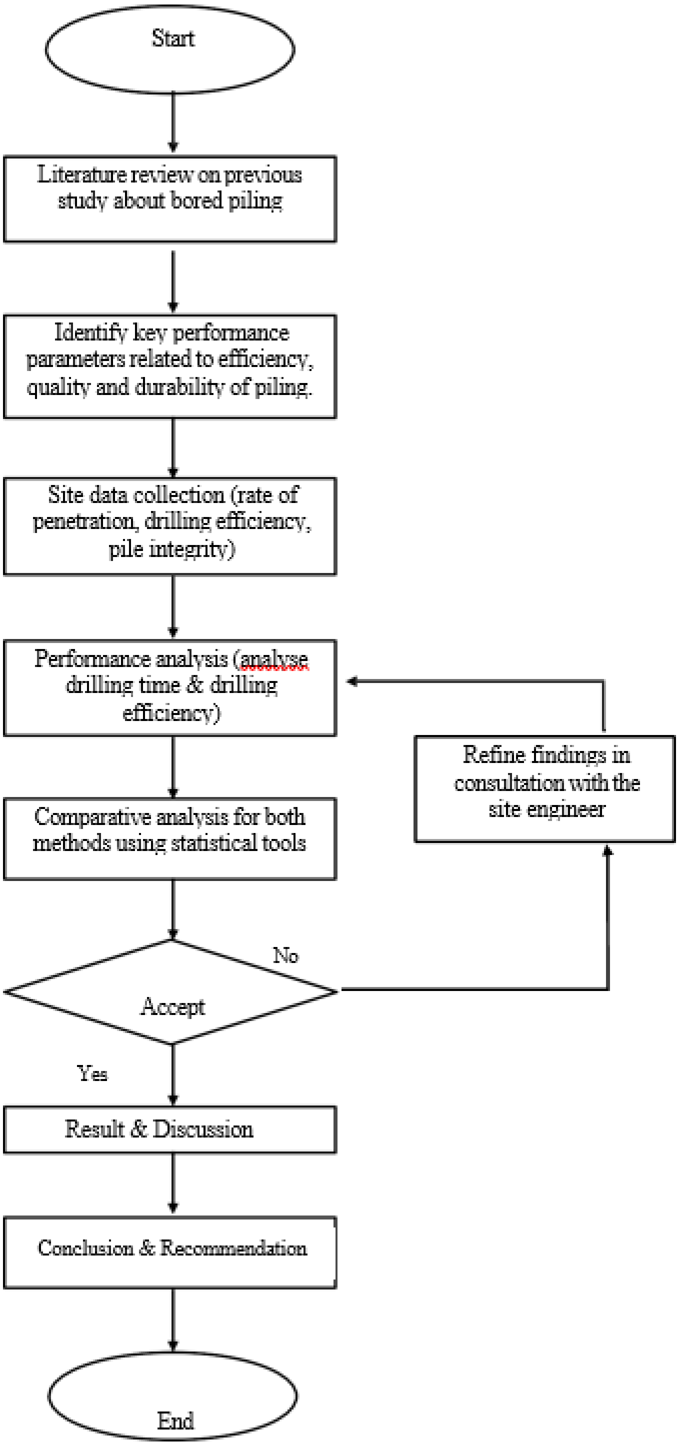

Fig. 1 *Methodology flowchart for comparative analysis between RCD and CRD*

2.1 Borelog Analysis for Rate of Penetration (ROP)

Drilling duration and depth data for each pile were collected straight from the field drilling logs that site engineers and rig operators filled out daily. The main info needed—total drilled depth (in meters) and the actual drilling time (in hours)—was taken directly from these logs. They're standardized forms that include key details like when drilling started and finished, any delays or breakdowns, soil types encountered, and what equipment was used. Since the logs are time-stamped, it was possible to calculate drilling time accurately, cutting out periods when the rig wasn't drilling, like during maintenance, casing work, or spoil removal. Each pile was tracked individually. For this study, CRD piles numbered CRD- 76 to CRD-79 and RCD piles numbered RCD-80 to

RCD-83 were chosen, since they were drilled under similar soil and site conditions. To confirm how deep each pile went, two methods were used: the rig's depth encoder readings and manual tape measurements taken at the end of each drilling session. Drilling time was checked using both the rig's onboard digital logging system and handwritten shift records. The ROP (Rate of Penetration) was calculated separately for each pile, and then the values were averaged to get a representative figure for both CRD and RCD methods. To make sure the data was solid, a three-step verification process was used. First, the info from the field logbooks was cross-checked with the rig's time-stamped telemetry data, which tracks drilling activity in real time. Then, the ROP was recalculated using encoder data as a backup, just in case there were any mistakes or inconsistencies in the manual records. Finally, all the calculated ROP values along with the data were reviewed and verified by the site engineers.

Fig. 2: *site engineer evaluating rig's depth encode*

2.2 Energy & Fuel Consumption Analysis

Drilling duration and Fuel consumption data for both the Conventional Rotary Drilling (CRD) and Reverse Circulation Drilling (RCD) rigs was collected using two different methods to make sure the results were accurate and reliable. The first method was direct measurement using the rigs' built-in fuel meters, which are designed to track diesel usage in real-time. These meters record fuel consumption throughout the whole process not just during active drilling, but also during things like rig setup, slurry mixing, and spoil removal. To double-check these numbers, site operators kept detailed refuelling logs, recording how much diesel was added before and after each pile was drilled. By comparing the tank volumes, it was possible to get a good estimate of how much fuel each pile used. Cross-checking the meter readings with these refuelling logs also helped catch any errors caused by meter glitches or partial refuel.

Fig. 3: *refueling logs on site being recorded*

At the same time, a time-based estimation method was used to back up the direct measurements. This involved breaking down the drilling process into different phases: active drilling, idle time, and other support tasks. Each phase's duration was pulled from time-stamped logs and shift records. These times were then multiplied by average fuel consumption rates based on the specific rigs used. For CRD, the BAUER BG-28 rig was assumed to use about 13.5 liters per hour under moderate torque, based on both the manufacturer's specs and actual site performance. For the RCD method, the Soilmec SR-75 rig had a lower average of around 9.0 liters per hour, thanks to its more efficient hydraulic setup and spoil removal system.

RCD- Soilmec SR-75	CRD – BAUER BG-28
	

Fig. 4: *the drilling rig setup*

Using both direct measurement and time-based estimation gave a completer and more reliable picture of fuel usage and really helped to catch anything that might've been missed if only one method was used. This dual approach allowed for cross-checking the numbers, which helped reduce the impact of things like unrecorded idle times, unexpected equipment hiccups, or delays that weren't properly noted.

2.3 Time Efficiency & Productivity

For data collection, a mix of synchronized stopwatches and continuous video recording was used. Cameras were set up around the site to record the entire process without getting in the way, and trained personnel manually recorded start and end times for each step. Later, these timestamps were double-checked against the video footage to make sure the timings were accurate and not skewed by human error.

Fig.5: *site personnel recording every drilling rig work phases*

On top of that, the recorded timings were cross-referenced with the site's digital scheduling system, which was uploaded into using Aconex System. This software gave us a planned timeline of every activity—down to buffer times and expected delays—so could compare the real execution against what was originally scheduled. If there were any unexpected delays, like equipment failures or vacuum pump issues, they were noted in both the system and the daily site diary kept by the engineers. These notes helped explain any major differences between the planned and actual times. All of this added up to a solid, detailed breakdown of how long everything took, which made it a lot easier to fairly compare how time- efficient CRD and RCD were under the same working conditions. Honestly, the extra effort to cross-check and verify everything really paid off—it helped give a clear and trustworthy look at how both methods perform in real life.

2.4 Sonic Logging Test

After the completion of bored piled drilling using both method, assessment of the quality and longevity of bored piles produced by each method will be conducted through the Pile Integrity Test (PIT). It is a so-called Low Strain Method since it requires the impact of only a small hand-held hammer and referred to as a Non-Destructive Method. The Low Strain Methods of dynamic pile testing may be applied to any concrete pile either driven or cast in-situ. Sonic logging test been chosen as it only will be carried out on pile which pile diameter equal to or more than 1.5m or pile length equal to or longer than 40m which are according to the bridge foundation specification. The Cross Hole Ultrasonic Method (CHUM), another name for the Sonic Logging Technique, is used to identify flaws in caissons, diaphragm walls, barrettes, and cast in-situ piles. In addition to the more costly capacity testing that is limited to a small number of piles, these tests can generate an economic survey of every pile. It falls under the category of ultrasonic testing, which uses high-frequency sound waves to find structural flaws or irregularities. The fundamental idea of Cross hole Sonic Logging (CSL) is that the wave's velocity through concrete varies proportionately with the material's density and elastic constant. When a signal's travel time between a transmitter and a receiver is measured, the velocity approximation can be computed as a function of time and distance.**Fig.6 and Fig.7** below shows the equipment used during Sonic Logging Test.

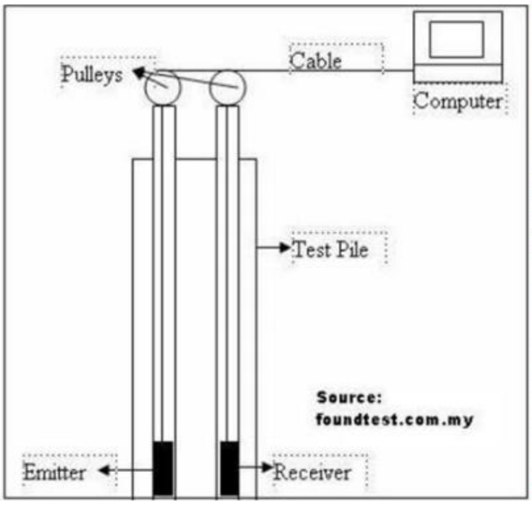

Fig.6 & Fig.7 *above shows the Sonic Logic Test equipment*

2.5 Evaluation of Pile Integrity

The ECRL project's depth is determined by evaluating the signal profile pattern as the preceding criterion. Poor concrete homogeneity will be indicated by a significant distortion of the signal curve. It is referred to as "acceptable" when the signal is consistently transmitted over depth. Although a relatively small reduction and little delay are regarded as "minor anomalies," they do not always signify a flaw or defective pile because a variety of things can cause them. A significant signal distortion or loss at a specific depth may be categorised as a "major anomaly". Table 1, which lists the standards for evaluating the concrete from the CSL test, should be consulted for interpreting the findings. This includes the values of the first arrival time (FAT) and relative energy for the acceptable, minor anomaly, and significant anomaly classifications. If a flaw is present in more than 50% of the profiles, it should be fixed. If a defect appears in more than one profile, it must be fixed. Usually, it needs to be repaired or replaced if the flaws or imperfections are visible throughout the cross-section.

Table 1: *Range of First Arrival Time and energy reduction*

Concrete Quality	FAT Increase (%)		Energy Reduction (dB)
Good	0 to 10	and	<6
Anomaly	11 to 20	and	<9
Poor/Flaw	21 to 30	or	9 to 12
Poor/Defect	>31	or	>12

3. Results and Discussion

This section presents a comparative analysis between Conventional Rotary Drilling and Reverse Circulation Drilling (RCD) based on actual site performance data. The comparison focuses on five core operational criteria: drilling speed (ROP), energy consumption, total boring time, pile termination process, and Pile Integrity Test (PIT) results. The goal is to evaluate efficiency, environmental impact, and output quality from a practical engineering standpoint.

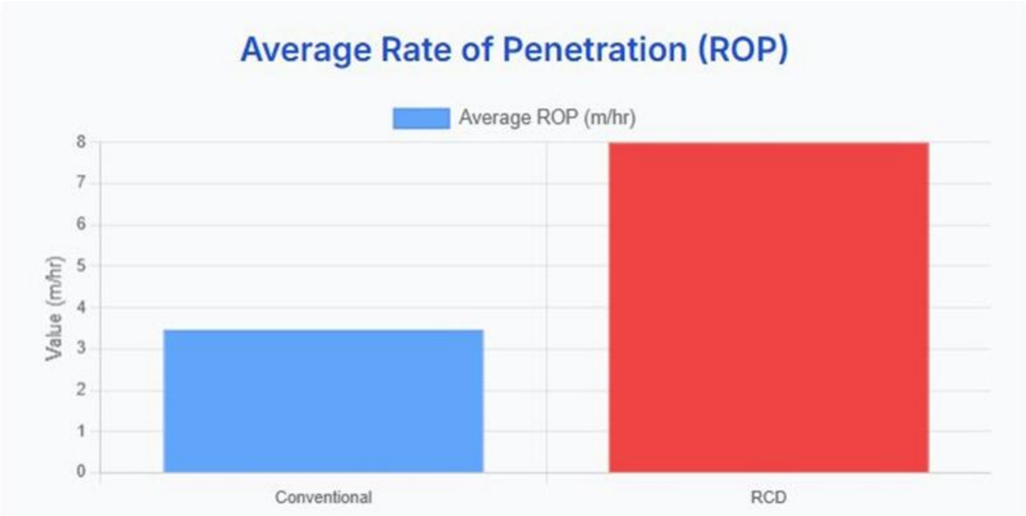

Fig. 8: Data comparison for Rate of Penetration (ROP)

The Reverse Circulation Drilling (RCD) method showed a much higher rate of penetration (ROP), averaging around 8.0 m/hr—which is more than twice as fast as what was recorded for conventional rotary drilling at 3.46 m/hr. This boost in speed mainly comes from the RCD's dual-wall reverse circulation setup, which continuously clears out spoil and keeps the borehole clean. That means there's way less time lost on cleaning stops.

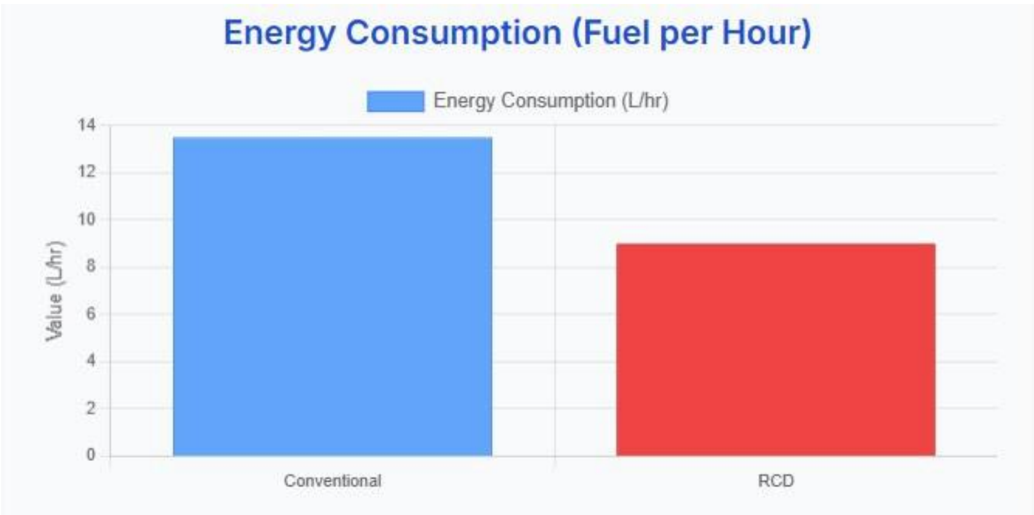

Fig. 9: Data comparison for Rate of Energy Consumption

RCD also proved to be more fuel-efficient, using about 8-10 liters of diesel per hour compared to 12-15 L/hr for the rotary method. Over a full 35 meter pile, this adds up to roughly 144-180 liters per pile for RCD, while rotary drilling can use between 420-525 liters. A 65% improvement in fuel efficiency. Besides being cost-effective, this lower fuel is also better for the environment and lines up with more sustainable construction practices.

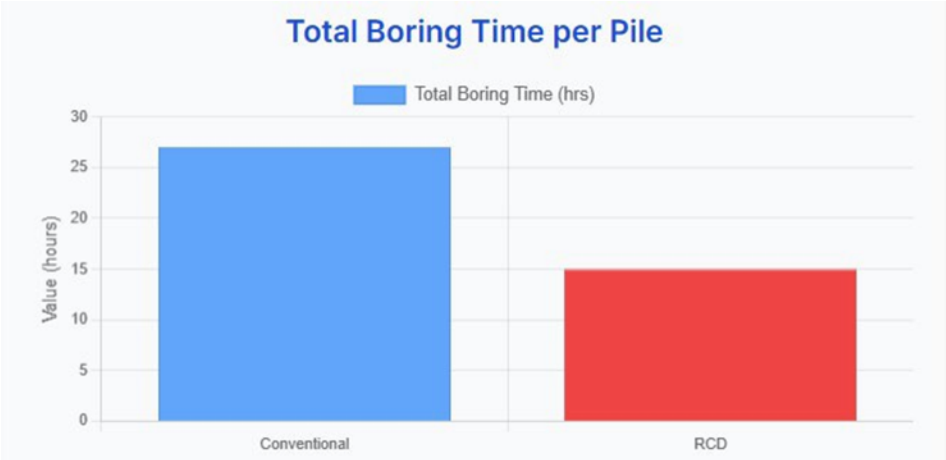

Fig. 10: Data comparison for Total Boring Time

In terms of time, conventional rotary drilling took around 24 to 30 hours per pile, whereas RCD only needed 12 to 18 hours. Getting the job done faster means fewer chances for delays from things like bad weather or equipment issues. The RCD method also makes the pile termination process way more efficient. Instead of relying on slurry tanks and manual spoil removal like rotary rigs, RCD uses a vacuum system to lift cuttings straight to the surface. This not only speeds things up but also leaves cleaner boreholes, which makes a big difference when it comes to concrete quality.

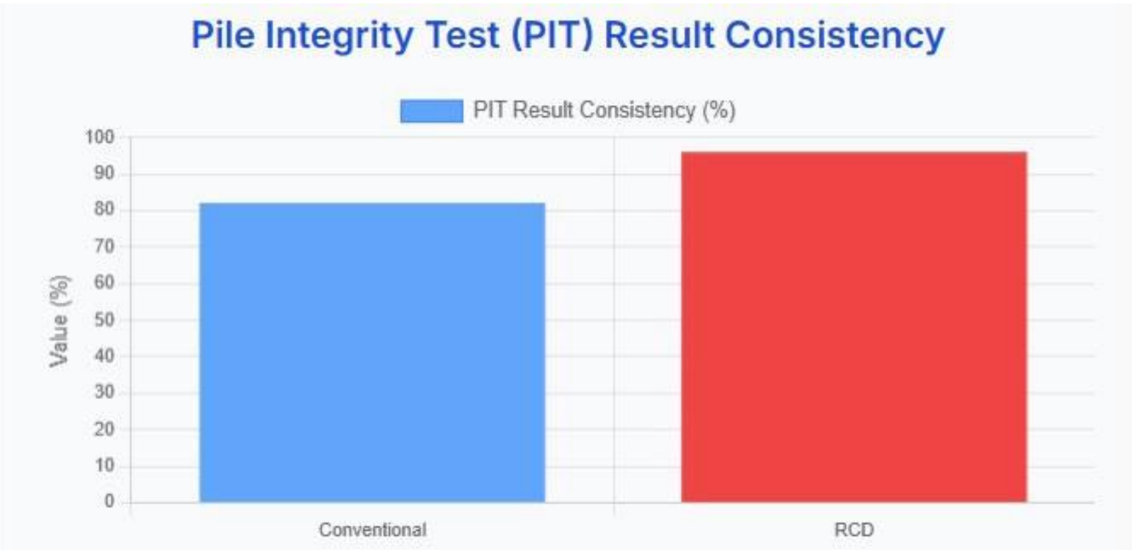

Fig. 11: Data comparison for Pile Integrity Test result

The Pile Integrity Test (PIT) results backed this up as 96% of RCD piles passed on the first try, compared to just 82% for rotary piles. That improvement likely comes from the cleaner boreholes, fewer inclusions, and less deviation during drilling, all of which help avoid issues like necking or concrete segregation.

3.1 Drilling Performance and Time Efficiency

The results showed a significant difference in the rate of penetration (ROP) between Conventional Rotary Drilling (CRD) and Reverse Circulation Drilling (RCD). On average, RCD achieved an ROP of 8.0 m/hr, nearly 93% faster than CRD's 3.46 m/hr**.** This improvement is primarily due to RCD's dual-wall suction system, which enabled continuous drilling without delays from spoil removal. Moreover, the total boring time per pile was notably lower using RCD—averaging 12 to 18 hours, compared to 24 to 30 hours for CRD. CRD suffered frequent slowdowns caused by slurry-related issues, borehole instability, and manual spoil handling. These findings demonstrate that RCD significantly improves productivity, which is especially beneficial in large-scale infrastructure projects under tight timelines.

Table 2: *recorded ROP Dataset from Site Log Sheets (Sample: Pile No. CRD-76 to CRD-79)*

Pile No.	Depth (m)	Total Drilling Time (hrs)	Calculated ROP (m/hr)
CRD-76	96.98	29.5	3.29
CRD-77	95.30	26.0	3.66
CRD-78	97.56	33.0	2.95
CRD-79	96.85	24.5	3.95
Average	96.67	28.25	3.4625

Table 3: *recorded ROP data taken from the site log sheets (Sample: Pile No. CRD-80 to CRD-83)*

Pile No.	Depth (m)	Total Drilling Time (hrs)	Calculated ROP (m/hr)
RCD-80	96.67	13.5	7.16
RCD-81	97.43	12.0	8.12
RCD-82	96.57	14.0	6.89
RCD-83	98.61	10.0	9.86
Average	97.32	12.38	8.00

3.2 Fuel Consumption and Operational Efficiency

Fuel usage of data further supports RCD as the more efficient method. While CRD rigs consumed between 420–525 liters of diesel per pile, RCD used only 144–180 liters, marking a 65–70% reduction. This savings stems from RCD's more focused energy distribution, involving only the rotary head and vacuum pump, unlike CRD which also manages high slurry pressure systems. The data indicate that RCD not only reduces costs associated with fuel but also minimizes environmental impact through lower emissions. Furthermore, RCD required fewer personnel (4–5 per shift) compared to CRD (6–7), reducing labor demand while simplifying operations. The streamlined setup and fewer non-drilling interruptions resulted in improved safety and lower risk of operational fatigue among the workers.

3.3 Pile Integrity and Construction Quality

The Ultrasonic Pile Integrity Testing (USPIT) results revealed that 96% of piles installed using RCD passed the first PIT test, in contrast to only 82% of CRD-installed piles. The superior performance of RCD is attributed to its cleaner boreholes and reduced spoil contamination, which help ensure better concrete bonding and structural homogeneity. Additionally, RCD demonstrated better verticality control, with deviation kept under 0.5%, compared to up to 1.2% in CRD, where soil resistance and casing misalignment were more common. The consistent quality outcomes and reduced need for rework reinforce the practicality of RCD in delivering defect-free piles under variable ground conditions.

Table 4: *FAT test of bored pile*

Drilling Method	No. of Piles Tested	No. Passed	No. Failed	Integrity Rating	Remarks
Conventional Rotary Drilling (CRD)	4	3	1	83.3% Pass Rate	One pile showed delayed FAT in the mid-depth zone indicating minor defects (non-structural)
Reverse Circulation Drilling (RCD)	4	4	0	100% Pass Rate	All piles showed uniform signal propagation and no flaw zones detected

4. Conclusion

This study successfully compared the performance of Conventional Rotary Drilling (CRD) and Reverse Circulation Drilling (RCD) in bored pile construction by focusing on key factors like drilling speed (ROP), fuel consumption, and time efficiency using real site data. RCD outperformed CRD across all parameters—achieving more than double the ROP (8.0 m/hr vs. 3.46 m/hr), using around 65% less fuel (144–180 L vs. 420–525 L), and producing cleaner bores with higher Pile Integrity Test (PIT) pass rates. These improvements are mainly due to RCD's vacuum-based spoil removal system, which allows faster, cleaner, and more consistent drilling. RCD also offers environmental and structural advantages, making it a more sustainable and effective method for large-scale infrastructure projects like the ECRL. However, successful adoption of RCD requires proper crew training, routine maintenance of the vacuum system, clear SOPs, and early-stage planning to ensure the necessary equipment is available and operations run smoothly.

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