

Evaluating Crosshole Sonic Logging in Indonesia: A Five-Year Overview

Rara Novianti

AECOM, Singapore, raradwin@gmail.com

Aksan Kawanda

Geotech Efathama, Indonesia

Ivan Edison

KTP Consultants, Singapore

ABSTRACT: The foundation is one of the structural components where ensuring pile integrity is essential to achieve the required strength. Unlike columns, beams, or other structures that can be visually inspected, foundations require specialized tools to assess their integrity. One of the tests specified in the Indonesian code is the Crosshole Sonic Logging (CSL) test, a method that relies on wave propagation to evaluate the integrity of cast-in-place bored piles. The purpose of this paper is to analyze the dataset of foundation construction in Indonesia, identifying patterns and trends within large datasets. This study aims to demonstrate how database analysis can be used to evaluate the distribution of foundation quality in Indonesia and observe trends in foundation construction practices. The study is based on a CSL test dataset collected over a 5-year period (2020–2024) and includes data from 1,672 bored piles located in various regions across Indonesia, covering diverse soil conditions and construction methods. The study indicates that (1) About 30% of tested piles fall into Class B & C (piles with defects) (2) Nearly 70% of the anomalies are located at the bottom of the pile (3) Piles with a diameter greater than 1.6 m or a length greater than 75 m exhibit defects in more than 50% of cases (4) Most anomalies occur on Java Island, accounting for 82% of all piles with defects.

KEYWORDS: Indonesia Construction, Foundation, Cross hole sonic logging (CSL), Database study.

1 INTRODUCTION

The use of bored piles is widespread in Indonesia, and analyzing the trends observed during bored pile construction is essential. Field workmanship has a significant impact on pile quality, and structural imperfections can adversely affect the transfer of loads from the superstructure to the ground.

As stipulated by geotechnical regulations in Indonesia, pile integrity is evaluated using the Cross-hole Sonic Logging (CSL) method. And CSL is the most performed verification technique on bored piles. The standard mandates testing one pile for every 20 piles of identical size (SNI 8460, 2017).

Camp et al. (2007) recorded that, out of 441 piles tested on different projects in South Carolina, around more than 70% of the projects had at least one pile containing a defect. Such defects in the integrity of the cast in situ pile can affect their pile capacity.

This paper presents an initial investigation into the relationship between bored pile workmanship and pile integrity, evaluated through Cross-hole Sonic Logging (CSL). The database will be progressively expanded to identify additional patterns and correlations, supporting broader practical applications. The analysis is based on a five-year dataset. This study provides a practical contribution on emphasizing the critical role of CSL in verifying pile integrity and addressing the limited availability of large-scale data analyses within the Indonesian context.

2 LITERATURE REVIEW

2.1 Cross-hole sonic logging (CSL)

ASTM D6760-16 (2016) defines and specifies the procedures for CSL method, which is used to evaluate the homogeneity and integrity of concrete in deep foundation elements such as bored piles, drilled shafts, concrete piles, or auger-cast piles. The application of this method may be further extended to diaphragm walls, barrettes, and dams. Under this standard, all such elements are collectively designated as “deep foundation elements.” The test measures the propagation time and relative energy of an ultrasonic pulse between parallel access ducts

(cross-hole), using pre-installed tubes embedded prior to casting of a deep foundation element.

The most common parameters used for CSL interpretation and assessment were first arrival time (FAT) and relative energy (RE) which were obtained independently from the processing of the signals. Consistent indications in both FAT and RE test results will lower the uncertainty and strengthen the assurance of the interpretation made (Amir, 2016).

Li et al. (2005) paper introduced a statistical probabilistic approach to evaluating the reliability of CSL, which depends on three major parameters: defect size, pile diameter, and the number of access tubes. Table 1 provides a summary of the minimum detectable defect size referenced in their work.

Table 1. Summary of the minimum detectable defect size by CSL (Li et al., 2005).

	Pile diameter (mm)	Percentage of detectable defect area*
Baker et al. (1993)	882	15%
Sarhan et al. (2002)	760	9%
Hassan and O'Neill (1998)	762	16.6%
Chernauskas and Paikowsky (2004)	914	20%
Iskander (2001)	900	10%

* Percentage of the cross-sectional areas of drilled shafts

2.2 CSL Rating Criteria

The interpretation and evaluation criteria of CSL testing results, are not well defined and controlled by uniform standards (Rosli & Hasbollah 2023). The evaluation criteria most widely adopted, as proposed by Likins et al. (2007), and commonly used in CSL report in Indonesia, is summarized in Table 2.

Table 2. CSL Evaluation Criteria. (Likins et al., 2007)

Category	Criteria
Good (G)	FAT increase 0 to 10% and Energy Reduction <6db is indicative of good quality concrete.
Questionable (Q)	FAT increase 11 to 20% and Energy Reduction of <9db. Results indicative of minor contamination or intrusion and/or questionable quality concrete.

Category	Criteria
Poor/Flaw (P/F)	FAT increase 21 to 30% or Energy Reduction of 9 to 12db
Poor/Defect (P/D)	FAT increase >31% or Energy Reduction > 12 db. Results indicative of water slurry contamination or soil intrusion and/or poor-quality concrete.

Deep Foundation Institute (DFI) published a white paper proposing an improved CSL rating criteria based on over 20 years of accumulated field experience. The revised rating criteria proposed new terms, providing clear delineations to aid in the interpretation CSL test result.

- Class A: Acceptable CSL test results.
- Class B: Conditionally acceptable CSL test results.
- Class C: Highly abnormal CSL test results.

Figure 1 presents a diagram of the CSL rating criteria (DFI, 2019). Figure 2 presents simplified plot between these 2 criteria (Rosli & Hasbollah 2023).

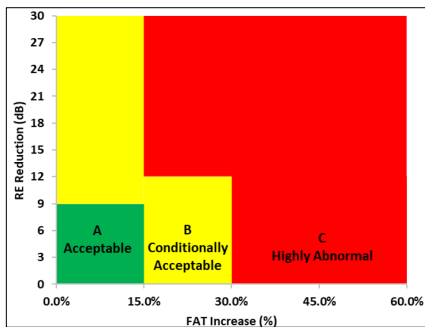


Figure 1. Graphical representation of CSL rating criteria. (DFI, 2019)

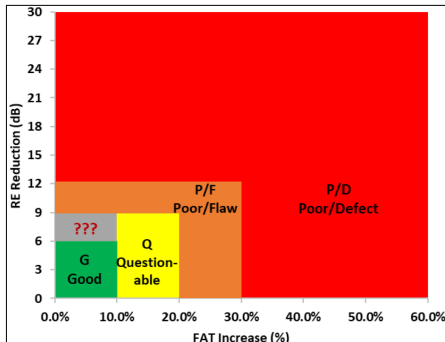


Figure 2. The simplified plot of 2 CSL rating criteria (Rosli & Hasbollah 2023)

The original report employed common criteria; however, the authors using simplified plot and adopt new CSL criteria proposed by DFI, 2019. Camp et al. (2007) suggest in practice, velocity reductions of less than 20% are generally disregarded (i.e., the “Questionable” rating is not used). Accordingly, author eliminated all data which classified as “Questionable” from the database.

3 DATABASE ANALYSIS

The 1,672 CSL record comprise of five-years dataset collected from Januari 2020 until December 2024. The data are distributed based on the location, as describe in Table 3 and illustrate in Figure 3.

Table 3. Distribution of CSL Data.

No	Location	Number of Data
1	Java	1187
2	Sumatera	324
3	Sulawesi	38
4	Southeast Islands	25
5	Kalimantan	98
Total		1672

Based on the spatial distribution of the data, most test locations are concentrated on Java Island, particularly in West-Java, which accounts for 789 records (nearly 50% of the total), followed by East Java with 308 (approximately 20%) and North Sumatra with 225 data (about 15%). This distribution may influences the observed data trends. Nevertheless, this study is intended as a starting point for future database research that can encompass other regions. The detailed numerical distribution is presented in Figure 3.

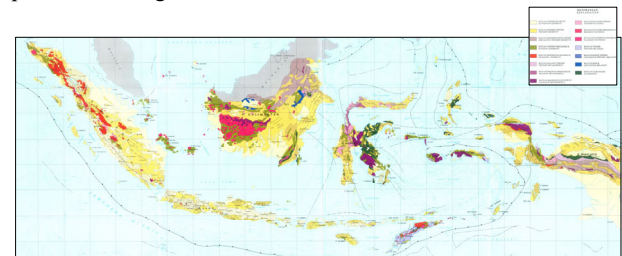


Figure 4. Indonesia Geological Maps (1996).

Based on Figure 4, Three major geologies of Indonesia are Quaternary alluvial deposits (Qal), Quaternary volcanic rocks (Qv), and Tertiary sedimentary formations (T). Quaternary alluvial deposits (Qal), shown in light yellow on geological maps and are widely distributed across Sumatra and Kalimantan; Quaternary volcanic rocks (Qv) shown in bright

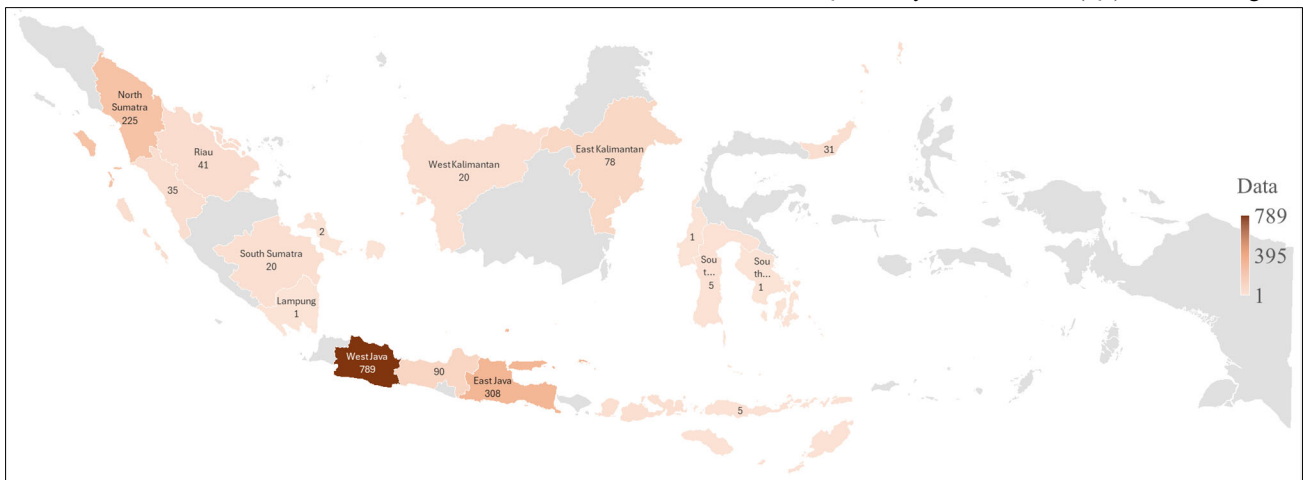


Figure 3. CSL Data Distribution.

pink and primarily concentrated along the volcanic arch of Java and the Barisan Mountains in Sumatra; Tertiary sedimentary formations (T) represented in shades of yellowish-brown and extending across Sumatra, Kalimantan, and Sulawesi Island.

Given the significant variability in soil conditions across dataset, this paper does not include a study of how soil characteristic affects the quality of pile integrity.

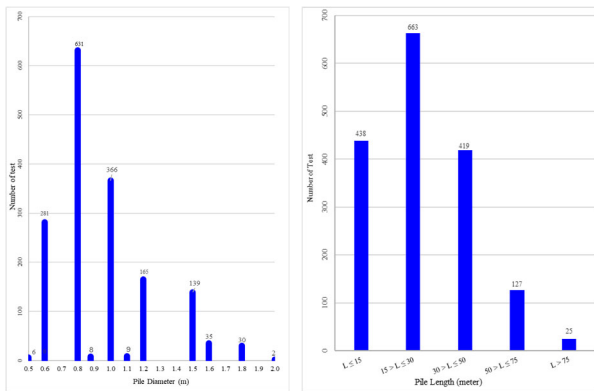


Figure 5. Distribution of Piles by Length and Diameter.

Figure 5 presents the distribution of pile diameters from the 1,672 tests analyzed. The majority of piles fall within the 0.6 m to 1.0 m range, which is the most commonly used size in Indonesia. Pile lengths vary from short piles (<15 m) to long piles exceeding 75 m. This indicates that the dataset used in this study largely represents typical bored pile dimensions in Indonesia.

4 RESULT AND DISCUSSION

4.1 Foundation Quality Based on CSL Result

The CSL test results were then tabulated for the discussion. Since this study aims to analyze the bored pile construction database in Indonesia, the initial step is to present the total number of piles classified into the three categories described in Chapter 2, as shown in Table 4.

Table 4. CSL Result from 2020 to 2024.

Year	Acceptable piles		Pile with defects	
	Class A	Class B	Class C	
2020	147	62	83	
2021	251	24	31	
2022	311	52	73	
2023	307	32	66	
2024	124	37	72	
Total	1140 (70%)		532 (30%)	

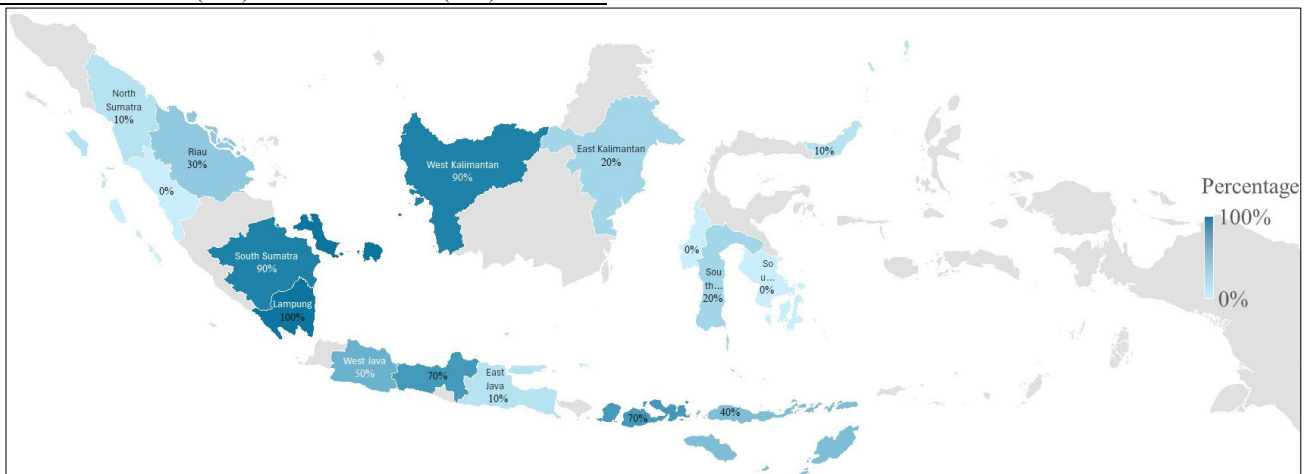


Figure 6. Distribution of Percentage Pile with Defects.

Based on Table 4, it is observed that 70% of the tested piles are classified as Class A, indicating that they are in acceptable condition with no significant defects. 10% of the piles are classified as Class B, which require confirmation of the observed irregularities, typically by retesting or visual inspection. The remaining 20% of the piles are classified as Class C, which suggests the presence of defects that may affect load-bearing capacity of the tested piles.

Table 5. Distribution of CSL Data.

No	Location	Acceptable piles	Pile with defects
1	Java	753	434 (37%)
2	Sumatera	278	46 (15%)
3	Sulawesi	34	4 (11%)
4	Southeast Islands	10	15 (60%)
5	Kalimantan	65	33 (34%)

Java has the largest share of defective piles, representing about 82% of all pile defects. To examine the construction quality, Table 5 shown the test results are categorized by island in Indonesia. The island with the highest proportion of pile defects is Southeast Islands, accounting for 60% of the tested piles there, followed by Java with 37%. Figure 6 illustrates the distribution by province rather than by island. The data indicate that the highest percentages of pile defects occurred in four provinces: Central Java, South Sumatra, Lampung, and West Kalimantan.

When assessing the proportion of defective piles relative to the total number of tests conducted at each location, the analysis indicates that regions with higher testing volumes reflecting larger number of actual piles, generally demonstrate better construction quality control. This trend is exemplified by West Java, which recorded the highest number of pile tests but reported 50% defect piles, followed by East Java and North Sumatra, each with approximately 10% defective piles relative to the total piles tested in that area. These observations suggest that standardized bored-pile construction practices have been effectively implemented across Indonesia's major islands, although defect rates vary by region.

This study also examines the distribution of pile CSL test results in relation to pile geometry. Table 6 and Table 7 summarize the distribution of acceptable and defective piles, categorized by diameter and pile length, respectively. Analysis of diameter data indicates that larger-diameter piles present greater challenges in maintaining drilled shaft stability and concreting quality control. Similarly, the trend observed in Table 7 shows an increase in defect occurrence with longer piles, suggesting a correlation between pile length and construction complexity. This observation aligns with the

findings illustrated in Figure 7, which further indicate that most pile defects occur near the bottom section of the pile.

Table 6. Summary of Pile Conditions by Diameter Range.

Diameter (m)	Acceptable piles	Pile with defects
0.5	2	4 (67%)
0.6	263	18 (3%)
0.8	406	225 (80%)
0.88	6	2 (25%)
1.0	264	102 (28%)
1.1	7	2 (22%)
1.2	96	69 (42%)
1.5	79	60 (43%)
1.6	4	31 (89%)
1.8	13	17 (57%)
2.0	0	2 (100%)

Table 7. Summary of Pile Conditions by Pile Length.

Length (m)	Acceptable piles	Pile with defects
$L \leq 15$	327	111 (25%)
$15 > L \leq 30$	479	184 (28%)
$30 > L \leq 50$	257	162 (39%)
$50 > L \leq 75$	68	59 (46%)
$L > 75$	9	16 (64%)

4.2 Pile with Defects

To further analyze piles with defects, the locations of the detected nonuniformities are illustrated in Figure 7. The data indicates that a significant proportion of defects recorded over the past five years occurred near the pile toe. Approximately 70% of the piles exhibited soft-bottom conditions, while the remaining 30% showed damage either at the pile head or within the middle section of the shaft, relative to the total number of piles with defects.

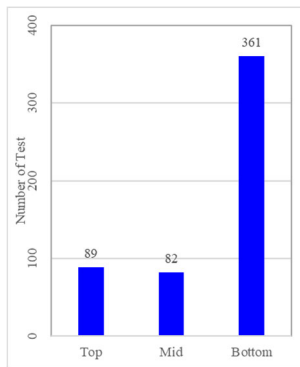


Figure 7. Distribution of Pile Defects Zone.

The pile defects in the pile body heavily affect its integrity and capacity, which have been investigated by researchers. A summary of the influence of pile defects on pile capacity is presented below (Yao et al. 2024).

Table 8. Summary of the influence of pile defects on pile capacity

Paper	Summary
Iskander et al. (2003)	Minor defects had little or no effect on skin friction. A soft bottom resulted in 33% reduction in end bearing.
Mo et al. (2025)	Construction-induced effects significantly reduce pile bearing capacity, with sediment individually leading to decreases of 24% compared to the ideal condition.
Wu and Wang (2009)	The existence of toe debris at the bottom of the cast-in-place bored piles not only affects their tip resistance but also reduces their side resistance. It is found that the ultimate bearing capacity of a single pile reduced by 11%–25% due to a thick toe debris at the bottom of the pile.

Paper	Summary
Yao et al. (2024)	The result indicates that maximum reduction in the ultimate bearing capacities of the toe debris defect decreased by 17% and that of the necking defect by 6.1%.
Zhang, J. G. (2005)	Pile necking is a common defect in the construction of cast-in-place bored pile foundations induced by water loss, mud cake, and soft clay fall into a drilled hole. Pile necking can induce a serious integrity problem and affect its bearing capacity.

4.2.1 Defects at Bottom of Pile

Based on the study data, 70% of the anomalies are located at the bottom of the pile, and this figure increases to nearly 90% when combined with the number of piles with defects at the top. These findings align with Camp et al. (2007), who reported that nearly 90% of the anomalies are located within the top two diameters or bottom two diameters of the shafts. One of the primary contributors to defects at the bottom of piles is soft-bottom conditions. Figure 8 shows the trend of soft-bottom occurrences observed in Indonesia over the study period.

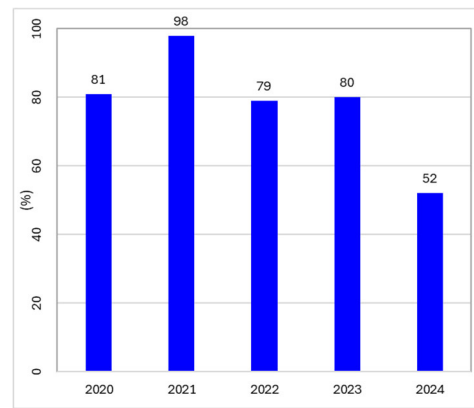


Figure 8. Yearly distribution of soft-bottom conditions (%).

This finding highlights that base cleaning remains a persistent challenge in Indonesia’s piling practices. However, Figure 8 reveals a positive trend, as the number of soft-bottom defects has steadily decreased over the years. This suggests that the implementation of more effective cleaning methods is beginning to yield measurable improvements, fostering optimism that defect rates will continue to decline in the future.

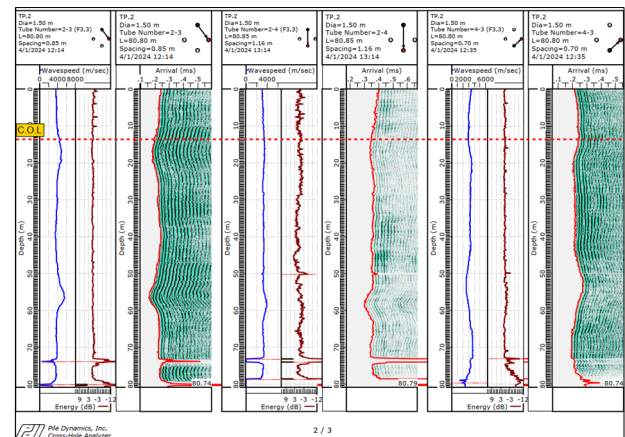


Figure 9. CSL Result of Soft Bottom.

Figure 9 presents a dataset collected in 2024. The figure indicates a noticeable reduction in First Arrival Time Force

Amplification Test (FAT) values at depths of 70-80 meters. This reduction is consistently observed across all access tubes, indicating a uniform pattern of weakening near the toe.

4.2.2 Defects at Top and Mid of Piles

Defects occurring at the top and middle sections account for approximately 30%, with data indicating that these two locations contribute equally. Figure 10 and Figure 11 indicate that these defects are primarily caused by necking. Pile necking is a common defect in the construction of cast-in-place bored pile foundations induced by water loss, mud cake, and soft clay fall into a drilled hole (Yao et al. 2024).

Debonding, which creates small gaps between the access tubes and concrete, is typically considered as most common scenario in upper portion of the shaft. The observed voids and erosional channels are believed as result of the formation of bleed water or bleeding - free water that rises to the surface of concrete after placement (Camp et al. 2007). Neville (1996) addresses bleeding and describes it as a form of segregation caused by subsidence or settlement of the solid constituents in a fresh concrete mix.

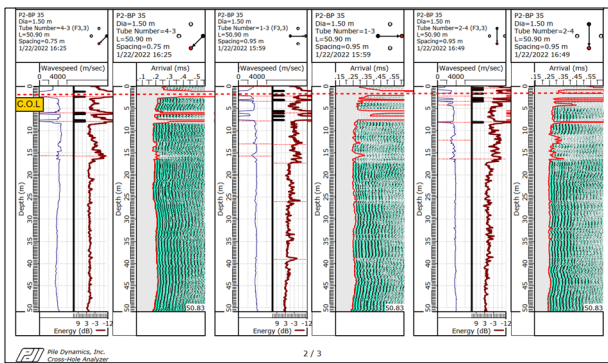


Figure 10. CSL Result of Top Defect.

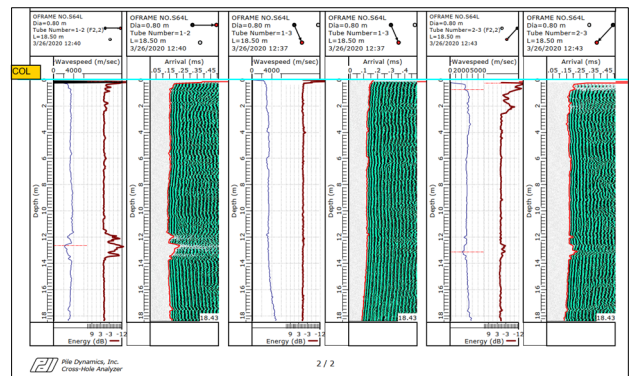


Figure 11. CSL Result of Middle Defect.

4.3 Recommendation of pile repair method assessment

This chapter presents a set of recommended pile repair strategies derived from engineering judgment and professional experience. These recommendations are intended to serve as general guidance for addressing common types of pile damage and are illustrated in the form of a flowchart to enhance clarity and facilitate practical application.

Huang (2018) summarize practice in Malaysia where for piles with obvious defects, such as Class III & IV piles (which class C according DFI class), repairs are needed. For other pile with minor defects, the consultant is required to combine with other methods (e.g. concrete coring etc.) and decide whether repair is necessary. While in China standard, the pile with minor defect that identified by professional testing engineer clearly specified will not require repairs.

Camp et al. (2007) suggested that ideally, the designer who selects the shaft diameter and length based on the design loading should also observe all phases of shaft construction, perform the CSL and make the final evaluation of the shaft acceptability.

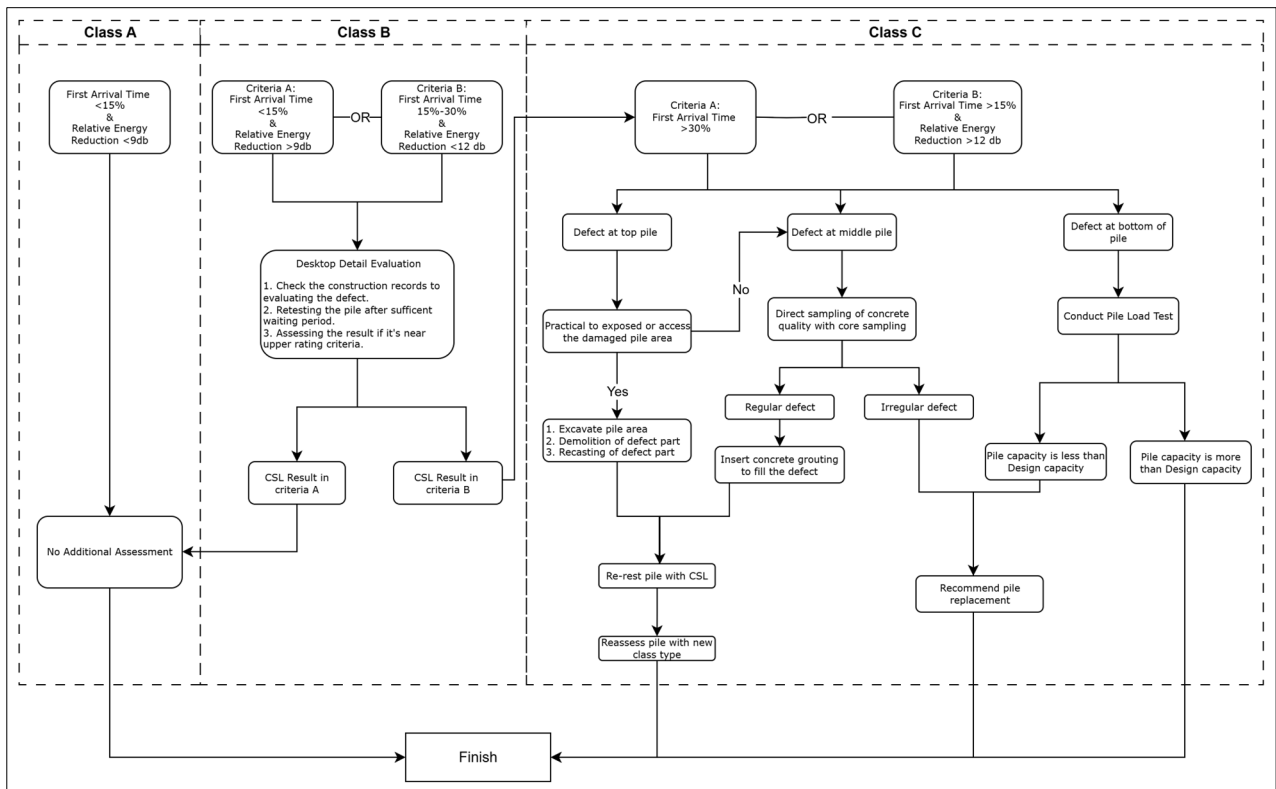


Figure 12. Flowchart of Recommendation Repair Methods

In this scenario, the final approval is made by the party having all of the relevant information about the shaft, including design loading, geotechnical capacity parameters, performance requirements, construction details, and CSL results. The proposed strategies should be evaluated and adapted based on site-specific conditions, engineering analysis, and professional discretion.

5 CONCLUSIONS

This paper presents a database study based on five years of data. The patterns observed in the test results have been analyzed, and the conclusions are outlined below.

1. A total of 1,672 CSL records were collected, with about 70% concentrated on Java Island.
2. It is observed that 70% of tested piles are classified as normal piles, while approximately 30% are classified as piles with defects.
3. These observations suggest that standardized bored-pile construction practices have been effectively implemented across Indonesia's major islands, although defect rates vary by region.
4. Analysis of diameter data indicates that larger-diameter piles and longer pile present greater challenges in maintaining drilled shaft stability and ensuring concreting quality control.
5. Approximately 70% of the piles exhibited soft-bottom conditions, while the remaining 30% showed damage either at the pile head or within the middle section of the shaft, relative to the total number of piles with defects.
6. Soft-bottom conditions remain a major issue in Indonesia, as indicated by the high percentage of pile defects. This is likely due to inadequate base cleaning, which often fails to fully remove sediment or mud deposits at the bottom of the pile. However, the study reveals a positive trend, as the number of soft-bottom defects has steadily decreased over the years.

6 ACKNOWLEDGEMENTS

The authors gratefully extend our sincere appreciation to PT.Geotech Efathama for data sharing. The findings presented in this paper are subject to limitations, as the data originates from a single testing company in Jakarta.

7 REFERENCES

- ASTM International, 2016. ASTM D6760-16, "Standard Test Method for Integrity Testing of Concrete Deep Foundations by Ultrasonic Crosshole Testing", astm.org.
- Badan Standarisasi Nasional, 2017. SNI 8460:2017, "Persyaratan Perancangan Geoteknik", bsn.go.id.
- Camp, W.M., Holley, D.W., and Caniva, G.J., 2007. Crosshole Sonic Logging of South Carolina Drilled Shafts: A Five Year Summary. *Contemporary Issues in Deep Foundations* 158.
- Chen, C., Wang, J., Quan, F., Zhu, L., Sun, W., and Wang, Y., 2025. Field Comparison of Vertical Bearing Capacity of Bored Piles with Various Post-Grouting Methods. *Geotechnical and Geological Engineering* 43.
- Deep Foundation Institute, 2019. Terminology and evaluation criteria of crosshole sonic logging (CSL) as applied to deep foundations. Hawthorne, NJ.
- Huang, K., 2018. A Research for Class II defect Bored Pile's Accept Criteria: A case of Penang Second Marine Bridge. *IOP Conference Series: Earth and Environmental Science* 128, 012080.
- Iskandar, M., Kelley, S., Ealy, C., and Roy, D., 2003. Drilled Shaft Defects: Detection, and Effects on Capacity in Varved Clay. *Journal of geotechnical and geoenvironmental engineering* 129, 1128-1137.

- Li, D.Q., Zhang, L.M., and Tang, W.H., 2005. Reliability Evaluation of Cross-Hole Sonic Logging for Bored Pile Integrity. *Journal of geotechnical and geoenvironmental engineering* 131, 1130-1138.
- Likins, G., Rausche, F., Webster, K., and Klesney, A., 2007. Defect Analysis for CSL Testing. *Contemporary Issues in Deep Foundations* 158.
- Mo, H., Liao, H., Guo, X., and Zhou, M., 2025. Influence of Construction-Induced Effects and Post-Grouting on the Performance of Mud-Protected Bored Piles: A Numerical Investigation. *Buildings* 15, 1457.
- Rosli, N.H. Che, and Hasbollah, D.Z. Abang, 2023. A Review of Cross-Hole Ultrasonic Logging For Foundation Integrity Testing and its Evaluation Criteria. *Construction* 3, 241-246.
- Yao, H., Ma, L., Duan, Z., and Guo, W. 2024. Reliability analysis of the cast-in-place bored pile with different defects. *Frontiers in Built Environment*. frontiersin.org.