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Evaluating Quality of Piles Constructed in Indonesia Through Five Year of Crosshole Sonic Logging Data

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ABSTRACT Deep 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, pile foundations require specialized tools to assess their integrity. One of the tests that can be utilized 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 CSL dataset of piles constructed 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, where 70% of the total piles are located, accounting for 82% of all piles with defects.

KEYWORDS Indonesia Construction; Foundation; Crosshole Sonic Logging (CSL); Database Study

1 INTRODUCTION

The use of bored piles is widespread in Indonesia, and ensuring the quality of 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, one pile integrity test is required for every 20 piles of identical size (SNI 8460, 2017). Crosshole Sonic Logging (CSL) is the most performed verification technique on bored piles. Camp et al. (2007) recorded that, out of 441 piles tested on different projects in South Carolina, 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.

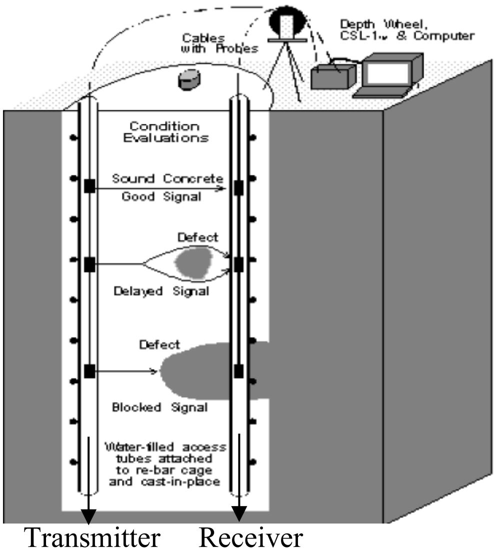
This paper presents an investigation into the relationship between bored pile sizes (length and diameter) and pile integrity, evaluated through CSL. The analysis is based on a five-year CSL dataset conducted between 2020 to 2024 across multiple provinces in Indonesia. This study provides a practical contribution on emphasizing the critical role of CSL in verifying pile integrity and addressing the limited availability of large-scale data analyses for bored piles in Indonesia.

2 LITERATURE REVIEW

2.1 Crosshole 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. CSL can also be used to check the integrity of diaphragm walls, barrettes, and dams. Under this standard, all such elements are collectively designated as “deep foundation elements.” CSL measures the propagation time and relative energy of an ultrasonic pulse emitted from a transmitter to a receiver placed at different access ducts (crosshole), using pre-installed tubes embedded prior to casting of a deep foundation element.

(a) CSL Test Equipment



(b) Illustration of CSL data collection

Figure 1. Crosshole sonic logging test

The most common parameters used for CSL interpretation and assessment are first arrival time (FAT) and relative energy (RE) which are obtained independently from processing of the signals. Consistent indications in both FAT and RE test data will lower the uncertainty and strengthen the assurance of the interpretation made (Amir, 2016). First arrival time (FAT) is the time required for the leading edge of the ultrasonic pulse to travel from the transmitter to the receiver, while relative energy (RE) or energy reduction is the relative signal strength of the pulse arriving at the receiver compared with a reference signal strength.

Li et al. (2005) paper introduced a statistical probabilistic approach to evaluate the reliability of CSL, which depends on three major parameters: defect size, pile diameter, and the number of access tubes (typical configuration shown in Figure 2). Table 1 provides a summary of the minimum detectable defect size referenced in their work.

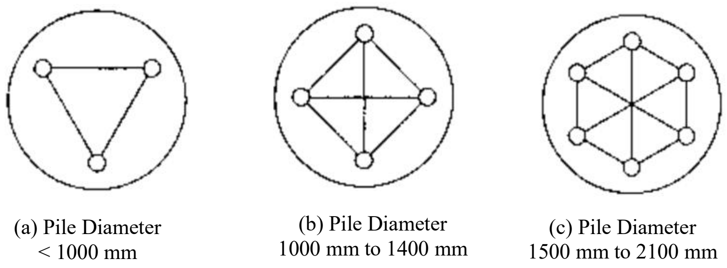


Figure 2. Minimum number of access tubes

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

	Pile Diameter (mm)	Percentage of detectable defect area*	Number of access tubes
Baker et al. (1993)	882	15%	4
Sarhan et al. (2002)	760	9%	-
Hassan and O'Neill (1998)	762	16.6%	3
Chernauskas and Paikowsky (2004)	914	20%	4
Iskander (2001)	900	10%	3 to 4

* Percentage of detectable defect area vs. 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 most widely adopted evaluation criteria is the one proposed by Likins et al. (2007). The criteria is summarized in Table 2.

Table 2. CSL evaluation criteria (Likins et al., 2007)

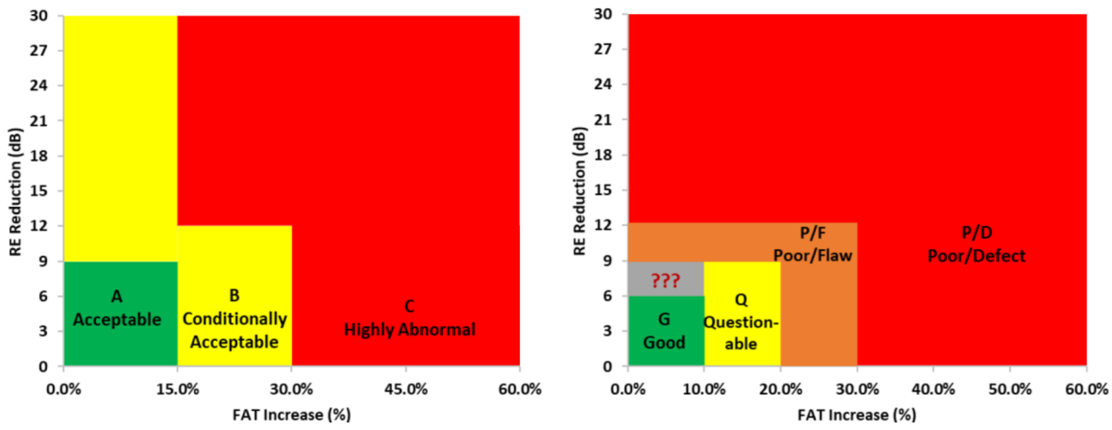
Category	Criteria
Good (G)	FAT increase 0 to 10% and Energy Reduction < 6 db is indicative of good quality concrete.
Questionable (Q)	FAT increase 11 to 20% and Energy Reduction of < 9 db. Results indicative of minor contamination or intrusion and/or questionable quality concrete.
Poor/Flaw (P/F)	FAT increase 21 to 30% or Energy Reduction of 9 to 12 db
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.

a. Class A: Acceptable CSL test results.
b. Class B: Conditionally acceptable CSL test results.
c. Class C: Highly abnormal CSL test results.

Figure 3a shows the criterion proposed by the DFI. A few years later, the rating criteria were simplified by Rosli and Hasbollah (2023).

In the original reports of CSL dataset used for this study, they employed common criteria by Likins et al. (2007). The results are reevaluated using the new CSL criteria proposed by DFI (Figure 3a) and the simplified plot (Figure 3b). Camp et al. (2007) suggest in practice, velocity reductions of less than 20% are generally disregarded (i.e., the "Questionable" rating is not used). As the "Questionable" rating is understood to reflect data quality issues encountered during data collection and may require further review and retesting. Hence, all data classified as "Questionable" were excluded from the database.



(a) Graphical representation of CSL rating criteria (DFI, 2019)

(b) The simplified plot of CSL rating criteria (Rosli & Hasbollah 2023)

Figure 3. CSL rating criteria

2.3 Typical CSL Result

Typical CSL results showing piles evaluated as "Good", "Questionable" and "Poor/Flow & Poor/Defect" are presented in figure 4 to 6 respectively. The green bars in the figure, often called the waterfall graph, give visual representation of ultrasonic pulses. From the waterfall graph, defects can easily be detected.

Figure 4 presents a CSL result rated as "Good", indicating a pile with satisfactory integrity. It can be seen that the waterfall graph is consistent throughout the pile depth and no significant anomalies are detected. Figure 5 shows a CSL result rated as "Questionable", where a potential reduction in wave velocity is observed only in trace 1-3 (tube number 1-3). As this anomaly is not reflected in the other tubes, the result may be attributed to data quality issues rather than an actual defect within the pile. Figure 6 presents CSL results for piles exhibiting defects. Figure 6(a) shows a defect near the pile head, indicated by a reduction in signal energy between depths 1 m to 3 m in trace 1-3, and between 5 m to 7 m in trace 4-3. Figure 6(b) shows a soft toe condition with an estimated thickness of 1.9 m, indicated by a reduction in signal energy at the pile toe. These examples provide a representative overview of the different CSL assessment outcomes considered in this study.

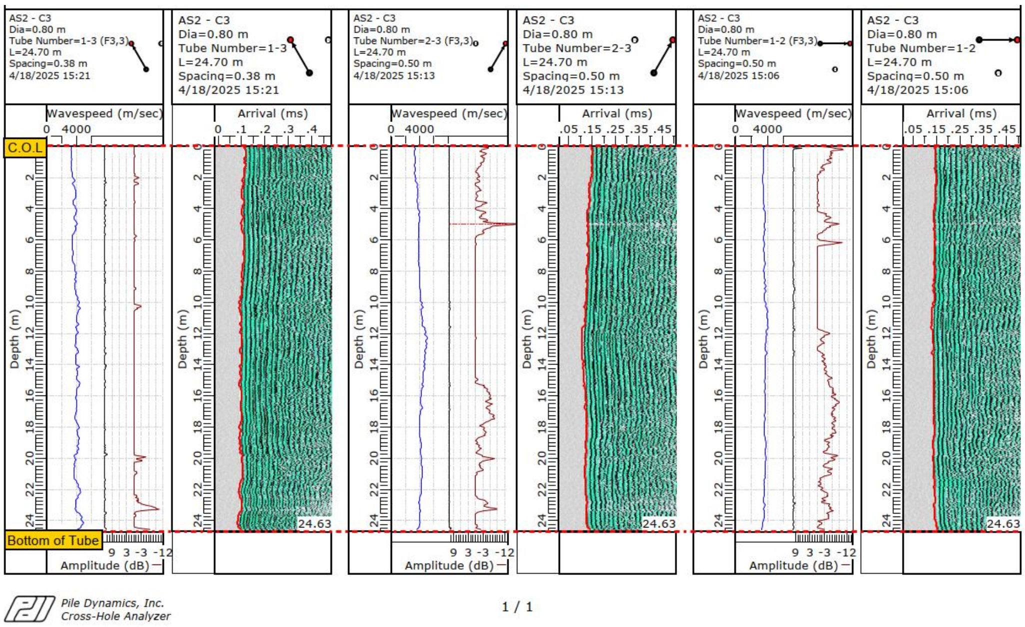


Figure 4. CSL results classified as "Good" categories

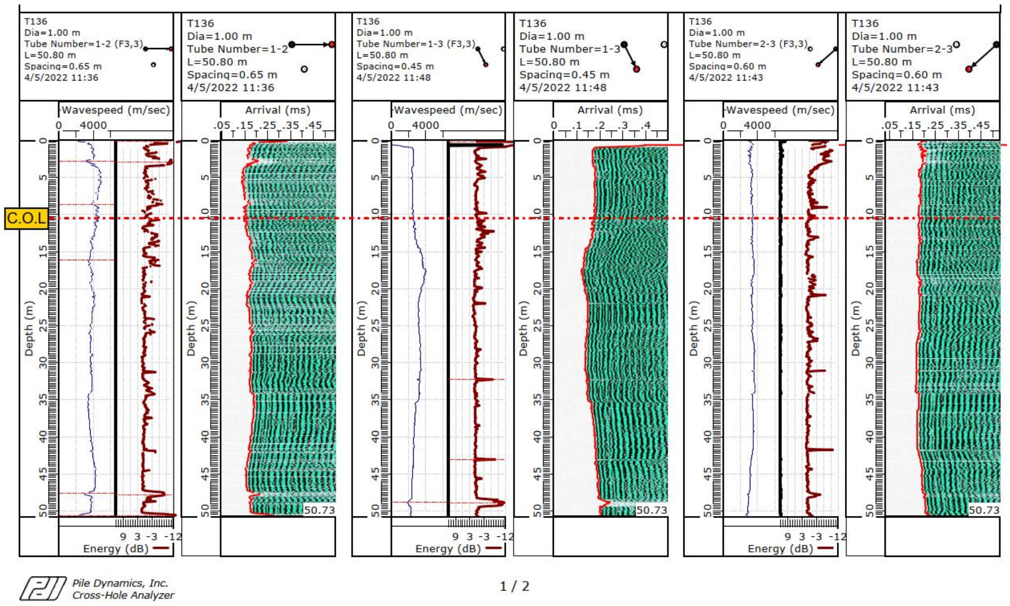
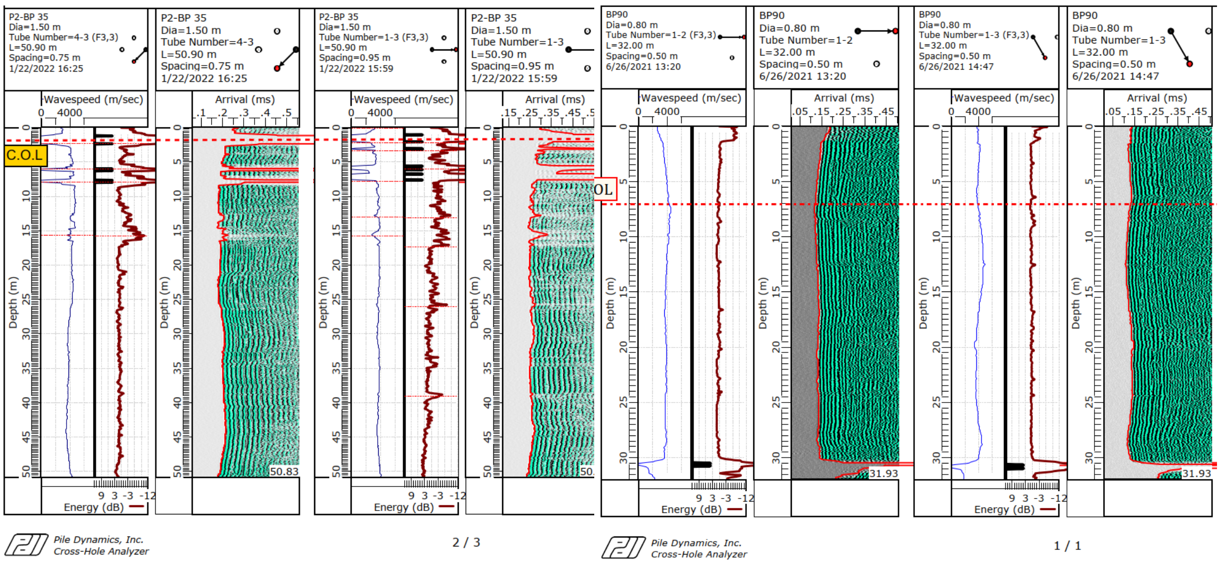


Figure 5. CSL results classified as "Questionable" categories



(a) Top Defect

(b) Bottom Defect

Figure 6. CSL results classified as "P/F" or "P/D" categories

3 DATABASE ANALYSIS

The five-years CSL dataset collected from January 2020 until December 2024 consist of 1,672 CSL records. The data are distributed across Indonesia and are categorized according to the major regions in Indonesia, as described in Table 3 and illustrated in Figure 7.

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 of the tests were conducted 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 is to be expected as more than half of Indonesia population live on Java Island, hence construction, especially high-rise buildings are more common in Java Island. However, it should be noted that 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 7.

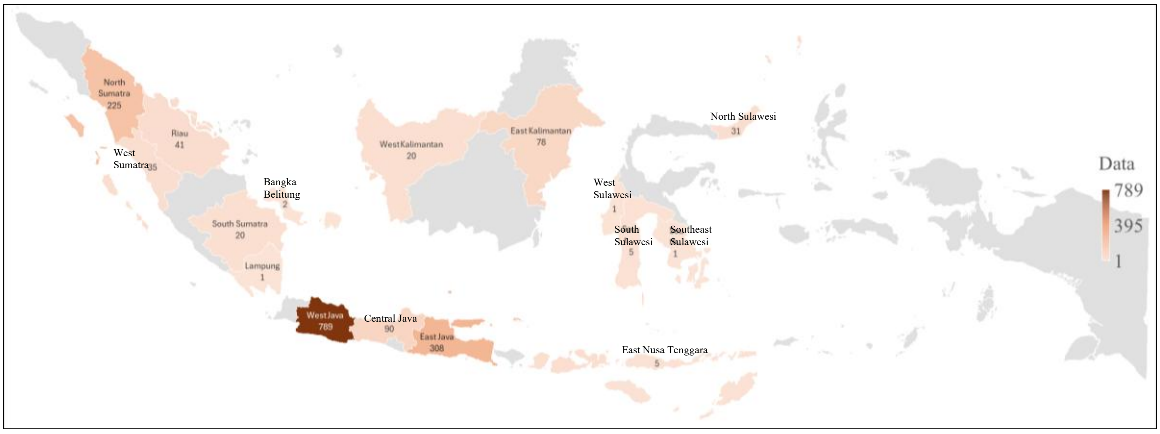


Figure 7. Illustration of CSL data distribution

Figure 8 presents the distribution of pile diameters and lengths 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.

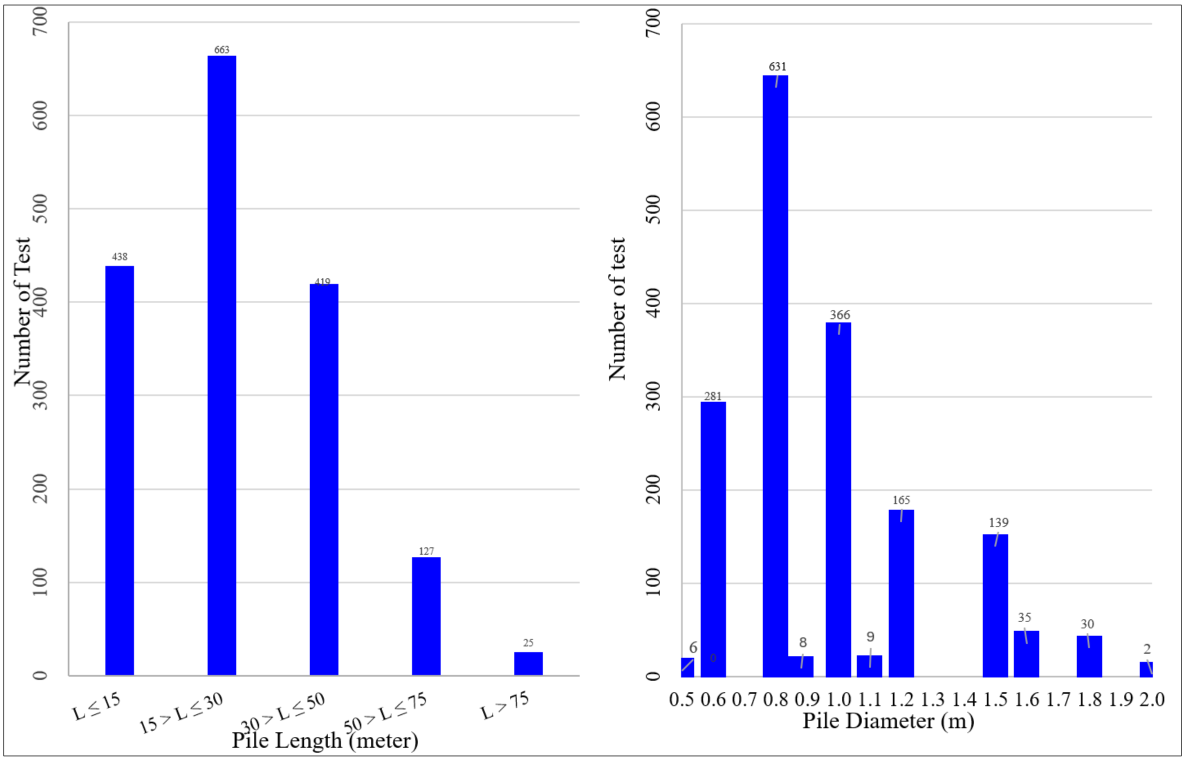


Figure 8. Distribution of piles by length and diameter

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. The results are tabulated in Table 4.

Table 4. CSL results from 2020 to 2024

Year	Acceptable piles	Pile with defects	
	Class A	Class B	Class C
2020	147 (50.3%)	62 (21.2%)	83 (28.4%)
2021	251 (82.0%)	24 (7.8%)	31 (10.1%)
2022	311 (71.3%)	52 (11.9%)	73 (16.7%)
2023	307 (75.8%)	32 (7.9%)	66 (16.3%)
2024	124 (53.2%)	37 (15.9%)	72 (30.9%)
Total	1140	532	

Based on Table 4, it is observed that 70% of the tested piles are classified as Class A, indicating that majority of the piles 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 (if the pile defects are in shallow depths and can be excavated for 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.

Next, the acceptable piles (Class A) and piles with defects (Class B & C) are recategorized based on their location. This is to examine the construction quality across various region. Table 5 shows the test results categorized by islands in Indonesia. Java has the largest share of defective piles, representing about 82% of all pile defects recorded. However, do note that more than 70% of the data is from Java Island. The island with the highest proportion of pile defects is Southeast Islands, in which 60% of the tested piles show defects, followed by Java with 37%. Figure 9 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.

Table 5. Summary of pile category

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

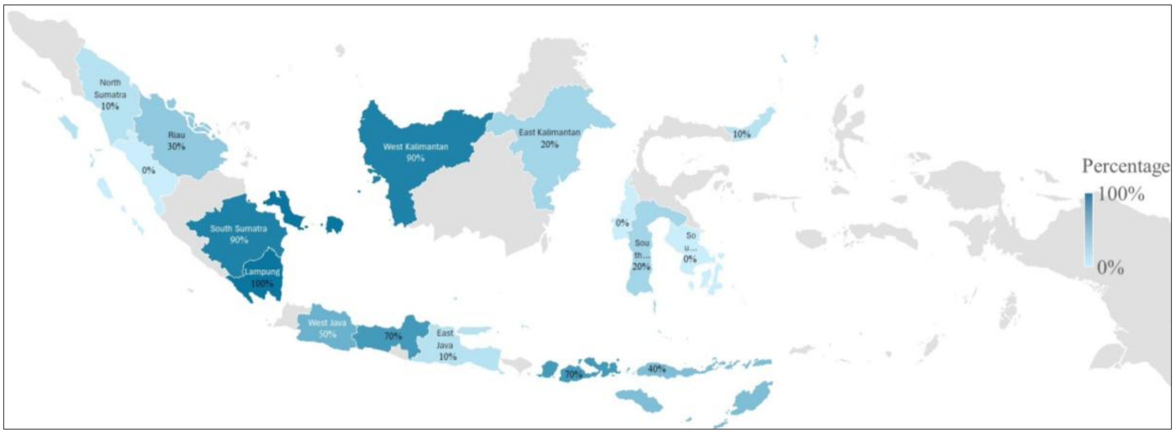


Figure 9. Distribution of percentage pile with defects

The third categorization was by pile sizes, namely its diameter and length. Table 6 and Table 7 summarize the distribution of acceptable piles and piles with defects according to pile diameter and pile length, respectively.

Table 6. Summary of pile conditions by diameter

Diameter (m)	Acceptable piles	Pile with defects
0.50	2	4 (67%)
0.60	263	18 (3%)
0.80	406	225 (36%)
0.88	6	2 (25%)
1.00	264	102 (28%)
1.10	7	2 (22%)
1.20	96	69 (42%)
1.50	79	60 (43%)
1.60	4	31 (89%)
1.80	13	17 (57%)
2.00	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%)

Based on Table 6, with the exception of 0.8 m diameter pile, the smaller pile diameters (below 1.1 m) exhibit defect rates below 30%, with 0.6 m, 0.88 m, 1.0 m, and 1.1 m diameter piles showing defect rates of 3%, 25%, 28%, and 22%, respectively. For larger pile diameters (1.2 m and above), the proportion of defects generally increases, with defect rates exceeding 40% for 1.2 m and 1.5 m diameter piles. The highest defect rates are observed for diameters of 1.6 m and above, more than 50% and reaching 100% for 2 m diameter piles. Table 7 shows a similar trend with respect to pile length. The defect rate increases progressively from 25% for piles with lengths of 15 m or less to 64% for piles exceeding 75 m in length.

Overall, the results suggest that pile geometry influences the difficulty in achieving satisfactory pile integrity. Smaller and shorter piles exhibit lower defect rates, whereas larger and longer piles show a noticeable increase in defects. These observations indicate that larger and longer piles present greater challenges in maintaining bore stability, concrete quality, and construction control during installation.

4.2 Pile with Defects

To further analyze in which part of the piles do defects occur the most often, the main pile defects are categorized based on where they are located. Three locations are identified, upper one third, middle third and lower one third. By main defects, the authors refer to piles with multiple defects. If defects are found in all three parts of the piles, the pile is categorized based on where the worst defects are found.

The data categorized by the location of main defects are illustrated in Figure 10. 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-toe conditions, while the remaining 30% showed damage either at the pile head or within the middle section of the shaft. When the defects at the top and bottom of the piles are combined, the proportion of defects occurring in those two areas is 90%. 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.

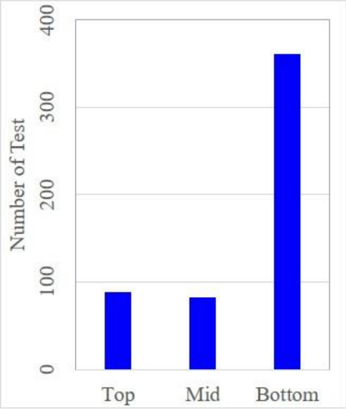


Figure 10. Distribution of pile defects zone

Pile defects in a pile body heavily affects its integrity and capacity. A summary of the influence of pile defects on pile capacity is presented in table 7.

Table 7. Summary of the influence of pile defects on pile capacity (Yao et al. 2024)

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 defects 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.
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, (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.

4.3 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 6 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 the 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.

Huang (2018) summarizes the practice in Malaysia where for piles with obvious defects, such as Class III & IV piles (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 the Chinese standard, pile with minor defect that is identified by professional testing engineer does not require repairs. Camp et al. (2007) suggested that the designer who design the shaft diameter and length should also be involved in supervising the bored pile construction, perform CSL tests and make the final decision on the bored pile acceptability.

4.4 Defects at Bottom of Pile

To study the quality of piles over the study period, the proportion of soft-bottom defects are plotted in yearly manner. Figure 11 shows the graph.

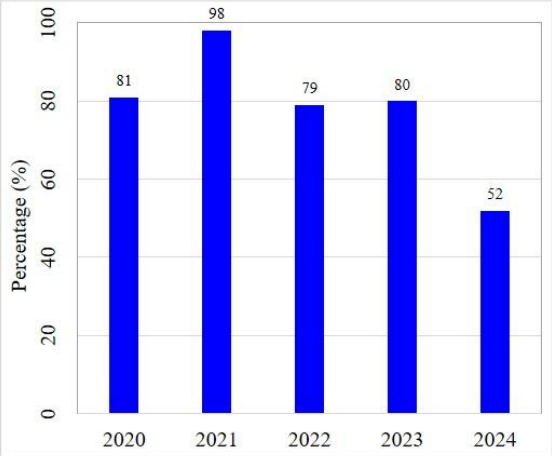


Figure 11. Yearly percentage distribution of soft-bottom conditions

This finding highlights that base cleaning remains a persistent challenge in Indonesia's piling practices. However, Figure 11 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.

5 CONCLUSIONS

This paper presents a database study based on five years of CSL data. The trend in bored pile construction and the conclusions are outlined below.

1. A total of 1,672 CSL records were collected, 70% of the data were from Java Island.
2. It is observed that 70% of tested piles are classified as acceptable, while approximately 30% are classified as piles with defects.
3. Analysis of defects occurrences with pile sizes indicates that larger-diameter and longer piles present greater challenges in maintaining drilled shaft stability and ensuring concreting quality control, i.e., more defects are detected in larger piles and longer piles
4. Approximately 70% of the defects detected are located at the pile toe, i.e., piles that exhibit soft-toe conditions, while the remaining 30% show defects either at the pile head or within the middle section of the shaft.
5. Soft-toe conditions remain a major issue in Indonesia, as indicated by the high percentage of pile defects located at pile toe. 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-toe defects has steadily decreased over the years.

DISCLAIMER

The authors declare no conflict of interest.

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