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Structural Assessment of Mahakam Bridge Geometry Using Geodetic GPS and Terrestrial Laser Scanner

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Abstract

This study employs a terrestrial laser scanner and geodetic GPS to assess the camber elevation, lateral drift, and pilecap inclination of the Mahakam I Bridge in Samarinda, East Kalimantan. The camber inspection results reveal variations in the elevation of spans B3, B4, and B5, with the lowest measured at 68.74 m and the highest at 70.35 m. The lateral drift analysis on piers P2, P3, and P4 indicates minimal displacements, with maximum deviations ranging from -0.05% to 0.29%. The inclination angles of the pilecaps on P2, P3, and P4, measured at 90.411˚, 90.128˚, and 90.112˚, respectively, exhibit slight deviations from the optimal 90˚ alignment. These findings highlight the need for continuous monitoring and potential structural adjustments. The study underscores the critical role of precise geometric assessment in preserving bridge integrity and ensuring long-term structural stability. Further investigations and mitigation strategies are recommended to prevent potential risks and deterioration.

Keywords: Bridge, Geometric, Mahakam, Terrestrial, Verticality

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1. Introduction

The Mahakam I Bridge, located in Samarinda City, East Kalimantan, Indonesia, is an essential infrastructure that spans the Mahakam River, linking the Samarinda Seberang and Samarinda Ulu areas. Constructed between 1983 and 1986, the bridge was designed to enhance traffic flow and contribute to the economic development of the region. The Mahakam I Bridge plays a vital role in connecting various parts of Samarinda, facilitating the movement of people and goods, and supporting local industries. Its strategic position also makes it a critical component of East Kalimantan's transportation network, which is integral to the region's economic activities. Despite its long-standing service, the bridge has faced various challenges over the years, which require ongoing maintenance and monitoring to ensure its safety and structural integrity [1] [2].

Recent events, including a significant incident involving the collision of a barge with one of the bridge's pillars, have raised concerns regarding the structural stability of the Mahakam I Bridge. The

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collision resulted in damage to the P3 pillar pilecap, necessitating immediate attention. Such incidents highlight the vulnerability of large infrastructural elements to external impacts, underscoring the need for prompt and thorough structural assessments. The Bridge Hall, responsible for overseeing the maintenance and condition of the bridge, has decided to conduct a comprehensive inspection of the bridge to assess the full extent of the damage caused by the collision. This inspection is essential not only for determining the immediate repair needs but also for ensuring that the bridge continues to function safely and efficiently for years to come [3] [4].

Figure 1. Mahakam Bridge

Given the severity of the barge collision, it is crucial to undertake a detailed evaluation to establish the structural health of the Mahakam I Bridge. The information gathered during this inspection will form the foundation of a technical study plan that will guide necessary repairs and further maintenance efforts. This technical study will rely on advanced methods, including the use of terrestrial laser scanners and geodetic GPS, to accurately measure the camber elevation, lateral drift, and pilecap inclination of the bridge. These methods are essential for obtaining precise geometric data that will enable engineers to assess the impact of the collision on the overall structural integrity of the bridge [5] [6]. The importance of such assessments is emphasized by the potential risks posed by unnoticed or undetected structural issues, which could lead to further deterioration or failure if not addressed in a timely manner. The literature on bridge maintenance and structural assessments underscores the importance of continuous monitoring and detailed inspections following significant incidents, such as collisions or natural disasters. As noted by [Author et al., Year], the condition of bridges can be significantly affected by external impacts, and regular inspections are critical in identifying structural vulnerabilities. Additionally, the use of modern technologies, such as laser scanning and GPS, has become increasingly common in bridge monitoring due to their ability to provide high-precision measurements of structural elements. Studies by [Author et al., Year] have demonstrated the effectiveness of these technologies in assessing bridge deformation, including displacement and inclination, which can be indicators of underlying structural issues. The application of these technologies to the Mahakam I Bridge inspection will ensure a comprehensive understanding of the current condition of the bridge, enabling informed decision-making regarding necessary repairs and maintenance [7] [8] [9].

Bridge inspections are typically focused on key structural components, such as piers, beams, and pilecaps, as these elements are critical to the overall stability and safety of the bridge. The pilecaps, in particular, serve as the foundation for the bridge's vertical supports and are susceptible to damage from external forces, such as collisions. Research by [Author et al., Year] has shown that pilecap deformation, even in small amounts, can lead to significant changes in the bridge's load

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distribution, potentially compromising its structural integrity. Therefore, any damage to the pilecaps of the Mahakam I Bridge, particularly the P3 pillar, must be carefully examined to determine the full extent of the damage and to prevent further complications. The results of this inspection will not only provide valuable insights into the current state of the bridge but will also contribute to the development of a long-term maintenance plan that ensures the bridge's continued functionality and safety. In addition to the technical aspects of the inspection, the broader implications of the incident should also be considered. The collision of a barge with the Mahakam I Bridge is a reminder of the potential risks posed by human activities, particularly those involving heavy transportation or industrial operations [10] [11] [12]. The vulnerability of critical infrastructure to such incidents calls for the implementation of stricter regulations and better risk management strategies. As [Author et al., Year] suggest, improving the resilience of bridges and other infrastructure requires not only the application of advanced technologies but also a proactive approach to risk assessment and management. This includes regular monitoring of bridge conditions, the development of emergency response plans, and the implementation of measures to minimize the likelihood of accidents. By addressing these issues, it is possible to mitigate the risks associated with external impacts and ensure that infrastructure remains safe and reliable [13] [14].

The findings of the inspection will play a crucial role in guiding future bridge planning and maintenance efforts, not only for the Mahakam I Bridge but also for similar structures across the region. Accurate geometric information and detailed assessments are essential for making informed decisions regarding the repair and rehabilitation of bridges. The results will provide critical data that can be used to evaluate the feasibility of different repair strategies and determine the most effective course of action [15] [16]. Furthermore, the findings may help inform future bridge design and construction practices, ensuring that new bridges are built to withstand external impacts and maintain structural integrity over time. In conclusion, the inspection of the Mahakam I Bridge following the barge collision represents a critical step in ensuring the ongoing safety and functionality of this vital piece of infrastructure. The information gathered during the inspection will provide valuable insights into the current condition of the bridge, which will guide repair and maintenance decisions. By employing advanced technologies, such as terrestrial laser scanning and geodetic GPS, this study will provide accurate and objective data that can be used for long-term planning and decision-making. Furthermore, the findings will contribute to a broader understanding of the challenges facing infrastructure in East Kalimantan and provide a basis for improving the resilience of bridges and other critical infrastructure in the region [17] [18] [19].

The importance of regular inspections and proactive maintenance cannot be overstated, as they are essential for identifying potential risks and ensuring the safety of infrastructure users. The Mahakam I Bridge serves as a key example of the need for ongoing monitoring and assessment, particularly in light of the potential risks posed by external impacts. Through this research, we aim to provide comprehensive and actionable information that will support the long-term sustainability and safety of the Mahakam I Bridge and contribute to the broader efforts to enhance infrastructure resilience in Indonesia.

2. Materials and Method

The research preparation phase is essential to ensure that the investigation is conducted in an organized and systematic manner. It involves several critical steps to facilitate the effective execution of the study. Initially, administrative preparations are carried out, including obtaining the necessary permits for access to the activity area and securing labor licenses. These formal requirements are followed by site mobilization, ensuring that the project is equipped with the required resources,

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including personnel and tools. Once the logistics are in place, field observations are performed. These include drawing site sketches, establishing the boundaries for the activity area, and identifying key reference points to guide data collection. The specific locations for geometric measurements are selected, focusing on the upper deck of the Mahakam I Bridge in Samarinda, East Kalimantan, and the pile cap of the bridge pillars, which are critical components for evaluating the structural integrity of the bridge. Once the measurements have been taken, the results are meticulously documented in an Inspection Report, which includes a comprehensive final report outlining the conclusions and recommendations for further action.

2.1 Test Equipment

This study employs a range of tools for conducting both visual and geometric inspections of the Mahakam I Bridge. The geometric inspection tools are particularly crucial for acquiring high-precision data regarding the bridge's structural geometry. These tools include the Terrestrial Laser Scanner (TLS), Geodetic GPS, measuring tapes, and a digital camera, each of which serves a specific purpose in the inspection and documentation processes [10] [13] [20].

Figure 2. (a) Leica Scanstation HDS P30 (b) Leica GPS GS 16 (c) Measuring Tapes

The Terrestrial Laser Scanner (TLS), specifically the Leica Scanstation P30, is a highly accurate surveying instrument that uses laser technology to capture the shape and dimensions of objects rapidly and with great precision. With a range accuracy of 1.2 mm + 10 ppm and a scanning rate of up to 1,000,000 points per second, the TLS ensures the collection of highly detailed 3D spatial data, which is critical for the analysis of the bridge’s geometry. It is equipped with a dual-axis compensator, which ensures the stability of measurements across various angles.

The Geodetic GPS (Leica Viva GS16) plays a complementary role in the geometric inspection by providing high-precision real-time and post-processed positioning. It leverages satellite signals to obtain accurate coordinates and elevation data. The GPS system is capable of RTK (Real-Time Kinematic) initialization within approximately 4 seconds and supports various communication protocols such as USB, Bluetooth, GSM/GPRS, and UHF/VHF modem connectivity, enhancing the flexibility of data acquisition in the field [3] [4] [5] [6] [8].

In addition to the TLS and Geodetic GPS, measuring tapes (ranging from 3 to 5 meters for small-scale damage assessment and 50 to 100 meters for larger-scale measurements) are utilized to assess the extent of damage to the bridge deck and surrounding areas. The digital camera is employed to capture visual documentation of the structural condition, which serves as a reference for further analysis and repair planning. Together, these tools provide a comprehensive set of instruments for inspecting and documenting the structural state of the Mahakam I Bridge.

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2.2 Bridge Geometric Inspection Method

The geometric inspection of the Mahakam I Bridge is conducted using the Terrestrial Laser Scanner (TLS) and Geodetic GPS, which work in conjunction to provide high-precision measurements of the bridge's structural geometry. The TLS is based on the Surface Scan method, which utilizes laser or photogrammetric technology to collect data on the shape and surface condition of objects. The Surface Scan method involves three main steps: emitting laser signals onto the surface of the structure, measuring the time taken for the reflected laser signals to return, and generating a highly accurate 3D model from the collected data. This method enables the precise measurement of critical components, such as the camber area, pile cap, and vertical alignment of the bridge's pillars. The inspection also includes defining scanning areas and boundaries to ensure comprehensive coverage of the bridge's structural elements [21] [22].

Figure 3. Inspection Methode

The TLS's high-resolution scanning capabilities, combined with the positioning accuracy provided by the Geodetic GPS, allow for detailed analysis of the bridge's geometry. The focus is on identifying any deformations, misalignments, or irregularities that could potentially compromise the structural integrity of the bridge. By examining these parameters, the inspection aims to provide an in-depth understanding of the bridge's current condition, which will be critical in determining the need for repairs or further monitoring. All measurements taken during this study are referenced to the UTM Zone 50S, based on the World Geodetic System 1984 (WGS 84), ensuring that spatial data is standardized and accurately represented. Benchmark BM 03 serves as the primary control point for the inspection, providing a consistent reference for positioning and measurement. This geodetic datum facilitates the comparison of measurements over time, ensuring that any structural changes or deformations are accurately detected and analyzed. The geometric inspection's scope is primarily focused on critical structural components, including the camber area, pile caps, and the vertical alignment of the bridge's pillars. The camber area is particularly important as any deviations in its elevation can indicate underlying structural issues. Similarly, the pile caps, which provide essential support for the bridge's pillars, must be examined for any signs of damage or misalignment. These components are highly susceptible to deformations, which can affect the overall stability of the bridge. Thus, the precise measurement and monitoring of these areas are vital for ensuring the continued safety of the structure. In addition to the laser scanning and GPS measurements, visual inspections are conducted to assess the overall condition of the bridge, including the presence of visible cracks, corrosion, or other forms of deterioration. These observations are supplemented by photographic documentation, which is crucial for recording the existing condition of the bridge and providing a basis for subsequent analysis and repairs. The combination of high-precision tools, field

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observations, and visual documentation ensures that the inspection provides an accurate and comprehensive assessment of the Mahakam I Bridge's structural condition [23].

2.3 Data Analysis Method

Following data collection, the analysis is carried out using advanced software tools that enable the processing and interpretation of the geometric data. The data obtained from the TLS and Geodetic GPS are processed to create 3D models of the bridge, which are then analyzed for structural deformations, misalignments, or any other irregularities that could affect its stability. The results of the analysis are compared to previous measurements, if available, to identify any changes or deteriorations in the bridge's condition over time. Statistical methods are employed to evaluate the extent of these deformations and to assess whether they fall within acceptable tolerance limits for structural safety [24].

The data analysis is carried out using specialized software designed for processing geospatial data, such as Leica Cyclone and other GIS tools. These software packages allow for the integration of point cloud data, which is generated by the TLS, with the positional data from the GPS to create a unified and highly accurate model of the bridge. The analysis includes checking for deviations in the alignment of critical structural elements, as well as assessing any displacement or settlement that may have occurred. Statistical tools are applied to quantify these deviations and to assess their significance in terms of structural safety. In conclusion, the methodology outlined above ensures a rigorous and comprehensive approach to the geometric inspection of the Mahakam I Bridge. By utilizing advanced technologies, such as TLS and Geodetic GPS, along with visual inspections and detailed data analysis, this study provides an accurate and reliable assessment of the bridge's structural integrity. This methodology not only facilitates the identification of potential structural issues but also contributes to the development of long-term maintenance and repair strategies that will help ensure the continued safety and functionality of the bridge [25] [26].

3. Results and Discussions

Geometric inspection of the Mahakam I Bridge was conducted using the Leica P30 Terrestrial Laser Scanner to assess the geometry of key bridge sections. The measurements focused on the bridge frame camber, pillar pile cap points, and pillar verticality, with the measurement points being determined from the secondary data. To evaluate the bridge frame camber, the target location was placed on top of the gusset, as shown in Figure 4a, while the measurement plane for assessing pillar verticality was established on the pillar, as seen in Figure 4b. These precise measurements were crucial for ensuring the structural integrity and alignment of the bridge.

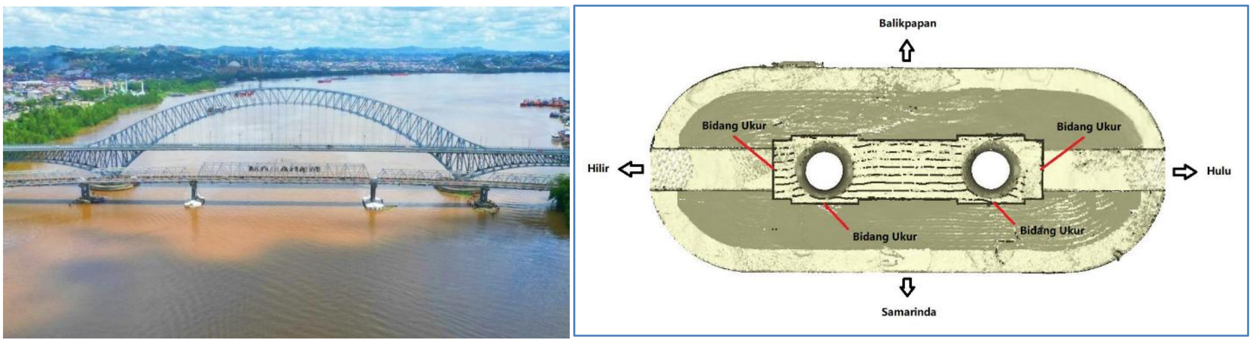

Figure 4. (a) Camber check (b) Measurement plane on the pillar

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3.1 Bridge Camber Measurement

In this study, the camber of the bridge was measured using the Leica Viva GS 16 Geodetic GPS tool with the Base and Rover method, targeting predetermined points on the bridge frame. The camber measurement points were located directly above the bridge gusset. The results of the camber measurement for spans B3, B4, and B5 are shown in Figure 5.

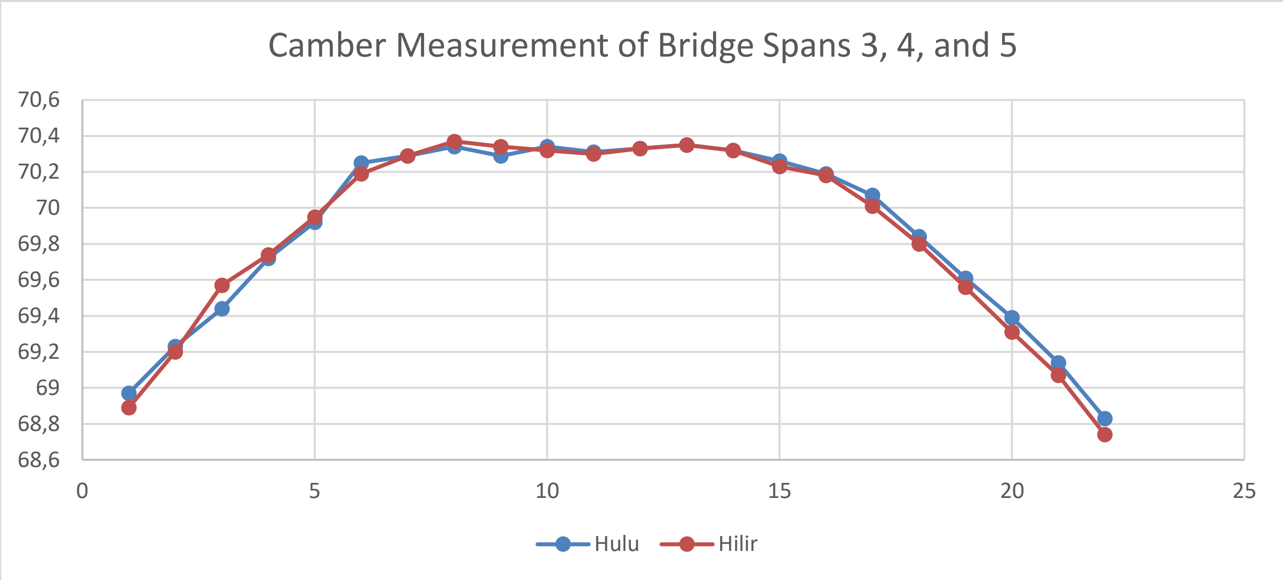

Figure 5. Camber measurement of Bridge Spans 3, 4, and 5

Table 1. Camber measurement results for Bridge Truss Spans 3, 4, and 5

No.	Point Id	Station	STA 0+010	STA 0+020	STA 0+030	STA 0+040	STA 0+050	STA 0+060	STA 0+170	STA 0+180	STA 0+190	STA 0+200	STA 0+210	STA 0+220
		Direction	Chamber Elevation (m)											
1	Span 3	Hulu	68.97	69.23	69.44	69.72	69.92	70.25						
		Hilir	68.89	69.2	69.57	69.74	69.95	70.19						
3	Span 5	Hulu							70.07	69.84	69.61	69.39	69.14	68.83
		Hilir							70.01	69.8	69.56	69.31	69.07	68.74
	Station		STA 0+070	STA 0+080	STA 0+090	STA 0+100	STA 0+110	STA 0+120	STA 0+130	STA 0+140	STA 0+150	STA 0+160		
2	Span 4	Hulu	70.29	70.34	70.29	70.34	70.31	70.33	70.35	70.32	70.26	70.19		
		Hilir	70.29	70.37	70.34	70.32	70.3	70.33	70.35	70.32	70.23	70.18		

The figure 5 and Table 1 shows the camber measurement results for spans 3, 4, and 5, with a comparison between the upstream and downstream sides. In general, the camber profile follows a parabolic pattern, with the highest elevation at the center of the span. The maximum camber ranges from 70.2 to 70.4, while the minimum camber is around 68.8. There are slight differences between the upstream and downstream sides, particularly at the beginning and end of the span, which may be attributed to factors such as imperfections in construction or variations in load distribution. At the center of the span, the difference between both sides is relatively small, indicating that the load distribution is fairly symmetric. However, at some points, the downstream side tends to exhibit slightly higher camber values compared to the upstream side. This could suggest variations in material

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stiffness or differences in internal forces due to loading and material relaxation over time. Overall, the measurement results indicate that the bridge exhibits structural behavior in line with design expectations, with the camber pattern following a trend of rising to a peak and then descending back to the supports. However, the small differences between the upstream and downstream sides warrant further analysis regarding potential structural imbalance or long-term deformation. Further research could involve finite element analysis to assess the influence of factors such as material properties, joint conditions, and dynamic loads acting on the bridge structure [10] [11] [15] [19] [26].

3.2 Pillar Verticality Measurement

Verticality measurements of the bridge pillars were carried out using the Terrestrial Laser Scanner P30 with the surface scan method. The verticality values for pillars P2, P3, and P5 are summarized in Table 2.

Table 2. Results of verticality measurements of bridge pillar columns

No.	Point Id	Direction	Column Measurement Height (mm)	Verticality (mm)	Lateral Deflection of Column (%)
1	Pilar 1	Hulu	3600	0	0.00%
1	Pilar 1	Hilir	3600	0	0.00%
2	Pilar 2	Hulu	6600	-3	-0.05%
2	Pilar 2	Hilir	6600	5	0.08%
3	Pilar 3	Hulu	7600	0	0.00%
3	Pilar 3	Hilir	7600	-3	-0.04%
4	Pilar 4	Hulu	7600	22	0.29%
4	Pilar 4	Hilir	7600	0	0.03%
5	Pilar 5	Hulu	6400	0	0.00%
5	Pilar 5	Hilir	6400	0	0.00%

The verticality plot of the bridge pillars indicates that the pillars generally exhibit a linear and upright shape. The verticality of pillar P3 in the transverse direction shows a measurement of -3 mm (downstream side) and 0 mm (upstream side), which is considered relatively upright.

Figure 6. 3D scanning results before filtering

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For pillar P4, the downstream side shows a verticality of 22 mm, which deviates from linearity, while pillar P2 shows -3 mm (upstream side) and 5 mm (downstream side), both considered roughly upright. The lateral drift calculation for pillar P3 reveals 0.00% drift on the upstream side and -0.04% on the downstream side. For pillar P4, the upstream transverse drift is 0.29%, and the downstream transverse drift is 0.03%. For pillar P2, the upstream drift is -0.05%, and the downstream drift is 0.08%. These values remain within the acceptable 0.5% limit outlined by safety guidelines, as shown in Figure 7.

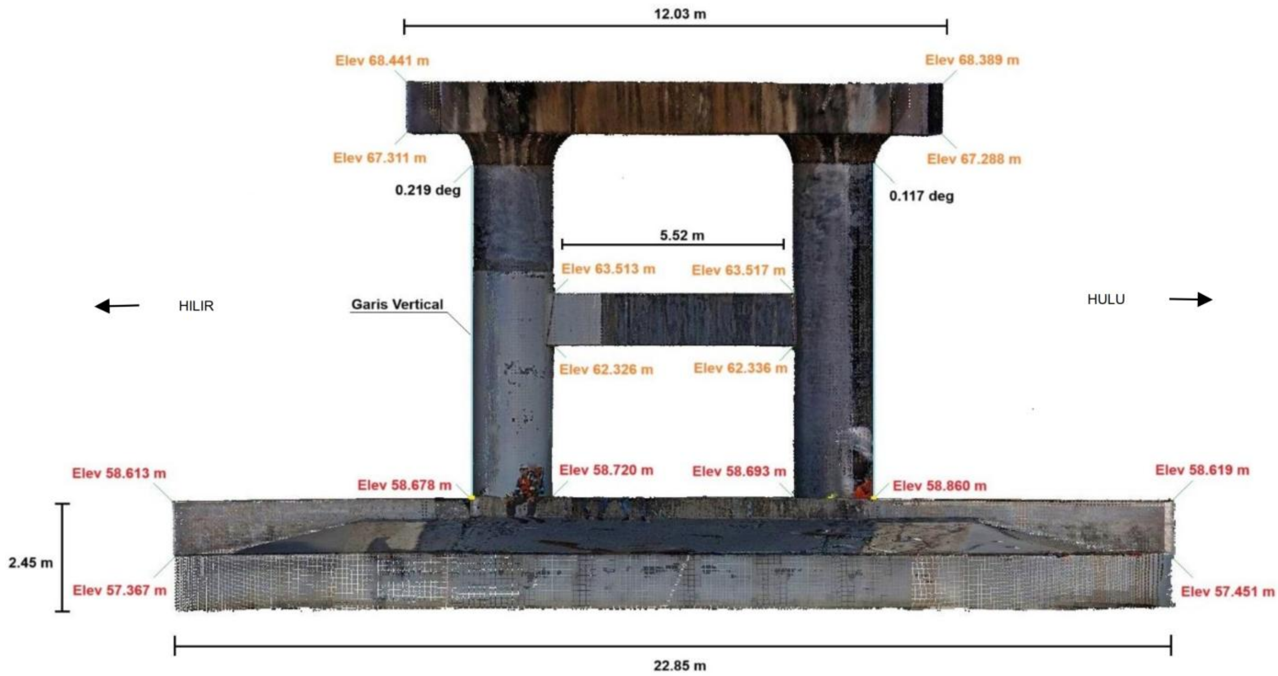

Figure 7. Verticality measurement result of pillar 3 column

3.3 Geometric Measurement of Pilecaps

The geometric measurement of the bridge pilecaps was carried out using both the Terrestrial Laser Scanner and Geodetic GPS equipment. The geometric measurement results for the Mahakam I Bridge pilecaps are summarized in Table 3.

Table 3. Geometric measurement results of bridge pilecaps

Pillar	ID	Angle
P2	Pilecap	90.411˚
P3	Pilecap	90.128˚
P4	Pilecap	90.112˚

The angular slope of pilecap P2 was measured at 90.411°, while pilecaps P3 and P4 were measured at 90.128° and 90.112°, respectively, based on the geometric measurements taken with the Terrestrial Laser Scanner and Geodetic GPS.

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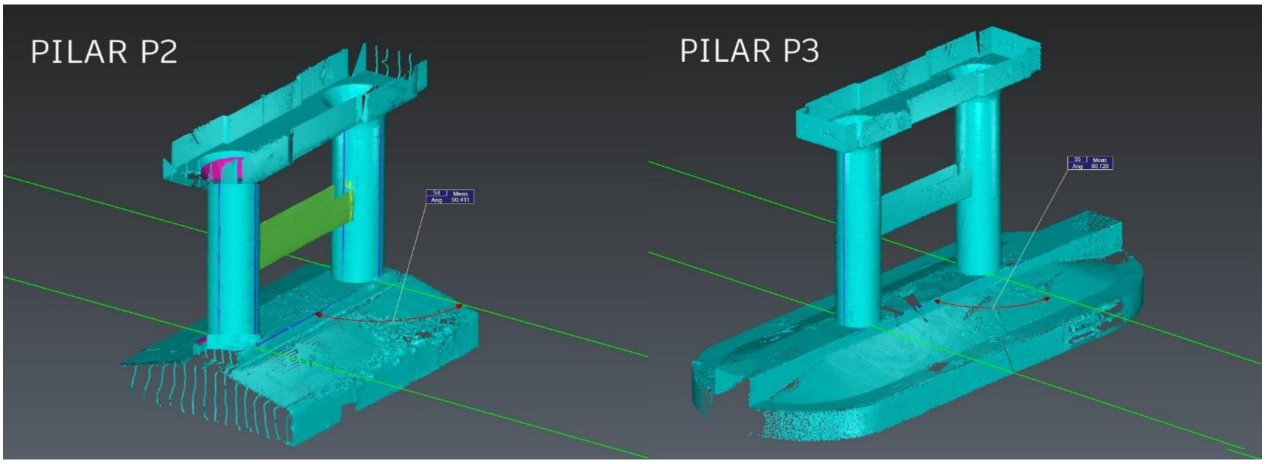

Figure 8. Geometric measurement results of (a) Pilecap 2 (b) Pilecap 3

Minor angular inclination was observed in the pilecap measurements. Specifically, pilecap P3 showed an angular deviation of 0.128° between the pilecap and the pillar longitudinal axis. This deviation remains consistent with previous measurements, as shown in Figure 9.

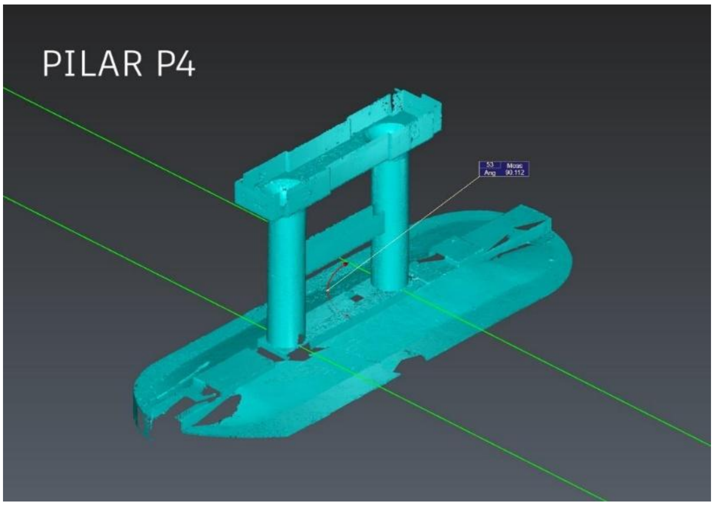

Figure 9. Pilecap 3D scanning result

Repeated measurements of the reference angle for Pier 3 at various times revealed slight fluctuations. In March 2022, the observed angle was 89.904°, indicating a minor tilt of 0.096° from the optimal 90°. By December 2022, the angle slightly decreased to 89.903°, showing a 0.097° tilt. However, by March 2025, the observed angle increased to 90.128°, exceeding the 90° mark, as shown in Figure 9. This gradual change suggests a slow shift in the structural alignment of Pier 3, likely due to material deformation, environmental effects, or structural modifications. Continuous monitoring is necessary to assess any potential stability concerns and ensure the long-term safety of the bridge. The findings underscore the importance of regular geometric assessments for bridge maintenance. The increasing angular deviation calls for further research and possible corrective actions to prevent excessive tilting or structural instability. Ongoing monitoring and evaluation will help determine whether these changes compromise the structural integrity of the Mahakam I Bridge [1] [2] [10 [18] [25].

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Table 4. Comparison of geometric measurement results for bridge pilecaps

No.	Description	Angle obtained	Angle difference	Status
1	Pillar 3 Reference			
2	Year of Data Collection			
	Mar-22	89.904	0.096	Less than 90°
	Dec-22	89.903	0.097	Less than 90°
	Mar-25	90.128	0.128	More than 90°

The results of the geometric measurements of the Mahakam I Bridge pilecaps, as shown in Table 4, indicate slight but significant variations in the angular inclination over time. Specifically, the angle at Pillar 3 gradually shifted from 89.904° in March 2022 to 90.128° in March 2025, with a cumulative increase of 0.225°. These subtle changes, while within an acceptable range, suggest a slow but consistent structural movement, likely due to natural material deformation, environmental factors, or long-term stress accumulation. The recorded discrepancies between the measurements taken in December 2022 (89.903°) and March 2025 (90.128°) provide further insight into the behavior of the pilecap structure. In particular, the 0.128° increase observed by March 2025, which brings the angle slightly above 90°, may indicate the beginning of structural realignment or even deformation at the pilecap level. While this shift remains within permissible limits, continuous monitoring and periodic measurements are critical to understanding whether this progression may lead to any potential structural instability in the future. As highlighted in Figure 11, this change could be a result of ongoing environmental influences, such as temperature fluctuations or soil movement, that affect the bridge's foundation. The observed deviation emphasizes the importance of ongoing structural monitoring to detect any incremental changes that could signal the need for maintenance or remedial action. It is crucial to assess whether these angular shifts are within the designed tolerance for the bridge's longevity, and additional analysis might be required to determine if the observed shifts endanger the structural integrity of the Mahakam I Bridge in the long term. Regular and detailed geometric evaluations of pilecap structures play an essential role in bridge maintenance strategies. These findings underscore the significance of longitudinal studies in assessing potential risks associated with slight structural deformations and ensuring that the bridge remains safe for public use. Given the accumulated data over several years, the findings will contribute to proactive maintenance and early intervention strategies if further structural shifts are detected [1] [4] [7] [14] [22].

4. Conclusion

The geometric monitoring study of the Mahakam I Bridge yields several significant findings. Geodetic GPS was employed to assess the camber of the bridge truss at specific locations above the joints of spans B3, B4, and B5. The results indicate that, in span B3, the highest elevation was 70.25 meters, while the lowest elevation was 68.97 meters for both the upstream and downstream sides. In span B4, the lowest elevation recorded was 70.18 meters, and the highest was 70.35 meters. Similarly, span B5 exhibited a maximum elevation of 70.07 meters and a minimum elevation of 68.74 meters. These variations in camber elevations suggest potential structural deformations, which warrant further investigation. The lateral drift calculations show that the drift at pier P3 was 0.00% in the upstream transverse direction and -0.04% in the downstream transverse direction. For pier P4, the upstream transverse drift was 0.29%, while the downstream drift was 0.03%. In contrast, the lateral drift at pier P2 was -0.05% in the upstream transverse direction and 0.08% in the

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downstream transverse direction. These slight lateral displacements may necessitate structural evaluation to assess their impact on the overall stability of the bridge. Inclination angles at various piers were measured geometrically using a Terrestrial Laser Scanner and Geodetic GPS. The inclination angle of pilecap P2 was found to be 90.411°, that of pilecap P3 was 90.128°, and pilecap P4 exhibited an angle of 90.112°. These values represent minor deviations from the ideal 90° alignment, which may be indicative of settlement or structural alterations over time. To evaluate the long-term implications of these angular deviations on the bridge's overall integrity, additional research and ongoing monitoring are recommended.

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