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Field Static Loading Test on 40.8 m Span PCU Girder Bridge

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ABSTRACT

Field load testing using static loading is widely applied as a non-destructive testing (NDT) method for bridge assessment due to its practicality and ability to provide immediate, on-site results. This approach is suitable for both new and old bridges, requiring strength evaluation to understand the behavior and fundamental characteristics of the bridge. In this paper, 40.8 span PCU Girder Bridge was tested with a static loading test to obtain key performance and response indicators, such as the maximum deflection of the bridge under static load. The research findings showed that the bridge's maximum deflection was -13.8 mm from the field load test, indicating the bridge structure is below the design limit of -35.7 mm, confirming its capacity to support a 192-ton load. The experimental results indicate that the bridge remains within the elastic range when subjected to the planned test loads. This suggests that the bridge has sufficient load-bearing capacity. Additionally, these findings reflect the current condition of the structure, which can serve as a foundation for ongoing structural health monitoring and future maintenance of the bridge.

Keywords: static load test; prestressed bridge; PCU Girder; deflection; on-field test.

INTRODUCTION

Prestressing technology, which involves applying prestress to concrete before external loads are applied, has enabled the construction of stronger, lighter, and more durable structures compared to non-prestressed concrete construction methods. Prestressed bridges are built by inserting steel tendons into fresh concrete and then tensing them to generate significant internal compressive forces once the concrete hardens. This process results in concrete elements with a higher capacity to resist tensile loads, thereby reducing the risk of cracking and deformation [3]. However, the strength of a bridge cannot be fully predicted solely by relying on visible signs of potential damage, such as creep, carbonation, cracks, non-structural elements, surface layer conditions, variations in boundary conditions, and discrepancies between as-built specifications and design specifications. To address these uncertainties, field loading tests offer a reliable solution for directly assessing the bridge's actual performance [10]. The static load tests serve as a crucial instrument for the acceptance and quality evaluation of new bridges [15]. The outcomes of the load tests demonstrate their impact on bridge design or construction, establishing a scientific foundation for acceptance upon completion and operational use [15]. In this paper, static load is deployed to obtain the maximum deflection of the bridge by 70%-80% live load condition according to [14].

Based on the statistical data provided by the Ministry of Public Works and Public Housing [9], bridge construction and revitalization program is being continued. As of 2023, there are 19,377 national bridges with a total length of 562,213.79 m. East Java Province has the highest number of bridges, totaling 1,037 units with a combined length of 36,417.62 meters. Within this context, a critical research focus is on developing safety assessment methods for existing bridges with static loading test, specifically addressing both serviceability and ultimate loading conditions. This study seeks to meet these needs through on-site approach, integrating design code requirements and field-test outcomes analysis to ensure effective quality control and load-bearing capacity assessment for the 40.8 m PCU Girder Bridge. Based on the [1], bridge evaluation standards outline two main approaches for load rating: analytical calculations and field testing. Analytical ratings rely on simplified assumptions, which may not accurately capture a bridge's response based on its current condition. In contrast, field testing provides a more realistic assessment of a bridge's live-load capacity by reflecting its actual in-service, as-built performance. Field testing allows for the verification of design and analytical assumptions, such as lateral load distribution, dynamic load allowance (impact factor), influence line, composite action, and unintended support restraints. Although field testing can be limited by factors like cost, time, test truck availability, traffic interruptions, safety concerns, access difficulties, and sensor installation challenges, it remains the most precise method. It provides some advantages, such as a deeper understanding of the behavior of bridges with innovative designs and modern construction methods, (2) an evaluation of the performance of older or deteriorated bridges, and (3) an assessment of a bridge's response to oversized or atypical vehicles. Some researchers have conducted static load tests on prestressed bridges, but the information regarding studies focused specifically on PCU-shaped girders is limited. This gap highlights the value of research on this topic, aiming to contribute meaningful insights into this specific bridge girder type.

[4], developed a comprehensive static load on a 32 m span highway flyover bridge in Singapore, which resulting deflection in four locations (P1 – P4) measured with a prism installed at the bottom of the girder and tracked with a laser tracker (FARO vantage laser tracker). [5] conducted a static loading test on the 45.2 m span PCU girder Zappulla viaduct bridge in Italy to assess whether the viaduct displayed any unexpected deflection or signs of cracking and damage under the maximum serviceability loads specified by the regulations, following 9.2.2 of NTC2018. It was verified that the residual deformations, after the removal of maximum serviceability loads, remained within 15% of the maximum deflections observed during the load tests. A strength evaluation with bridge load testing was also conducted by [7], that load testing provides accurate, real-world data on bridge performance, often revealing conservative assumptions in design models.

The findings suggest that in-field testing can prevent unnecessary repairs or replacements by confirming the adequacy of a bridge's load-bearing capacity. This approach supports safer and more cost-effective bridge maintenance and asset management practices. Field load testing remains the most crucial method for comprehending the behavior and fundamental characteristics of bridges for various applications. Despite advancements in modern structural analysis through computational tools, there are many instances where field load testing cannot be entirely circumvented. This necessity arises from uncertainties in material properties and structural modeling of numerical prototypes, as well as concerns regarding serviceability limit states. Analytical bridge assessments fundamentally rely on precise data about material characteristics, support conditions, the contribution of non-structural components, deterioration effects, and various other factors. To simplify matters, conservative assumptions are frequently employed to address these uncertainties in numerical analyses. Consequently, it is often found that during field load testing, the actual load-carrying capacity of bridges exceeds predictions made by analytical methods [13].

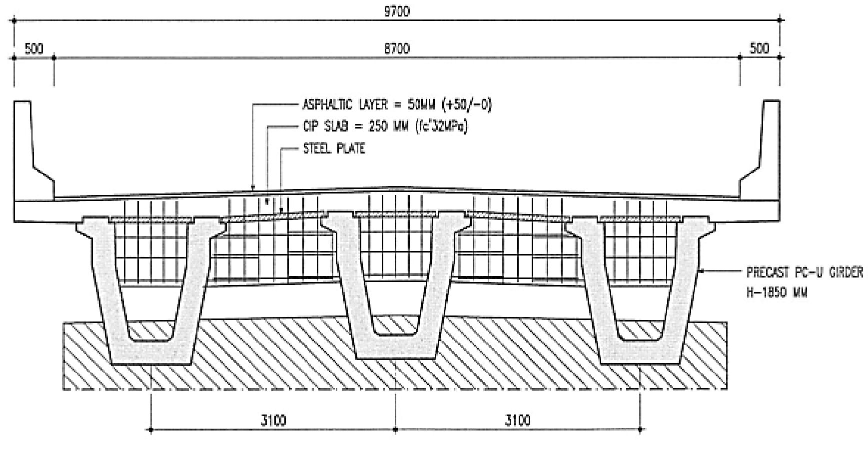

Figure 1. Section profile of 40.8 PCU bridge *Source: DED of 40.8 m PCU Bridge (2023)*

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This condition explained by [6]; the performance and capacity of an engineering system are not solely based on good design but also on the execution during the construction phase. For example, the final strain and stress results of a steel-concrete composite, suspension, or cable-stayed bridge in the unloaded condition at the end of construction highly depend on the methods and execution of the construction on-site. This indicates the field test result had a higher chance of surpassing the finite element threshold result. In this paper static load testing is conducted in PCU-Girder bridge, the profile section can be seen in Figure 1. The bridge was designed as a simple span and linked from each pier girder with 2 exterior and 1 interior U-Girder. The static load test involves applying loads to the bridge, typically placing the load at the mid-span in a stationary (static) condition to observe the bridge's response under these circumstances [11]. The deflection limit for bridge spans is regulated by [2], which states that the maximum allowable deflection for a concrete bridge designed for vehicle and general crossing is given by Equation 1. δ is the deflection limit of the bridge. l is the bridge span for decks with no pedestrian traffic.

$$\delta = l/800 \quad (1)$$

This addresses the bridge's performance under normal usage conditions, focusing on factors such as deflection and cracking.

RESEARCH METHODS

The main objective of this static loading test is to measure the bridge's deformation (deflection). This static test involves applying a fixed load to the bridge and measuring its response to ensure that the bridge can withstand the load without experiencing excessive deformation. Deflection measurements are taken to determine how much the bridge bends under a given load. The static loading test is illustrated in Figure 2.

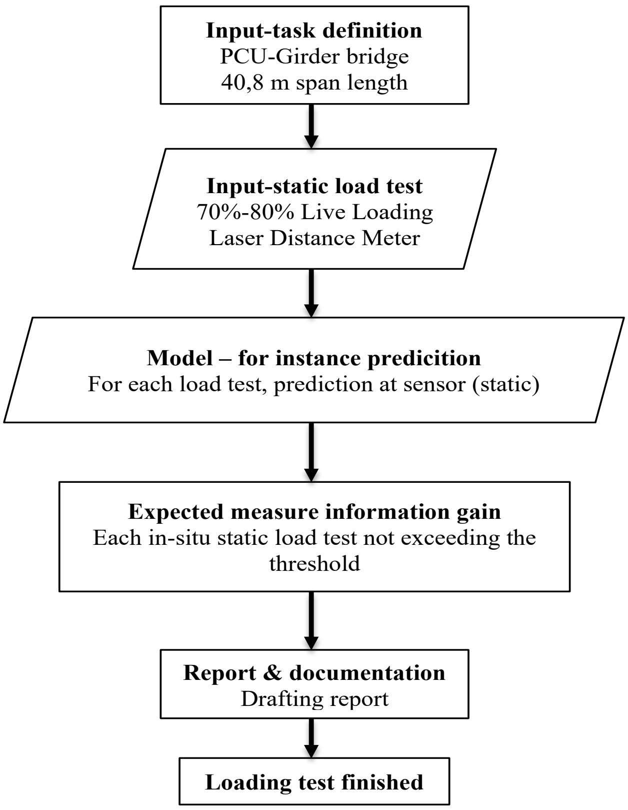

Figure 2. Flow chart of field static load test analysis

The references used in the static testing are the Ministry of Public Works and Public Housing [12] and [8], The loads used in this test is static loads. The truck load requirements and the bridge information for testing the 40,8 m PCU-Girder bridge can be seen in Table 1.

Table 1. Detailed Load Specification

Span length (L)	40m
Span Width (B)	8m
Calculated weight (252ton x 70%)	176 ton →8 truck 24 ton (76%)

Bridge Information

The 40.8 m PCU bridge presented in this paper was recently finished and is being tested before being opened to the public. The bridge was designed as a simple span and linked from each pier girder with 2 exterior and 1 interior U-Girder. The overall length of the bridge is 40.8 m, and the width is 9.7 m (Figure 3). The superstructure is made up of f_c' 70 MPa for the beam, f_c'28 MPa for the diaphragm, and f_c' 32 MPa for the slab. The stress jacking force is 75 UTS in 1860 MPa of tensile strength with low relaxation 12.7 mm strand.

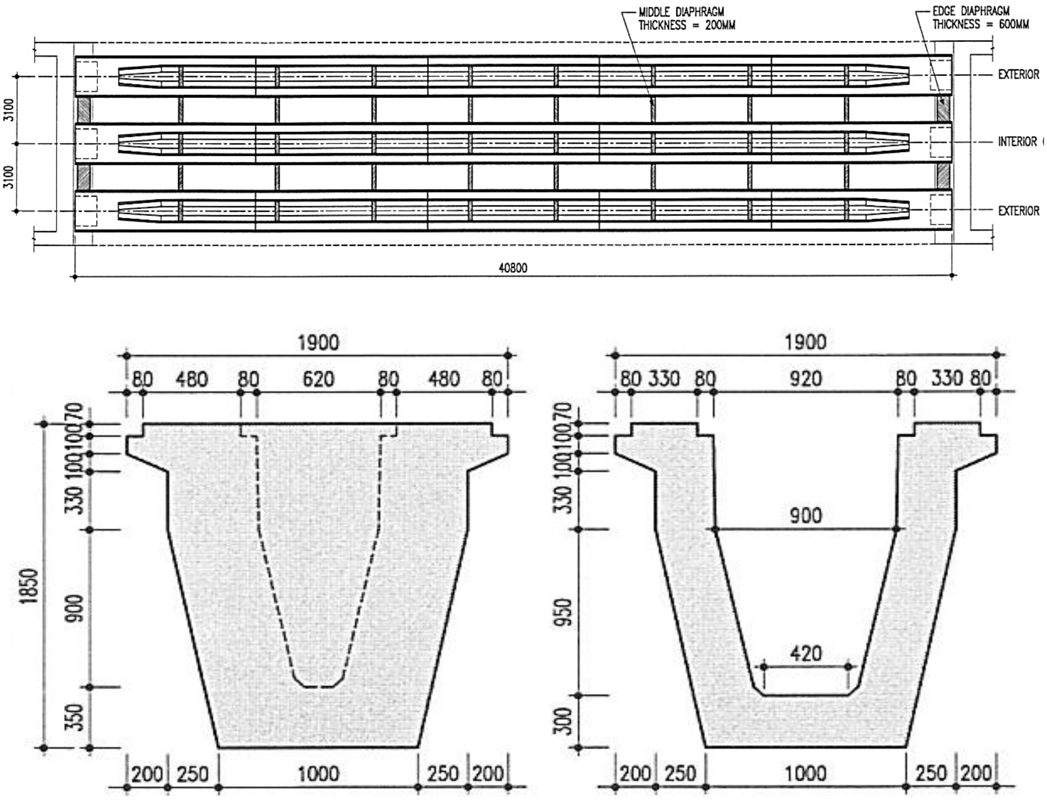

Figure 3. Details of PCU bridge dimension *Source: DED of 40.8 m PCU bridge (2023)*

For the static testing phase, we employed a specific type of dump truck, known as a tronton truck. This truck was selected due to its suitable weight and design characteristics. Each truck weighs 24 tons and has a cargo volume capacity of 27 m³, making it an ideal choice for simulating realistic loading conditions on the bridge. The dimensions of the dump truck are significant for the testing process. Each truck has a length of 8.985 meters, which is crucial for ensuring proper positioning during the load application phase. As illustrated in the image below, the trucks are arranged strategically across the bridge span to maximize the effectiveness of the load testing. In total, the testing setup involves eight trucks, with a cumulative weight of 176 tons. This weight is intentionally greater than the initially calculated load requirement of 70% capacity.

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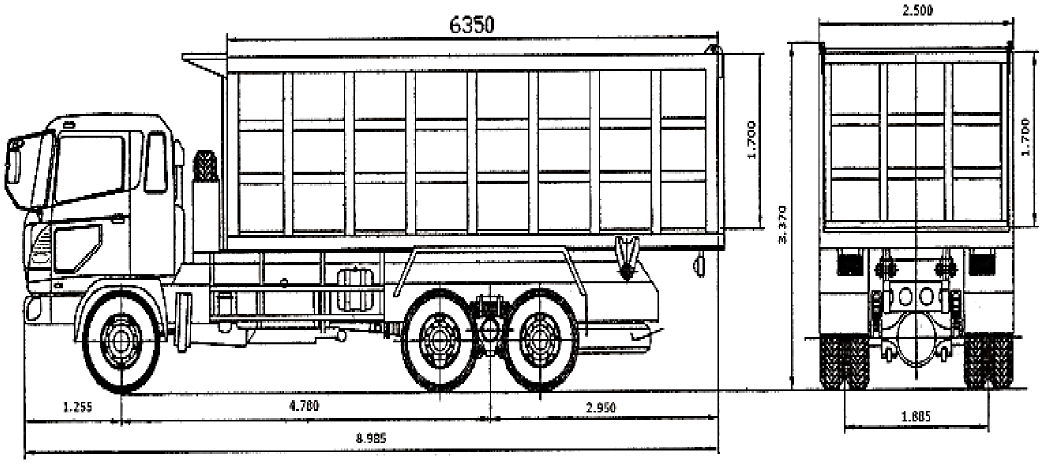

Figure 4. Dimension of loading truck

By exceeding this planned load, the testing conditions become more challenging, allowing for a thorough evaluation of the bridge's structural performance under extreme loading scenarios. This rigorous testing approach not only helps in identifying potential weaknesses in the bridge design but also provides valuable insights into its overall behavior under static loading conditions. The results obtained from this testing will be instrumental in assessing the bridge's safety, durability, and long-term performance.

Specific Truck Weight and Position

The trucks used for static testing were weighed and numbered before being positioned for loading. Heavier trucks are generally placed in the center to provide maximum load on the bridge structure. The trucks were numbered from 01 to 08. Complete data regarding the trucks used in the static test can be seen in the table below. The weights of the trucks were configured such that the heaviest trucks (01 and 05) were positioned in the center of the span. Overall, the truck loads used in this testing were greater than planned, providing a more challenging testing condition and allowing for a more comprehensive evaluation of the bridge's structural performance.

Table 2. Actual truck weight

Number	Weight (Ton)
01	26,34
02	25,69
03	24,44
04	23,79
05	26,75
06	25,32
07	25,74
08	24,91

Source: Field load testing on PCU Bridge (2023)

Figure 5. Truck layout

Table 2 describe the real weight of the truck on-site loading and the layout of the loading test is shown in Figure 6 which illustrate the various stages of the testing process. The experimental static load test positive moment test focuses on determining the maximum moment experienced at the center of the bridge span (Figure 5). This is achieved by symmetrically placing the trucks along the span of the bridge to ensure even distribution of the load. By positioning the trucks in this manner, we can accurately assess how the structure reacts under the influence of the heaviest loads concentrated at the midpoint.

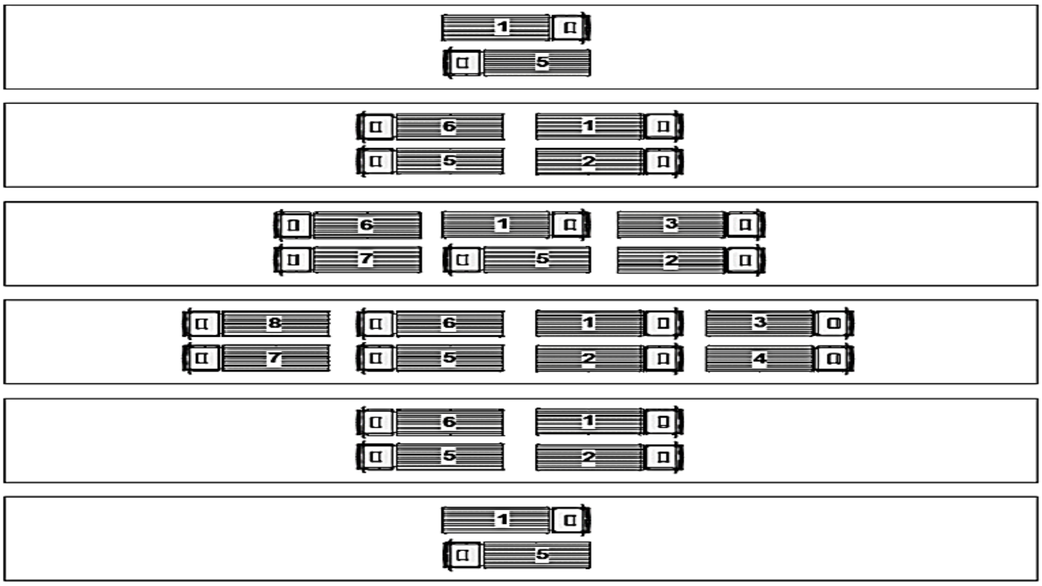

Figure 6. Layout of static loading test

These visuals provide a clear representation of the setup, including the arrangement of the trucks, the measurements taken, and the specific locations of load application.

Sensor position on bridge span

In this loading test, Laser Distance Meters (LDMs) are used to measure bridge deflection and are positioned at the beginning, end, quarter-span (1/4), mid-span (1/2), and three-quarter span (3/4) of the bridge. Mounted beneath the bridge and directed at the underside of the girders, these sensors capture deflection data at key locations, providing a detailed view of how the bridge responds to loading. This setup allows for precise monitoring of vertical movement, aiding in the structural performance assessment, as shown in Figure 8 below.

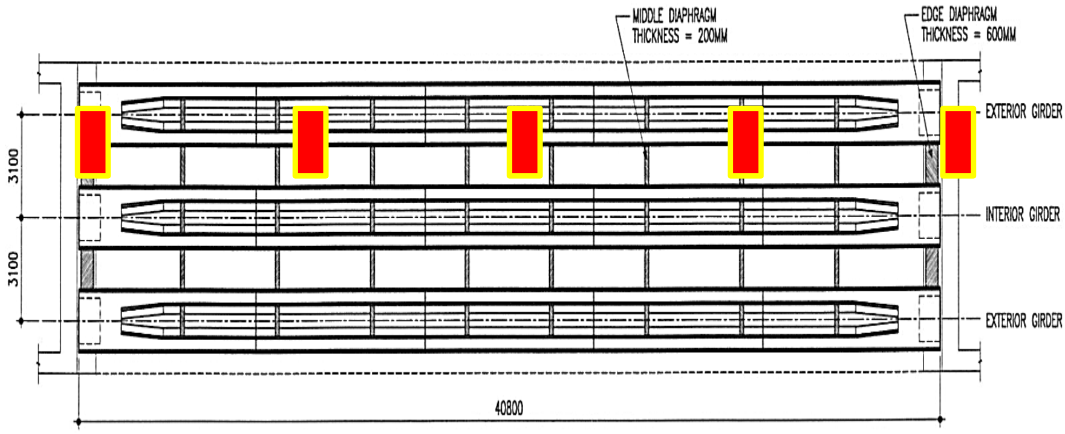

Figure 8. On-site LDM position Source: DED of 40.8 m PCU bridge (2023)

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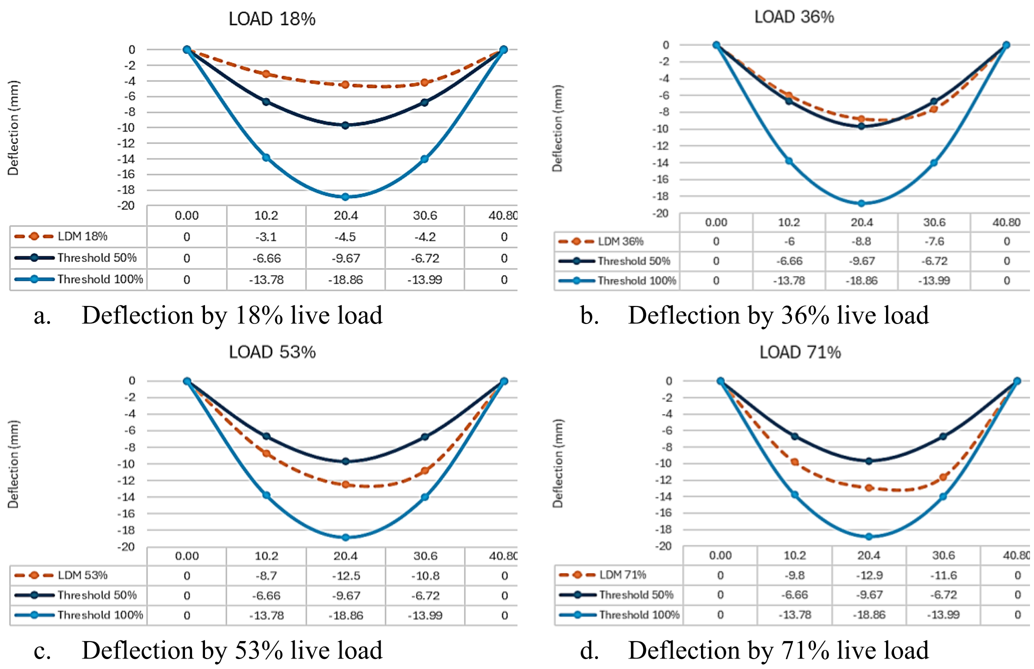
RESULT AND DISCUSSION

The result of static loading test is being showed in the table below, it is obtained from the LDM sensor vertical displacement. The table provides data from a static load test conducted on a bridge, detailing how the structure responds to incremental loading. The test involved multiple stages, with each step adding trucks to simulate different percentages of the design live load (LL). Deflections were measured at various points along the bridge span, including specific locations at quarter-length intervals (1/4 L, 2/4 L, 3/4 L) and at two reference points, P5B and P6B. The result will be compared to deflection result from [5] which the bridge dimension is simillar to the 40.8 m PCU girder bridge. The deflection result can be seen in Table 3 below.

Table 3. On-site static load test results

Step	Qty	W (Ton)	%LL Design	Deflection δ (mm)					Allowed δ L/800 (mm)	δ from 70% LL Design (mm)
				P5B	1/4 L	2/4 L	3/4 L	P6B		
40,8 m PCU Bridge										
1	0	0	0%	0.00	0.00	0.00	0.00	0.00	-51.00	-35.70
2	2	48	18%	0.00	-3.10	-4.50	-4.20	0.00	-51.00	-35.70
3	4	96	36%	0.00	-6.00	-8.80	-7.60	0.00	-51.00	-35.70
4	6	144	53%	0.00	-8.70	-12.50	-10.80	0.00	-51.00	-35.70
5	8	192	71%	0.00	-9.80	-12.90	-11.60	0.00	-51.00	-35.70
6	4	96	36%	0.00	-6.80	-9.80	-8.50	0.00	-51.00	-35.70
7	2	48	18%	0.00	-4.10	-5.20	-4.90	0.00	-51.00	-35.70
8	0	0	0%	0.00	0.30	0.00	0.20	0.00	-51.00	-35.70
45,2 m PCU Bridge [5]										
1	0	0	0%	0.00	0.00	0.00	0.00	0.00	-56.50	-39.55
2	2	98	50%	0.00	-6.66	-9.67	-6.72	0.00	-56.50	-39.55
3	4	196	100%	0.00	-13.78	-18.86	-13.99	0.00	-56.50	-39.55



a. Deflection by 18% live load
b. Deflection by 36% live load
c. Deflection by 53% live load
d. Deflection by 71% live load

Figure 9. Various bridge deflection by experimental static load test

Table 3 presents on-site static load test results for the 40.8 m PCU bridge, which is the primary focus of the research, with the 45.2 m PCU bridge [5] included for comparison and validation purposes and Figure 9 visualize the deflection result. An incremental loads were applied from 0% to 71% of the design live load (LL), and deflections were recorded at various points along the span. The recorded deflections are compared against two limits: the maximum allowable deflection (L/800) of -51.00 mm and a stricter limit for 70% of the LL design, set at -35.70 mm. The results indicate that the 40.8 m PCU bridge performs well under loading, with maximum deflections reaching -12.90 mm at full load, which is well within the allowable limit. The 45.2 m PCU bridge [5], used for comparison, also demonstrated similar performance, with maximum deflections staying within the permissible range, supporting the validity of the 40.8 m PCU bridge's results and indicating a consistent testing methodology.

CONCLUSION

The static load test conducted on the 40.8 m PCU Girder Bridge has demonstrated that the bridge performs satisfactorily under the applied loads, indicating a robust load-bearing capacity. The results, obtained from both experimental field testing and finite element modeling, reveal that the bridge’s maximum deflection values-ranging from -13.8 mm in field testing to -16.88 mm in Midas Civil analysis-remain significantly below the allowable deflection threshold of -35.7 mm. This confirms the bridge’s capability to safely support loads up to 192 tons, even under stringent test conditions, thereby validating its design against anticipated operational demands. Additionally, the successful calibration of the finite element model to match the actual bridge performance provides a reliable baseline for ongoing structural health monitoring. This model serves as a predictive tool for future evaluations, offering insights into potential behavior changes due to environmental or load variations over time. The alignment of numerical predictions with real-world performance also underscores the finite element model's validity in capturing critical structural responses, which can assist in proactive maintenance planning. The bridge's elastic behavior under static loads further supports its resilience, with observed deflections staying well within the elastic limit. This outcome not only reaffirms the design specifications but also demonstrates the effectiveness of prestressing in mitigating excessive deformations. The test outcomes, when compared to international standards and deflection limits (such as the AASHTO guidelines), highlight that the bridge exceeds basic performance expectations, ensuring both its safety and longevity. In conclusion, the 40.8 m PCU Girder Bridge meets structural performance standards for deflection and strain under static loads, verifying its integrity for public use. This research contributes to the broader understanding of PCU girder bridge performance, supporting the application of static load testing and finite element analysis in the evaluation and maintenance of similar bridge structures across Indonesia. The insights gained from this study are instrumental for future bridge safety assessments and underscore the necessity of field load tests to validate numerical models in accurately representing real-life bridge behavior.

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