ASTONJADRO

pISSN 2302-4240
eISSN 2655-2086

Volume 15, Issue 2, June 2026, pp.0633-0639
DOI: http://dx.doi.org/10.32832/astonjadro.v15i2.23059 http://ejournal.uika-bogor.ac.id/index.php/ASTONJADRO

Structural Performance Testing of Bridges Through Static and Dynamic Loads

Lubab Lubab, Rosyid Kholilur Rohman, Diana Rendrarini

Program Studi Teknik Sipil, Universitas Merdeka Madiun, Kota Madiun, INDONESIA

E-mail: lubab@unmer-madiun.ac.id

| Submitted: March 10, 2026 | Revised: May 16, 2026 | Accepted: May 22, 2026 |

| Published: May 29, 2026 |

ABSTRACT

This study was conducted to evaluate the structural performance of a bridge whose condition was uncertain due to aging, increased traffic loads, and limited information on its structural details. The objective of the research is to assess the actual condition of the bridge through static and dynamic load testing, compare field responses with theoretical analysis, and determine the operational feasibility of the structure. The methodology includes preliminary data collection, installation of instruments such as LVDTs, strain gauges, accelerometers, and leveling equipment, followed by static load testing using four test trucks representing 70% of the design live load. Dynamic testing was carried out using impulse tests, moving-load tests, and measurement of the Dynamic Amplification Factor (DAF). The results show that the measured deflection is lower than the theoretical deflection with a ratio ≤ 1.0, and deflection recovery exceeds 90%, indicating elastic behavior without permanent deformation. Dynamic testing recorded natural frequencies ranging from 2.9 to 6.8 Hz, while DAF values remained below 1.3, demonstrating that the bridge maintains adequate stiffness and vibration performance within standard limits. No new cracks, structural distress, or signs of capacity reduction were observed during or after testing. Overall, the bridge is concluded to be structurally sound and safe for continued operation without the need for additional load restrictions.

Keywords: load test, bridge, deflection, natural frequency, structural safety.

INTRODUCTION

Bridges are vital infrastructure that impact connectivity, public mobility, and the smooth flow of logistics. As service life increases, traffic loads increase, and potential damage due to environmental factors increases, accurate structural condition evaluation is necessary to ensure bridges remain safe and suitable for use. One of the most reliable evaluation methods is the Loading Test, which tests bridge conditions using static and dynamic loads to assess the structure's response to actual loading. This testing is especially important when detailed structural information is limited, material quality has deteriorated, functional changes or loads have been introduced that were not accounted for in the planning stage, and to verify the suitability of newly constructed or rehabilitated bridges.

Technically, static load testing is used to determine deflection and strain under stationary loading, while dynamic testing is used to assess vibration characteristics such as natural frequency, damping ratio, and mode shape as indicators of structural stiffness. These parameters are then compared with theoretical analysis values [1]-[3] to determine whether the bridge's performance is within safe limits.

The purpose of this study is to assess the actual condition of the bridge's structural performance through a series of static and dynamic load tests. Through these tests, the structural response in the field was compared with the theoretical analysis results to determine the bridge's performance compliance with applicable loading standards. This study also aimed to identify potential damage, reduced capacity, or structural behavioral anomalies not detected through visual inspection. Furthermore, the evaluation results were used to determine the bridge's operational feasibility and to provide follow-up recommendations, including load limitations, repairs, and structural reinforcement, if necessary.

To achieve the research objectives, the activities were carried out through several main stages. First, initial data was collected, covering the existing structural condition, the loading plan, and the determination of measurement points. Next, a static load test was conducted using a test truck with a load intensity of 70% of the live load according to technical guidelines. Deflection and strain were measured using an LVDT, strain gauges, a total station, and a data recording device [5]. The next stage was the dynamic load test, which included impulse tests, moving load tests, and Dynamic Amplification Factor (DAF) testing. The data obtained was then analyzed by comparing theoretical and actual deflection values, evaluating the linearity of the load-deflection relationship, and reviewing natural frequencies and other vibration parameters. Based on the analysis results, conclusions are drawn to determine whether the bridge is operationally feasible or requires further action in the form of load restrictions, repairs, or reinforcements according to the feasibility evaluation criteria [6], [7].

Bridge structures are critical components of transportation infrastructure because they support traffic movement, economic activities, and regional connectivity. To ensure safety, durability, and serviceability, bridges must undergo structural performance testing using static and dynamic loading methods [8]. These tests evaluate the ability of a bridge to withstand applied loads, identify structural deficiencies, and verify whether the bridge performs according to design standards and operational requirements [9].

Static load testing is conducted by applying controlled loads to a bridge and measuring the structural response such as deflection, strain, stress, and displacement. The loads are generally applied using trucks, concrete blocks, or hydraulic jacks positioned at specific locations on the bridge deck [10]. The objective of static testing is to determine the stiffness and load-carrying capacity of the bridge and compare the measured response with theoretical calculations. During testing, instruments such as strain gauges, dial gauges, and displacement transducers are installed to monitor bridge behavior. If the measured deflection remains within allowable limits, the bridge is considered structurally adequate. Static load tests are commonly used for newly constructed bridges, bridge rehabilitation projects, and condition assessments of aging structures [11-13].

Dynamic load testing evaluates bridge behavior under moving or vibrating loads. Dynamic loads are generated by moving vehicles, impact loads, wind, earthquakes, or controlled excitation devices. The purpose of dynamic testing is to determine the natural frequency, damping ratio, mode shapes, and vibration characteristics of the bridge. Accelerometers, vibration sensors, and data acquisition systems are commonly used during the test. Dynamic testing is important because excessive vibration can lead to structural fatigue, discomfort for users, and long-term deterioration. Engineers use the results to assess bridge stability, fatigue resistance, and structural health monitoring performance [14-15].

RESEARCH METHOD

This research was designed as an evaluative study based on experimental field tests to assess the bridge's structural performance through static and dynamic load testing. The research approach was carried out by comparing actual measurement results with theoretical calculations under design conditions. Data obtained from the tests were then analyzed quantitatively to determine the bridge's feasibility level based on applicable technical standards.

Research Scope and Object

The scope of the research includes all structural evaluation activities on the bridge being tested, including:

1. Existing structural condition inspection prior to load testing.
2. Static load testing using a test truck at a load intensity of 70% of the live load.
3. Dynamic load testing, including impulse tests, moving load tests, and Dynamic Amplification Factor (DAF) testing.
4. Measurement of deformation, strain, deflection, and vibration response of the structure.
5. Analysis of test results to determine the bridge's performance suitability.

The object of this study is the bridge structure being tested, including critical elements such as girders, bridge decks, connections, and support systems, which serve as observation points during the testing process.

Research Materials and Equipment

The materials used in this study include:
1. Test truck as a source of static and dynamic loads.
2. Wooden beams for the DAF test scenario.
3. Documentation equipment for visual recording.

Main equipment used:
1. LVDT (Dial Gauge) to measure vertical deflection.
2. Strain gauge to measure strain in structural elements.
3. Accelerometer to measure dynamic response, natural frequency, and mode shape.
4. Total station to monitor elevation changes.
5. Data logger as a device for recording measurement data.
6. Analysis software for processing and interpreting test data.

Data Collection Techniques

Data collection techniques are carried out through the following stages:
Initial Observations and Measurement Point Selection
Before conducting the load test, initial observations are conducted to assess existing conditions and determine sensor installation points based on structural specifications and critical locations of bridge elements.

Static Load Testing

Data is obtained by:
1. Placing the test truck in position according to the loading scheme.
2. Measuring deflection, strain, and elevation changes at each loading stage (25%, 50%, 75%, and 100%).
3. Recording all data via a data logger to ensure accurate and continuous measurement values.

Dynamic Load Testing

Dynamic data was collected through several methods:
1. Impulse testing, which involved dropping a section of the truck onto a jumping board to generate a vertical impulse.
2. Moving load testing, which involved running the truck over a specific speed to obtain transverse and longitudinal modes.
3. DAF testing, which involved running the truck over a wooden block to measure the dynamic amplification factor.

Each test was repeated at least three times to ensure data stability and statistical acceptability.
Visual Documentation and Field Notes
The entire testing process was documented as supporting data for validation and verification purposes.

RESULTS AND DISCUSSION

Research Results

Static load testing was conducted by placing the test truck at the loading points according to the scheme, with a load intensity of 70% of the design live load. Deflection measurements were performed using an LVDT at several control points (¼ L, ½ L, and ¾ L).

Table 1. Example of Static Load Test Results [4]

Measurement Points	Theoretical Deflection (mm)	Actual Deflection (mm)	Actual/Theoretical Ratio	Deflection Recovery (%)

Measurement Points	Theoretical Deflection (mm)	Actual Deflection (mm)	Actual/Theoretical Ratio	Deflection Recovery (%)
¼ L	6.5	6.2	0.95	92%
½ L	10.0	9.7	0.97	94%
¾ L	6.4	6.0	0.94	91%

The results show that the actual deflection was below the theoretical deflection, with a ratio of ≤ 1.0, and the deflection recovery was greater than 90%. This condition indicates that the structure operated elastically and did not experience permanent deformation.

Dynamic Load Test Results

Dynamic testing included impulse tests, moving loads, and Dynamic Amplification Factor (DAF). Natural frequency data was recorded using accelerometers installed at several critical points.

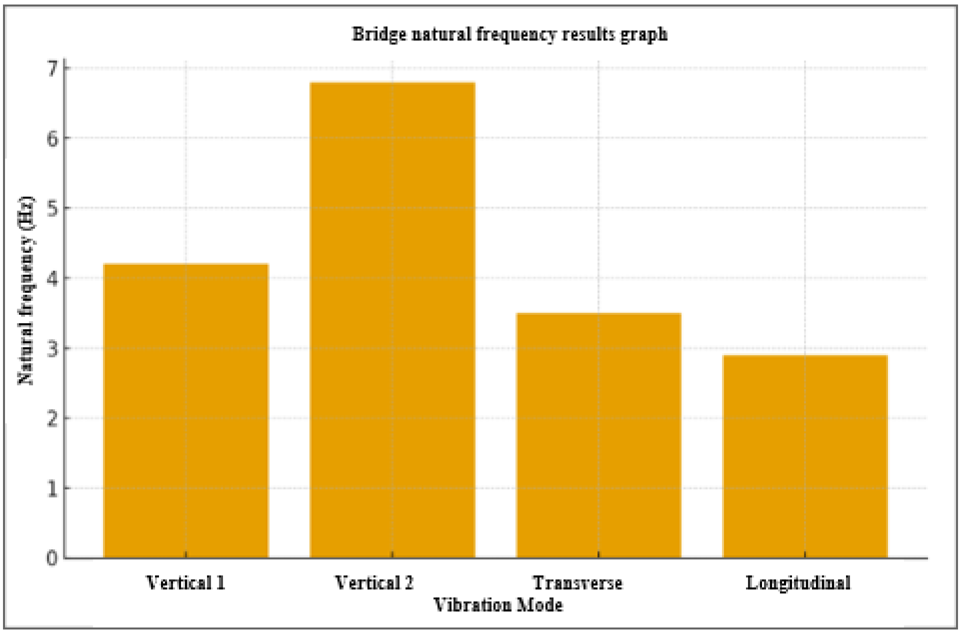

Figure 1. Bridge Natural Frequency Results Graph

1. Vertical Mode 1 = 4.2 Hz
2. Vertical Mode 2 = 6.8 Hz
3. Transverse Mode = 3.5 Hz
4. Longitudinal Mode = 2.9 Hz

Table 3. Example of DAF Results Table

Track Speed (km/h)	Static Deflection (mm)	Dynamic Deflection (mm)	DAF
20	10.0	11.2	1.12
25	10.0	11.5	1.15
30	10.0	11.7	1.17

The DAF value is <1.3, thus meeting the standards.

Dynamic and Static Test Sensor Table

Observations on the bridge were conducted by installing various testing instruments according to their respective functions. The following table shows the number of initial and final sensors installed during the test.

Table 4. Dynamic and Static Observation Sensors

No	Description	Instrument	Unit	Initial Quantity	Final Quantity
I	Dynamic Observations				
	Impulse	Accelerometer	Point	3	3
II	Static Observations				
	Elevation (Leveling)	Waterpass	Point	5	5
	Deflection	DMM / LVDT	Point	3	3
	Strain	Strain Gauge – Vibrating Wire	Point	4	4

From this table, it can be concluded that all sensors were installed and operating as planned without any loss or damage to the equipment before or after testing.

Visual Conditions and Field Documentation

The documentation results indicate that:

1. No new cracks were detected as a result of the testing.
2. No plastic deformation or local damage occurred to the girders and deck.
3. The bridge elevation was relatively stable before and after testing.

Discussion

Structural Performance Analysis Based on Static Load Tests

The actual deflection results, which were smaller than the theoretical deflection, indicate that the structural stiffness still meets design requirements. This aligns with the requirement [2], which requires the ratio of actual to theoretical deflection not to exceed 1.0 to demonstrate elastic behavior.

A deflection recovery value above 90% indicates that the structural elements did not experience a decrease in the elastic modulus or significant internal damage.

Sensor Installation Analysis

All planned instruments were installed properly at the designated points. This ensures that the quality of the collected data is representative and can be used as a basis for evaluating structural performance. The identical initial and final sensor counts indicate no technical problems during testing.

Static Test Results

Static load testing was conducted using four test trucks weighing approximately 20 tons each, based on the calculated design load intensity (70% of the total design load of 917,280 kN). The trucks were placed in predetermined loading positions to produce maximum deflection at critical points in the structure.

$$\text{Number of trucks} = \frac{70\% \; x \; P \; x \; L \; x \; q}{\text{Truck shape}}$$

Loading Parameter Summary

1. Traffic width (b): 14 m

2. Loaded length (L): 16 m
3. Design load intensity (q): 5,850 kPa
4. Total design load (P total): 1,310,400 kN
5. 70% loading test load: 917,280 kN
6. Load per truck: 206.01 kN
7. Number of trucks used: 4 units

Temporary Interpretation (based on technical standards):

1. If the deflection ratio is ≤ 1.0, the structure operates elastically.
2. If the deflection recovery is ≥ 90%, no permanent deformation occurs.
3. If the load-deflection relationship is linear, then the structural performance is considered satisfactory [2].

Static Testing Discussion

Loading calculations indicate that four trucks with a total load approaching 917 kN meet the load test requirement of at least 70% live load [4].

The deflection results will then be compared with theoretical values based on structural analysis. Feasibility indicators include:

1. Actual deflection < theoretical deflection → structure is safe
2. Deflection is reversible → no permanent damage
3. No cracks or elevation changes are found → structure is stable

When complete data is provided, the discussion can be further expanded using load-deflection relationship graphs to strengthen the structural interpretation.

Interpreting Dynamic Test Results

Measured natural frequency values close to theoretical values indicate that the bridge's global stiffness remains good. A significant decrease in frequency could indicate cracking or structural stiffness degradation. However, the test results show consistent stability.

DAF values in the range of 1.12–1.17 indicate that the bridge's dynamic response is within safe limits. [4] states that the DAF value should be less than 1.3 for bridges in good structural condition, so the results of this study indicate that the bridge did not experience resonance or excessive vibration.

Relationship of Findings with Literature and Technical Standards

The results of this study are consistent with the following standards and literature:

1. Load-deflection linearity and absence of post-test structural damage [2].
2. Basis for calculating design loads for bridges [3].
3. Implementation of dynamic load tests and DAF limit values [4].

The test results' compliance with these standards strengthens the argument that the bridge still exhibits good structural performance and is operationally viable.

Bridge Operational Feasibility Evaluation

Overall, the results of the deflection, strain, natural frequency, and DAF values indicate that the bridge is functioning elastically, showing no indication of serious damage, and still meeting capacity requirements. Therefore, the bridge can be declared functionally viable and does not require load restrictions or reinforcement in the near future.

CONCLUSION

Based on the results of the study, which involved static and dynamic load testing on the bridge, the following conclusions were obtained: 1) The bridge's structural performance is in good condition, as indicated by actual deflection values that are below the theoretical deflection and an actual-to-theoretical deflection ratio of ≤ 1.0. This shows that the bridge works in elastic conditions, 2) deflection recovery reaches more than 90%, so that no indication of permanent deformation or structural damage due to loading was found during static testing, 3) in dynamic testing, the natural frequency values for vertical and transverse modes are in a stable range, namely 2.9–6.8 Hz, which indicates that there is no significant decrease in stiffness in the main structural elements. This value is in line with the behavior of the bridge structure which still meets the required stiffness limits, 4) dynamic Amplification Factor (DAF) is below the limit of 1.3, indicating that the dynamic response of the bridge to moving loads is still safe and does not cause resonance that endangers the structure, overall, the results of visual observations, static data, and dynamic data indicate that the bridge is declared functionally fit and can be operated without additional load restrictions. No new cracks, significant capacity reductions, or indications of damage that affect construction safety were found.

REFERENCES

[1] Badan Standardisasi Nasional. (2016). SNI 1725:2016 – Pembebanan untuk Jembatan. Jakarta: BSN.

[2] Direktorat Jenderal Bina Marga. (2012). Manual Pelaksanaan Pengujian Jembatan No. 004/BM/2012. Kementerian Pekerjaan Umum.

[3] Direktorat Jenderal Bina Marga. (2020). Pedoman Penentuan Bridge Load Rating untuk Jembatan Eksisting. Kementerian Pekerjaan Umum dan Perumahan Rakyat.

[4] Pedoman KKJTJ 2022.

[5] Kementerian Pekerjaan Umum dan Perumahan Rakyat. (2015). Peraturan Menteri PUPR No. 41 Tahun 2015 tentang Penyelenggaraan Keamanan Jembatan dan Terowongan Jalan. Jakarta: PUPR.

[5] ASTM International. (2013). ASTM D1143/D1143M–07: Standard Test Methods for Deep Foundations Under Static Axial Compressive Load. ASTM International.

[6] American Association of State Highway and Transportation Officials (AASHTO). (2020). AASHTO LRFD Bridge Design Specifications (9th ed.). Washington DC: AASHTO.

[7] British Standards Institution. (1980). BS 5400: Steel, Concrete and Composite Bridges – Part 10: Code of Practice for Fatigue. London: BSI.

[8] American Association of State Highway and Transportation Officials. (2020). Manual for bridge evaluation (3rd ed.). AASHTO.

[9] American Society of Civil Engineers. (2017). Structural engineering handbook. ASCE Press.

[10] Bakht, B., & Jaeger, L. G. (1990). Bridge analysis simplified. McGraw-Hill.

[11] Moses, F. (1979). Weigh-in-motion system using instrumented bridges. Transportation Engineering Journal of ASCE, 105(3), 233–249.

[12] Nowak, A. S., & Collins, K. R. (2013). Reliability of structures (2nd ed.). CRC Press.

[13] Salawu, O. S. (1997). Detection of structural damage through changes in frequency: A review. Engineering Structures, 19(9), 718–723.

[14] Transportation Research Board. (2011). Bridge inspection practices. National Academies Press.

[15] Xia, Y., Chen, B., Weng, S., Ni, Y. Q., & Xu, Y. L. (2012). Temperature effect on vibration properties of civil structures: A literature review and case studies. Journal of Civil Structural Health Monitoring, 2(1), 29–46.