Loading Test and Temperature Effect on Steel Arch Bridge

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Abstract. Before the bridge is operated, it is necessary to do a test to find out whether the bridge has met the applicable requirements and regulations and works properly with the service load. Tests include static and dynamic loading of bridges on the Water Front City bridge, Bangkinang, Riau. Static load test in the form of measurement of deflection and strain of the bridge structure when carried out the load on the bridge in a controlled and measurable manner. The given load is at least equal to the bridge service load according to specifications and service defects that occur do not exceed the specified limits. While the dynamic load test is in the form of recording bridge behavior when receiving dynamic loads. Static loading is carried out by placing several truck vehicles with measured dimensions and loads on each wheel to determine the amount of deflection and stress at \(\frac{1}{4} - \frac{1}{2} - \frac{3}{4}\) spans. Static load test results on the structure of the bridge, the maximum strain that occurs in reinforcing steel and concrete in loading conditions with a load of 2 trucks (50 tons), 4 (100 tons), 6 (150 tons), 8 (200 tons), 10 (250 tons) and 12 trucks (300 tons) respectively 17.62 MPa, 52.82 MPa, 61.95 MPa, 51.08 MPa, 105.49 MPa and 128.48 MPa. In unloading conditions, the maximum strain is 51.31 MPa, 70.38 MPa, 52.47 MPa, 88.71 MPa, 75.20 MPa and 13.21 MPa respectively. The temperature difference of 15\(^\circ\)C in arch element gives camber in the middle of the span of 15 mm for the arc and 13 mm for the girder. The natural frequency of the WFC bridge is 1,127 Hz which occurs in the vertical direction at a span of 100 meters.

1. Introduction

Water Front City (WFC) bridge is located in Kampar District, Riau Province. The WFC Bridge located in Bangkinang City is a three-span 50 m - 100 m - 50 m arc bridge with an arc element and girder extending the box profile and all structural elements made of steel. The load from the longitudinal girder is transferred to the arc using a cylindrical vertical rod. Prior to the opening bridge to public, a vehicle load test is carried out to determine whether the bridge strength has been properly controlled and measured [1]. The given load is at least the same as the bridge service load in accordance with the design, meets the applicable requirements and codes and can function properly. Load testing on the bridge is one method of measuring the bridge structure response both through static and dynamic loading tests. Static load test in the form of measurement of deflection and strain of the bridge structure when the load is applied to the bridge gradually loading and unloading. While the dynamic load test is in the form of recording bridge behavior when receiving dynamic loads. Static load test will provide information in the form of distribution patterns of forces in the superstructure due to the load. Whereas in dynamic tests, it is useful to measure the natural frequency of bridges. If there is a shift in the natural frequency of the bridge, then it can be further calculated regarding the condition of the bridge.

The purpose of static and dynamic load testing will be used as an analysis of bridge capacity and database of initial bridge conditions that can be used as an evaluation of the condition of the bridge in the future.
2. Methods

The WFC Bridge with a total length of this arc bridge span is 200 meters can be seen in Figure 1.

![Figure 1. WFC Bridge and Sensors.](image1)

To find out the strain that occurs during loading tests [1-6], 10 strain gauges of TML type FLA-6-11 were installed in 10 different locations which can be seen in Figure 2. Only the 100 meter middle section bridge segment will be tested.

![Figure 2. Location of Strain Gauges.](image2)

For deflection measurements, waterpass and total station were used instead of LVDTs [1-6] due to river conditions with deep and heavy currents do not possible. Waterpass (WP) and total station (TS) placement plan can be seen in Figure 3.

![Figure 3. Loading Test Measurement Device.](image3)

![Figure 4. Truck Position on The Bridge.](image4)

Loading in static and dynamic tests use a 25 tonne load dump truck. In static testing, the total
number of trucks used is 12 trucks, Figure 4. In static loading loads 0-50-100-150-200-250-300 tons and vice versa for unloading.

In dynamic tests, the truck is passed on a wooden track with a height of 200mm. Dynamic testing is carried out 5 times with 5 different excitation load locations, namely load excitation on the center line of the main span L/2 bridge, L/2 span A lane, L/4 bridge at center line, L/4 span A lane and on the 50 meter side span L/2 A lane.

The implementation of the bridge loading test carried out refers to the load test standard of the Association of American Society Highway Transport Organization (AASHTO).

3. Result and Discussion

Stages of static load test can be seen in Figure 5 and Table 1. The results of the measurement of bridge deflection for each resulting load configuration can be seen in Table 1. The longitudinal girder deflection curve and load- deflection graph in the girder can be seen in Figure 6.

![Figure 5. Loading Stages.](image-url)

The results of measurement of arch deformation on the main span of the bridge can be seen in
Table 2 and Figure 7.

Table 2. Arch Deflection at the Main Span.

| STA | U3 (0) | U3 (50) | U3 (100) | U3 (150) | U3 (200) | U3 (250) | U3 (300) |
|-----|--------|---------|----------|----------|----------|----------|----------|
|     | mm     | mm      | mm       | mm       | mm       | mm       | mm       |
| 25  | 0,000  | 6,140   | 7,379    | 0,611    | -2,242   | -0,836   | -0,662   |
| 50  | 0,000  | -19,678 | -25,499  | -16,446  | -10,947  | -13,554  | -11,847  |
| 75  | 0,000  | 5,380   | 5,753    | 2,092    | 0,010    | 0,824    | -0,856   |

Figure 6. Load-Deflection Curve.

Figure 7. Deformation-Load Curve of Arch.

Designed deflection in girders and arches is 34,750 mm and 25,499 mm, respectively, smaller than the allowable deflection L/800 = 125 mm. Deflection at L/2 shows a tendency that is opposite to deflection at L/4 and 3L/4 because the more the load is centered towards the L/2 the greater camber at L/4 and 3L/4. However, the more the load is evenly distributed towards the side, the deflection at L/2 also gets smaller, as well as deflection at L/4 and 3L/4.

Based on observations of all test equipment WP1, WP2, TS1, TS2, TS3, TS4 and comparing the suitability of the designed load-deflection curve with the actual test results, it was concluded that measurements based on TS2 and WP1 and WP2 were used for further analysis.
TS2 measured deflection at L/4, L/2 and 3L/4 sections of the main span bridge, and girder’s actual and designed load-deflection curves are given, respectively in Figure 8, Figure 9, and Figure 10.

The curves conclude that the designed deflection at L/4, L/2 and 3L/4 gives a tendency that corresponds to the actual deflection and the actual deflection is smaller than the designed deflection.

The analysis shows that the temperature difference of 15°C gives camber in the middle of the span of 15 mm for the arc and 13 mm for the girder or each temperature difference of 1°C causes a camber of 1 mm. The difference in deflection in the arc and girder shows that due to the weight of the bridge itself, the hanging rod accepts the tensile force as designed. With the influence of temperature, the deflection that occurs during testing needs to be corrected by reducing the measured value during testing with a deflection opponent of 15 mm as shown in Figure 11.
Maximum strain measurements on web of girder during loading stage can be seen in Table 3 and 4.

Table 3. Maximum Strain and Stress for each Static Test Loading Stage.

| Loading Stage | Maximum Tension | Strain, με |
|---------------|-----------------|------------|
|               | SG 1 SG 3 SG 5 SG 7 |            |
| 50            | 17.62           | -83.24     |
| 100           | 52.82           | 264.12     |
| 150           | 61.59           | 225.41     |
| 200           | 51.08           | 180.77     |
| 250           | 105.49          | 139.79     |
| 300           | 128.48          | 139.43     |

The position of the strain gauge on the X1 and X2 side and the strain curve resulting from the static loading test can be seen in Figure 12 and 13, respectively.
Table 4. Maximum Stress and Strain Static Test at Loading Stage.

| Loading Stage | Maximum Tension | Strain, µε | SG 2 | SG 4 | SG 6 | SG 8 |
|---------------|-----------------|------------|------|------|------|------|
| 50            | 17.62           |            | -77.91 | 69.43 | -28.91 | -37.91 |
| 100           | 52.82           |            | 238.09 | 79.82 | 38.47 | 149.41 |
| 150           | 61.59           |            | 201.12 | 36.47 | -12.21 | 309.76 |
| 200           | 51.08           |            | 183.83 | -60.51 | -50.83 | 255.38 |
| 250           | 105.49          |            | 58.18 | -60.51 | -38.83 | 527.47 |
| 300           | 128.48          |            | 173.86 | 6.50 | 24.84 | 642.41 |

Maximum strain measurements on web of girder during un-loading stage can be seen in Table 5 and 6.

Figure 13. Position of Strain Gauge and Strain Curve Static Test at Loading Stage.

The position of the strain gauge on the X1 and X2 side and the strain curve of the static test in the un-loading stage can be seen in Figure 14 and 15.

Table 5. Maximum Stress and Strain Static Test at Un-loading Stage.

| Loading Stage | Maximum Tension | Strain, µε | SG 1 | SG 3 | SG 5 | SG 7 |
|---------------|-----------------|------------|------|------|------|------|
| 250           | 51.31           |            | 179.89 | 40.54 | 4.54 | 141.21 |
| 200           | 70.38           |            | 351.88 | 35.82 | 51.19 | 212.20 |
| 150           | 52.47           |            | 218.15 | 202.09 | 112.30 | 58.63 |
| 100           | 88.71           |            | 141.42 | 115.60 | 57.44 | -110.70 |
| 50            | 75.20           |            | 118.21 | 187.76 | 102.97 | 130.14 |
| 0             | 13.21           |            | 17.96 | 64.54 | 5.22 | -67.69 |
Table 6. Maximum Stress and Strain Static Test at Un-loading Stage.

| Loading Stage | Maximum Tension | Strain, µε |
|---------------|-----------------|------------|
|               | SG 2            | SG 4       | SG 6       | SG 8       |
| 250           | 51.31           | 80.52      | 178.54     | 25.88      | 256.56     |
| 200           | 70.38           | 74.48      | 220.51     | 107.86     | 311.55     |
| 150           | 52.47           | 262.36     | 168.90     | 69.65      | 167.65     |
| 100           | 88.71           | 443.55     | 161.71     | 47.00      | 363.75     |
| 50            | 75.20           | 375.99     | 225.30     | 114.85     | 134.88     |
| 0             | 13.21           | -32.07     | -50.41     | 18.39      | 66.04      |

Five times dynamic testing were conducted with excitation load positioned at: (1) the center line of the main span at L/2, (2) the main span at L/2 bridge side, (3) center line of the main span at L/4, (4) the main span at L/4 bridge side, and (5) at midspan of the 50-meter span.
The dynamic test uses impact excitation from trucks that weigh 25 tons, while the test devices consist of four accelerometer sensor units, with 3 units installed vertically, and one unit mounted laterally. Illustration of test and excitation parameters can be seen in Figure 16 and Figure 17.

![Figure 16. Position of Accelerometer.](image1)

![Figure 17. Position of Vertical Excitation Loading.](image2)

Based on the quality of the data, the test reference uses an accelerometer sensor in the position in the center of the vertical direction (accelerometer number 2).

In dynamic test 1, the reading frequency of the impact excitation can be seen in Figure 19. Graph of Frequency Domain can be seen in Figure 20. Frequency spectrum (Hz) for dynamic test 1 in the middle of the span and in the center of the bridge gives frequencies of 1.13485, 1.75385, 2.99187, 3.30137, 3.71404, 5.05522, 8.45976, 12.0706, 12.4833 and 13.2055.

At the second dynamic test, excitation impact was given at center line and on the right side of bridge. Frequency spectrums (Hz) for dynamic test 2 are 1.79214, 2.90451, 3.33709 and 10.0113.

In the third dynamic test, excitation impacts in a quarter and in the center of the bridge. Frequency spectrum (Hz) of dynamic test 3 shows values of 1.1327, 1.98222, 2.97333, 3.68126, 4.95555, 8.49522, 10.0527 and 12.4597.

In the fourth dynamic test, the excitation impact is on the quarter and on the right side of the bridge. Frequency spectrum (Hz) for dynamic test 4 shows values of 1.127, 1.97224, 2.95836 and 10.0021.

In the fifth dynamic test, excitation impacts at L/2 from the side arc (P1-P2) and on the right side of the bridge. The frequency spectrums (Hz) of the dynamic test 5 are 1.98237 and 2.79384.

The measurement results show that the natural frequency for a short span of 50 meters is 1.98273 Hz while for a span of 100 meters long is 1.127 Hz.

4. Conclusion
1. In testing with a symmetrical configuration loading, maximum stresses at steel web of girder for loading sequence of 50, 100, 150, 200, 250, and 300 tons are 17.62 MPa, 52.82 MPa, 61.59 MPa, 51.08 MPa, 105.49 MPa and 128.48 Mpa, respectively. This value is still below the yield stress of the steel used which is 370
MPa.

2. The maximum stresses at un-loading stage of 250, 200, 150, 100, 50, and 0 tons are 51.31 MPa, 70.38 MPa, 52.47 MPa, 88.71 MPa, 75.20 MPa, 75.20 MPa and 13.21 Mpa, respectively.

3. Under unloading conditions the stresses do not return to their original value. For example, at a loading of 50 tons a stress of 17.62 MPa, while in an un-loading condition of 75.20 MPa or a stress difference of 57.58 MPa.

4. Testing under 70% of the actual load gives deflection smaller than the designed deflection. It means that the bridge is more rigid than it was designed.

5. The 15mm camber that occurs on the bridge girder due to its own weight without live load is caused by a temperature difference of 15°C on the lower and upper surfaces of the arc element. Because the four pedestals are in the form of pin connection, the bridge can only expand upwards and cause the girder to rise during the day and back down at night.

6. Strain and deflection values due to truck load test are smaller than required in AASHTO so that the bridge structure still behaves elastically where the structure conditions return to normal (no residual structure response occurs) after un-loading.

7. The natural frequency of the WFC bridge is 1,127 Hz which occurs in the vertical direction at a span of 100 meters. However, with a middle span arch that reaches a height of 15 meters, the natural frequency is most likely to occur in this curve in the lateral direction which cannot be observed during testing.

8. The results of load test concludes that the Water Front City bridge is still elastic for 70% of designed load and safe to operate.

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