The Evaluation of Changes in Chamber Position to Deflection of Arch Steel Bridge in Extreme Loads

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The Evaluation of Changes in Camber Position to Deflection of Arch Steel Bridge in Extreme Loads

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Abstract Visualization of the camber position, which has a negative value on the steel frame arch bridge causes user inconvenience and can even lead to a collapse hazard. Siak III Bridge is a national steel frame arch bridge as access between Pekanbaru City and other cities in Sumatra. Based on visual observations, the camber position has a negative value. Monitoring in the form of direct measurement of the bridge center coordinates using a total station tool to show that the camber decreases from the proper condition of the bridge coordinates. Purpose of this study to evaluating the performance bridge structure due to the combination load during the service life of the structure. Therefore, the methodology carried out was to analyze the performance of the bridge based on the model adopted from the 3D bridge and focused on bridge deflection. The analysis is carried out to estimate the deflection ratio of the bridge due to the load and to obtain critical conditions of the bridge structure. The deflection study uses Finite elements with SAP 2000 software. The results showed that based on the maximum deflection value caused by loading (SNI) T-02-2016 the condition of the actual bridge model was −196,470 mm at the ultimate load conditions and −185,731 mm under service load conditions. This result is still below the maximum allowable deflection (L/800) of 200 mm. the benefits of this research can be an input for the government and parties related to bridge inspection in providing appropriate assessments for maintenance, repair, and improvement of bridge functions.

Keywords Deflection · Negative camber · Arch steel bridge · Bridge evaluation

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1 Introduction

Damage to the bridge structure is a decrease in strength due to changes in material properties and changes in bridge geometry, which reduce the function of the bridge today or the future of the bridge. Siak III Bridge which was built in 2011 has a type of curved steel frame that has a span of 160 m long, 11 m high and 11 m wide, the kind of truss is reinforced concrete. This bridge has not been equipped with a bridge Structural Health Monitoring (SHM) tool. Based on field testing and visual observation, it is known that the Siak III Bridge camber is negatively found in the center position, as shown in Fig. 1.

Deflection of the camber exceeds the limit can affect the ability of service structure. From Fig. 1, the position of the camber significantly affects the deflection value of the bridge structure, the camber should be positive (convex). But the negative camber (concave) looks. Deflection is an essential factor that is calculated to determine the level of use of the bridge (serviceability) and can predict the performance of the bridge structure. Assessment of deflection can be done with a neural network system [9]. This method is a reliable solution in determining deviation in real terms. Besides, the determination of deflection can be done by the direct testing method [4]. This method can be used to obtain bridge conditions through a periodic investigation process on a bridge so that it can determine the stage of maintenance and repairs. But the method can only assess the state of the bridge through a visual survey method with equipment such as linear variable differential transformer (LVDT). Because of these limitations, deflection can be known by numerical methods with the help of finite element software [1]. This study aims to determine the remaining deflection values that occur in actual conditions with the help of finite element programs. The analysis is focused on the health of the bridge. The negative opponent of the camber is then simulated against a combination of loading, which is varied with extremely earthquake loads and service load (traffic).

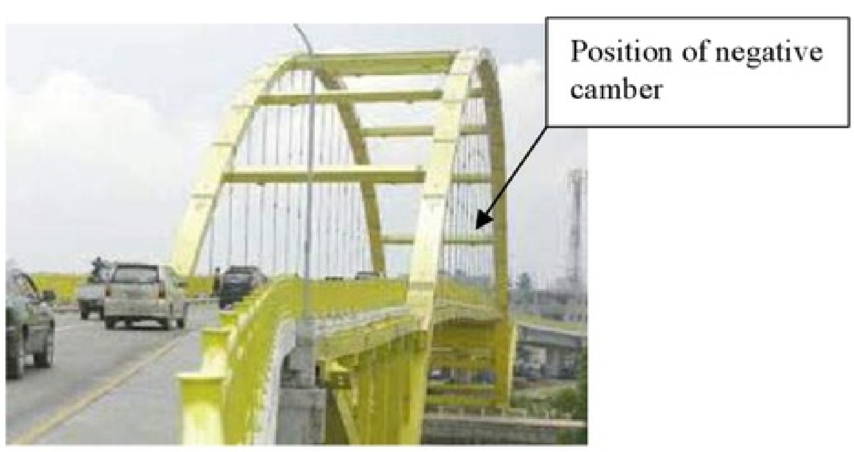

Fig. 1 Visual observation arch steel bridge of Siak III bridge

2 Literature Review

Many studies have been conducted on the assessment of bridges. The study was conducted among others who did real testing using LVDT sensors on bridges. The results of the study show that the accuracy of deflection results depends on many factors, including the location of the vehicle, vehicle speed, vehicle weight, and the exact position of the sensor [5]. Research that develops artificial neural network method. That shows that deflection value depends on the results of periodic testing data on a bridge so that it can determine the appropriate action for bridges [8]. This study focuses more on the use of deflection standards that have been formulated in Indonesian government regulations [10].

The bridge that receives the load will experience deflection. Based on the standards of the directorate general of Bina, the maximum allowable deflection limit is L/800 (Table 1), where L is the length of the span [2]. The following is the deflection permit based on the Directive in the Directorate General of Highways, as shown in the table. For the deflection for beams on two supports or continuous girder, requirements deflection is 1/800 × span.

Based on SNI 03-1729-2015 on Planning Steel Structures with the LRFD Method that, composite structure components have moments of inertia that are greater than the elements of non-composite structures; consequently the deflection in the composite structure components will be smaller [3]. So for deflection in steel before the composite can be calculated based on Eq. (1).

$$\delta = \left(5/384 \times Qt \times L^4\right)/(E \times Ix) \quad (1)$$

1. Maximum deflection in girder due to even load (Q), centralized load (P), and moment (M) given by Eqs. (2), (3) and (4) respectively:

$$\delta maks = 5/384 \times Q \times L^4/(Es \times Itr) \quad (2)$$

2. Maximum deflection on the girder due to centralized load (P):

$$\delta maks = 1/48 \times P \times L^3/(Es \times Itr) \quad (3)$$

Table 1 Technical guidelines for the design of steel frame structures in the directorate general of highways

No	Description	Deflection (δ)
1	Maximum deflection for beams on two supports or continuous girder	1/800 × span
2	Maximum deflection for some pedestrian paths	1/ 1000 × span
3	Maximum deflection due to dead load	1/300 × span
4	Maximum deflection for live loads on cantilever structures	1/300 × span

3. Maximum deflection in girder due to moment load (M):

$$\delta maks = 1/72\sqrt{3} \times M \times L^2/(Es \times Itr) \quad (4)$$

where,

δ deflection
Qt total load on girder before composite
L length of bridge span
E steel elastic modulus
Ix moment of inertia
Q total weight itself
P centered load
M moment load

2.1 Camber

The camber bridge is a floor girder with a directional position that is convex arch, which is positive. The camber is design with a positive value because if gravity loads, it is expected that the condition of the truss surface/bridge floor remains flat/ not concave. Therefore the negative camber value under service load conditions can be worrying [7].

2.2 Combination of Loading According to SNI T-02-2016

Components and connections on bridges must fulfill a combination of loads. The purposed to determine in each boundary condition, including Strong I criteria taking into account the average load without taking into account wind loads. While Strong II, the burden of select vehicles without taking into account the wind [6]. In Strong, III is a standard load plus a wind load (90–126 kmh instead). The extreme combination is a combination that takes into account earthquake loads, while extreme combination 2 takes into account the load arising from ship collisions, vehicle collisions, floods. Combination of service load 1 is a combination of loads that take into account the bridge operating load and wind load. The combination of service load II is intended to prevent the stress of steel structures. Combination service III further reviews the tensile stress in the direction of the bridge extending. Combination service IV is used to calculate the tensile stress in the column to control the size of the crack. In boundaries, status is a fatigue condition (Table 2) in

Table 2 Load combinations

Boundary stats	MS MA	TT TD TB TP	EU	EW_s	EW_L	BF	EU_n	Use one		
								EQ	TC	TC
Ultimate I	γp	1.8	1	–	–	1	0.5/1.2	–	–	
Ultimate II	γp	1.4	1	–	–	1	0.5/1.2	–	–	–
Ultimate III	γp		1	1.4	–	1	0.5/1.2	–	–	–
Ultimate IV	γp		1		–	1	0.5/1.2	–	–	–
Ultimate V	γp		1	1.4	–	1	0.5/1.2	–	–	–
Extreme I	γp	*EQ*	1	–	–	1	–	1	–	–
Extreme II	γp	0.5	1	–	–	1	–	–	1	1
Serviceability I	1	1	1	0.3	1	1	1/2	–	–	–
Serviceability II	1	1.3	1	–	–	1	1/2	–	–	–
Serviceability III	1	0.8	1	–	–	1	1/2	–	–	–
Serviceability IV	1	–	1	0.7	–	1	1/2	–	–	–
Fatigue	–	0.75	–	–	–	–	–	–	–	–

Note γp can be $\gamma_{MS}, \gamma_{MA}, \gamma_{TA}, \gamma_{PR}, \gamma_{PL}, \gamma_{SH}$ depending on $-\gamma_{EQ}$ is a living factor for earthquake conditions

connection with fatigue life due to induction of the load, which is unlimited in time. That Boundary status for combination load can be seen in Table 2. From Table 2, there is any combination to analysis and to get the maximum value.

2.3 Load Groups and Symbols for Loads

The following permanent and transient loads must be calculated in bridge planning:

Permanent Load

MS = dead load of structural components and nonstructural bridges
MA = pavement, and utility dead load
Transient Load
TB = force due to brakes
EQ = earthquake force
TD = ”D” lane load
TT = truckload “T”
TP = pedestrian load
ET = force due to gradient temperature.

3 Research Methods

The case in this study based on the Siak III Bridge. Model of the bridge was defined on SAP 2000. The longitudinal section of the bridge and the bridge perspective can be seen in Fig. 2. Twenty-one nodal bridge numbers will be used as reference points in analyzing deflection.

This research by the collection of bridge data needed, including standard archery image, bridge coordinate measurement data, and data from bridge material testing, as shown in (Table 3).

3.1 Research Instrument

To measure deformation and displacement, total station, as shown in Fig. 3. Measurements on the part of the structure of the bridge, namely the girder section. The purposed to determine the existing bridge's camber, which is known to have a tendency not to match the camber on the bridge planning data. The analysis by comparing secondary data planning with the results of measurements in the field.

The finite element model of the bridge was developed using the structural analysis program SAP 2000. Four node shell elements were used to represent the top and bottom flanges, the webs, and diaphragms besides modeling work based on coordinates obtained from the AutoCAD 2010 program. The direction of axis used is x-axis for length bridge and y-axis for the height of the bridge. Then the section properties are determined according to the secondary data obtained. The loads that were defined included in the structure, such as dead loads, live loads, and earthquake loads. This loading as an indicator of checking cross-section resistance and structural strength. This modeling refers to the Indonesian National Standard (SNI) T-02-2016 concerning Standard for Loading for Bridges and designs that see to the Planning of Steel Structures for Bridges.

Meanwhile, the calculation method used uses the deflection of the camber exceeds the limit can affect the ability of service structure (LRFD) code created by AISC. In this section, enter the geometry data of the bridge. After the modeling,

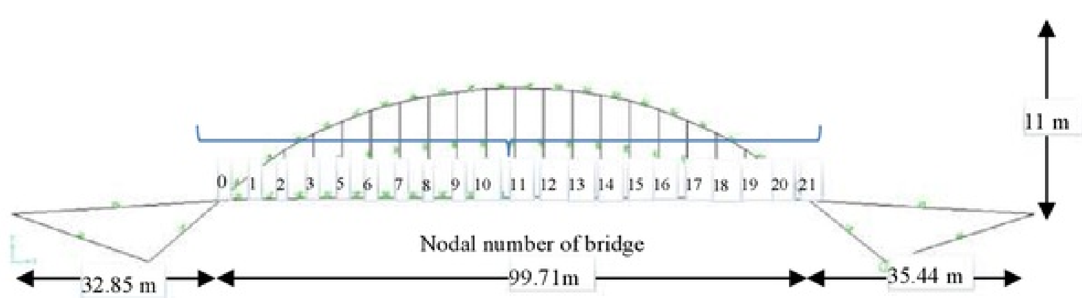

Fig. 2 Longitudinal cross section of bridge

Table 3 Section properties of bridge

Section properties material	Dimensions
Hanger dimension	
Diameter hanger	100 mm
Road width	7000 mm
Width of shoulder bridge	1600 mm
Total bridge width	10,200 m
Frame dimensions	
– Arch rib (box steel)	1200 × 800 m tw = 24 mm
– Tie beam	600 × 600 mm tw = 24 mm
– Floor beam	400 × 400 mm
Mechanical properties of structural steel	
– Structural steel	JIS G 3106 SM YB
– Stress yield (fy)	295 MPa
– Ultimate strength (fu)	490 MPa
– Modulus of elasticity	200,000 MPa
– Specific gravity	78.5 kN/m^3
Hanger steel	Grade 490
– Yield stress	490 MPa
– Ultimate stress	610 MPa
Modulus of elasticity	210,000 MPa
Weight gravity	78.5 kN/m^3

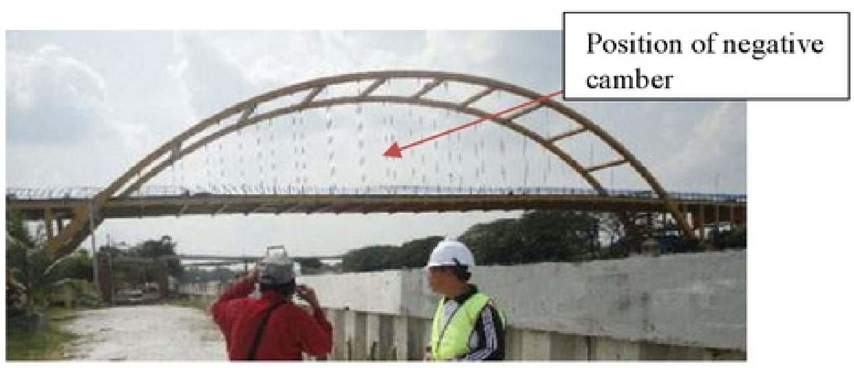

Fig. 3 Measuring camber position bridges with total station

checked the structure. This analysis is useful for determining deflection that occurs in modeling existing structures. The modeling carried out in the finite element program can be seen in Fig. 4.

Calculation of loading is carried out to determine the load acting on the bridge. The finite element modeling included theoretical and combination burdens which were adjusted to SNI for 2016 so that the existing bridge performance produced.

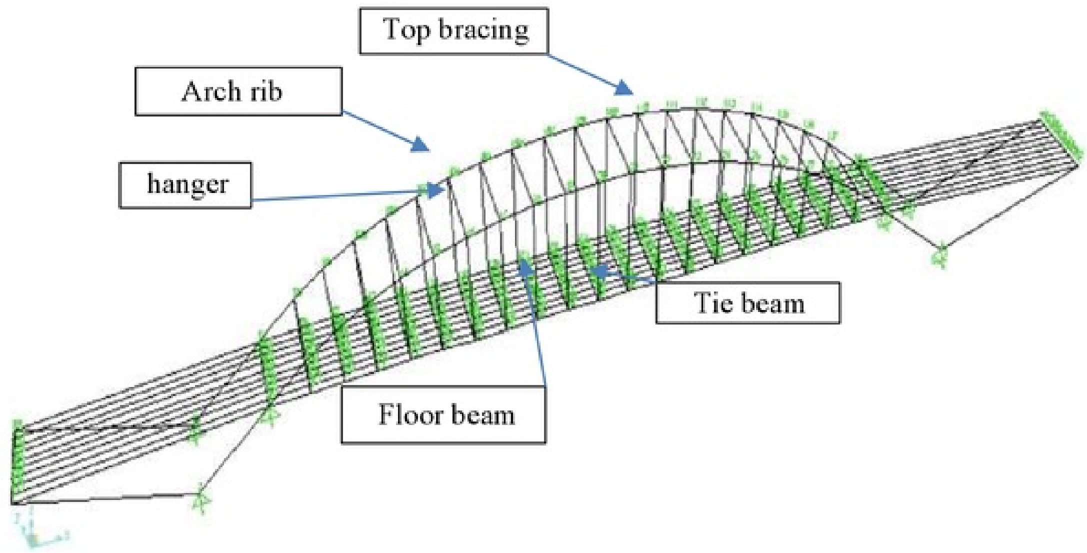

Fig. 4 Arch bridge with all its element

The actual modeling, this is done to determine deflection and force of the rod that occurs on the bridge. Own weight is given automatically and counted by soft-ware. The dynamic load input to the modeling calculated. The evenly divided load used is BTR = 9.0 (0.5 + 15/160) = 5.34375 kN/m^2 and the centralized line load used is 49 kN/m with a dynamic enlargement factor of 1375. The weight test truck and the placement of the load of the test truck adjusted to the conditions at the time of load testing.

3.2 Earthquake Data

The seismic load is calculated based on Earthquake Resilience Planning Procedures for Building (SNI 03-1726-2002) with dynamic methods Response Spectrum Analysis. From the analysis of retrieved conditions provide value style/greatest moments as a basis for planning. In the study of structures against earthquake loads, building mass will determine the force of inertia caused by the earthquake. The earthquake recordings selected for analysis are earthquake response spectrum records in Pekanbaru, Riau region as can be seen in Fig. 5.

4 Result and Discussion

In the actual research, deflection values that occur due to a combination of service, extreme, and fatigue load. This values obtained to compared with the deflection value of the L/800 permit (L is the length of the bridge) which is equal to 150 mm.

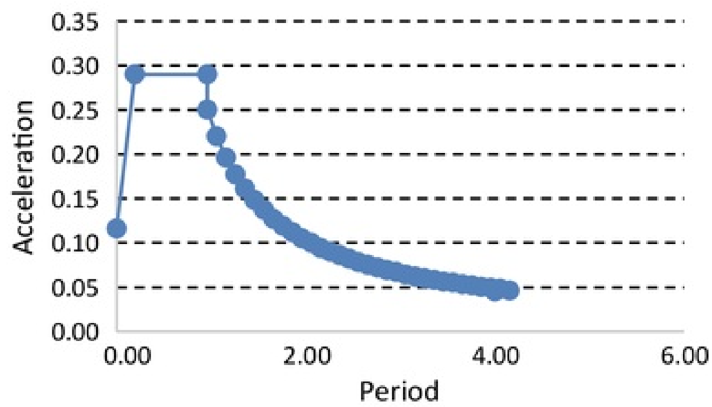

Fig. 5 Input data on the response spectrum of Pekanbaru earthquake

The following is the deflection value of the load combination according to SNI 1725-2016 concerning loading for bridges. The subsequent analysis will be to find the point that has the most significant displacement, then compared with the allowable deflection. From Table 4, there are 4 points (466, 467, 468, 470) which have the most considerable displacement in each of the coordinates. The resulting deflection value can see in (Table 4).

The results showed that based on the maximum deflection value caused by loading (SNI) T-02-2016 on the condition of the actual bridge model is −196,470 mm under the ultimate load conditions Strong II) means a combination of loading associated with the use of bridges to bear individual vehicle loads determined by the owner without taking into account the wind load. Maximum deflection is −185,731 mm at serviceability II, a combination of loading intended to prevent melting of the steel structure and slip on the joints due to the load of the vehicle. This value is still below the maximum permit deflection (L/800) which is

Table 4 Combination deflection value of SNI 1725-2016 load

Combination of loading	Joint	Deflection Z (mm)	Deflection permits SNI (mm)	Deflection LRFD (mm)
Extreme I	468	−106.423	200	666.7
Extreme II	468	−102.796	200	666.7
Fatigue	466	−84.876	200	666.7
Strong I	466	−139.850	200	666.7
Strong II	467	−196.470	200	666.7
Strong III	470	−56.490	200	666.7
Strong IV	470	−57.913	200	666.7
Strong V	470	−57.507	200	666.7
Serviceability I	467	−153.317	200	666.7
Serviceability II	467	−185.731	200	666.7
Serviceability III	468	−132.253	200	666.7
Serviceability IV	470	−57.202	200	666.7
Maximum	467	−196.470	200	666.7

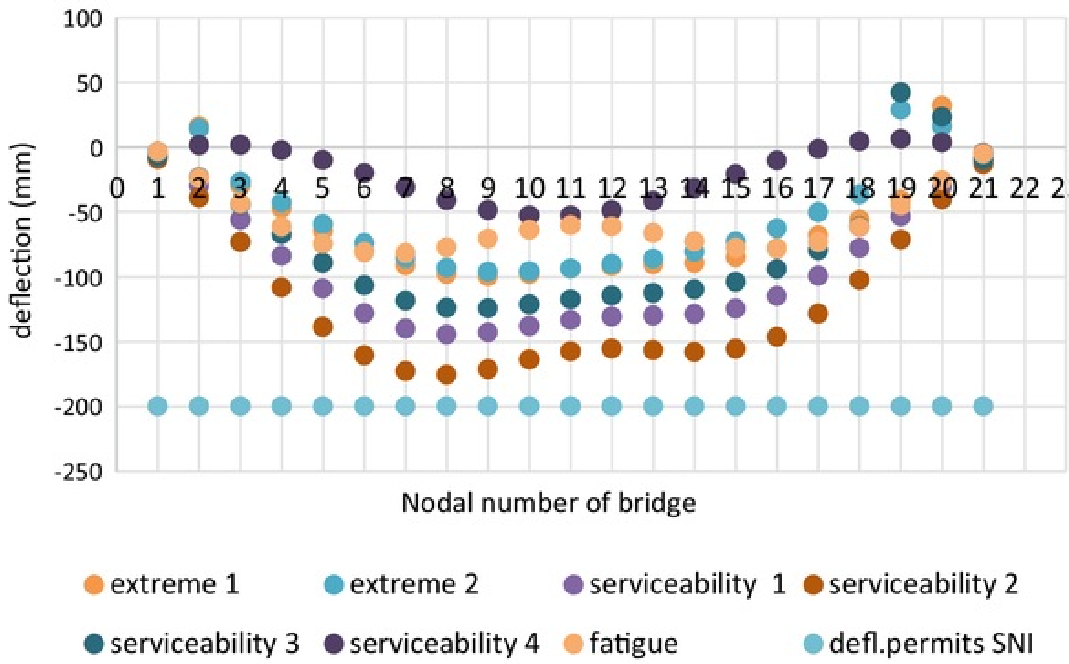

Fig. 6 Deflection value in each load combination

200 mm and 666.7 mm according to the LRFD requirements. The deviation of each girder nodal point was analyzed and compared to the deflection permits that had calculated shown in Fig. 6.

From Fig. 6 above, it can show that all nodal bridges, when subjected to a various combination are still safe and capable of serving. Each point that experiences deflection is below the deflection permit point (200 mm), while the combination that most determines the state of de-flection can be known is service condition 2.

5 Conclusion

The results showed that based on the maximum deflection value caused by loading (SNI) T-02-2016 the condition of the actual bridge model was −196,470 mm at the ultimate load conditions and −185,731 mm under service load conditions. This value is still below the maximum allowable deflection (L/800) of 200 mm. It hoped that this research could be an input for the government and parties related to bridge inspection in providing appropriate assessments for maintenance, repair, and improvement of bridge functions.

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