Mechanical Characteristics of the Butterfly Bridge Using the Finite Element Method

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Abstract

The construction of the Siak City-Indonesia Butterfly Bridge, which carries the European concept, was built in 2015, using steel as its main component almost completely. In general, the butterfly bridge uses cable-stayed but this bridge uses a profile pole as a supporting pole on this bridge. Using the Finite Element Method (FEM) can see the mechanical characteristics produced from a butterfly bridge.

The author uses the 2017 MARC Mentat Software to get the Finite Element Method results in this situation. This assessment aims to determine the mechanical characteristics of the deflection response of various degrees and elevation profiles and assessment of the bridge's natural frequency vibrations. The Sei Melengo Butterfly Bridge has a total length of 75,000 mm and a width of 10,800 mm. Curved structures that are often used in modern buildings, are structures called rigid arches.

In modeling a butterfly bridge consists of 2 parts namely Steel (Shell) and Concrete (Solid). In the case of 3D modeling using the Finite Element Method where 63 degree angles are modeled according to material data in the field. Based on the results of the analysis using the 2017 MARC Mentat Program, the level of deflection generated by an angle of 63 degrees with distributed loading is 44.3 mm. The deflection does not exceed the permitted standard, which is 1/800 span length of 63.4 m, which is 79 mm.

3D modeling was also designed at an angle of 53 degrees and 73 degrees and the height of the profile increased by 0.2 and the height of the profile decreased by 0.12. From the results of the analysis of an angle of 73 degrees and a high profile of 0.2 is a very good and strong bridge model because it has a very small deflection rate of 38.2 mm and 40.5 mm compared to a 63 degrees angle with a high profile of 0.16. The mechanical characteristics of natural frequency vibrations produced by all models of less than 5 Hz, at an angle of 73 degrees experience a different bending mode in the 2nd Mode compared to other models.

Keywords: The Butterfly Bridge, Finite Element Method (FEM), Steel Bridge, Bridge

1. INTRODUCTION

The butterfly bridge (3D arch) is principally a type of steel frame bridge in which one or more steel. In Indonesia, butterfly bridge use is not yet rampant, only in the United States and Europe. The following is a picture of a butterfly bridge design in the city of Austin, United States. This bridge has a span length of 56 m with all parts using steel and has a total of 11 m[1].

Fig. 1. The Butterfly Bridge at 2nd Street, America

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Fig.1 shows the arch of the 2nd St. Bridge is canted approximately 15 degrees from vertical. The arches were fabricated from weathering steel plates in a trapezoidal cross section. Cross frames and stiffeners are welded to the inside of the arch rib. Hanger connection plates supporting structural strand hangers bolt to the cross frames and stiffeners[2].

Fig. 2. The Butterfly Bedford, England

Fig. 2 shows a butterfly bridge was opened by Big Ears in 1998 after an architectural competition and was notoriously expensive. The bridge, at 32m in span, has twin steel arches which are inclined like butterfly wings. The two inclined tubular steel arches form the primary structure from which the hardwoodtimber deck is suspended by means of a system of rod hangers connected to transverse steelbearers that are integral with the balusters supporting the handrails. The two curved tubes support the suspended steel and timber deck with stainless steel cables[3)].

In 2015 a butterfly bridge was built in Indonesia combined with modern concepts such as in European countries. This bridge, in principle, is a steel frame bridge. Usually, in European countries, the butterfly bridge uses a cable-stay, but on this bridge it uses a profile as a support pole with a slope angle of 63 degrees.

The purpose of this work is to analyze the profile poles using the finite element method which will be compared with several polar angles profiles, which will be reviewed in terms of strengthening the steel profile pole against the response of the bridge structure, to the weight of the structure, and strand deflection. To get these results, the author uses the MARC Software.

2. THE BUTTERFLY BRIDGE IN INDONESIA

2.1 Study Area

Fig. 3 shows that the butterfly bridge sei melengo is situated in Kampung Tengah Village, Mempura Subdistrict, Siak District, the bridge was constructed in 2015 through Siak Regency's Department of Highways and Irrigation and was constructed on a riverbank dividing Kampung Tengah town Kecamatan Mempura from the section of Siak City Highway. The bridge was constructed to support facilities connecting the Siak City road to Kampung Tengah town, Mempura sub-district.

Fig. 3. Location Area of the Butterfly Bridge, Siak City, Indonesia

2.2 Explanation of the Butterfly Bridges in Indonesia

Fig. 4 shows that Sei Melengo Butterfly Bridge has a length of 75,000 mm and a total width of 10,800 mm. Curved structures that are often used in modern buildings, are structures called rigid arches. This

Fig. 4. The Butterfly Bridge, Siak City, Indonesia

butterfly bridge consists of several parts, namely profile poles, decks, bridge floors, abutments and arches.

The material properties on the bridge are shown in Table 1.

Table 1. Material Data Properties of the Butterfly Bridge

No	Information	Material	Size	Unit
1	Young's Modulus (E)	Steel	200,000	MPa
2	Poisson Ratio (μ)	Steel	0.3	
3	Mass Density	Steel	7,850	kN/m^3
4	Young's Modulus (E)	Concrete	25,000	MPa
5	Poisson Ratio (μ)	Concrete	0.2	
6	Mass Density	Concrete	2,400	kN/m^3

If this curved shape is made well, then this kind of structure can carry axial loads without bending or bending the structural elements.

Fig.5 shows a butterfly bridge, the use of profile poles is very important, whether the settings are stable or not. on this bridge has 11 profile poles with the maximum profile pole height is 9,731.5 mm and the minimum profile pole height is 3,367 mm with a 63 degrees. From the picture it can be seen that each distance between one profile pole and the other profile pole is 3,000 mm[4)].

Application of girder beams in the construction world is generally used for bridge construction which is a flexible structural component composed of several plate elements. on this bridge, the girder is composed of several plates with a thickness of 12 mm with a length of each 3,000 mm girder. 2 longitudinal girders on this bridge have a total length of 63,400 mm. On the arc of this bridge, formed from several plate elements with a thickness of 14 mm. The number of segments is very influential on the distribution of force on the bridge, the fewer the number of segments the greater the force that is carried by the buffer column.

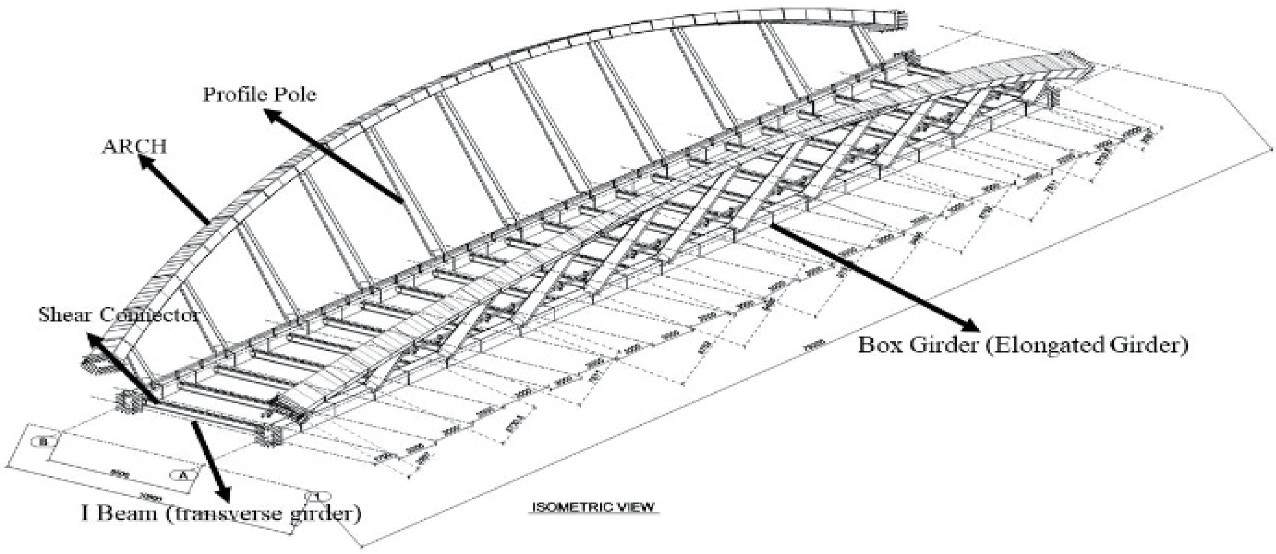

Fig. 5. Isometric View of the Butterfly Bridge

This bridge has a length per box segment is 3,000 mm with a 63 degrees supported by several profile poles. Bridge floors use galvanized corrugated steel plates which function as scaffolding (concrete casting) at the time of execution, installed between stringers (elongated girder) with a minimum grade of 36 steel quality. The shape of steel deck and its thickness must be the same for all types of bridges.

The connection between the steel deck and cross girder (transverse girder) or stringers (elongated girder) uses bolts (not welds). On this bridge the total length of the steel deck is 63.4 m.

On the floor system, the distance between cross girder (transverse girder) is 6.0 m and has a length of 7,500 mm. Transverse girder and longitudinal girders are equipped with practical shear connectors, each with a D16 size. This explanation is shown in Fig. 6.

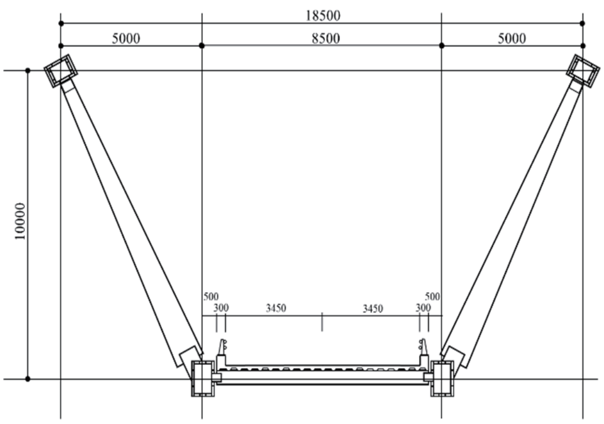

Fig. 6. Cross Section of the Butterfly Bridge

3. EVALUATION METHOD

3.1 Finite Element Method

The method used in completing this thesis is by means of the finite element method. The finite element method is a method of modelling of an object to divide into smaller parts as a whole still has the same properties as the whole thing before it was divides into smaller sections (discretization). The finite element method can be used to analyze various types of structures, such as plane truss, space truss, plane frame, space frame, beam, and grid[5)].

The Finite Element Method is a method that divides the burdened material into several elements that will be calculated continuously[6)]. The Finite Element Method is one of the most widely used numerical methods in the world of engineering and teaching in the world. This method attempts to solve equations with variables that exceed the available equations (partial differential equations) and other integration equations that result in discretization of continuum objects. Although in the form of an approach, this method is known to be quite effective in solving complex structures in the analysis of solid body mechanics.

3.2 Loading Structure

Loading specifications are based on National Regulation SNI 1725 – 2016[7)] which is a revision of National Regulation SNI T-02-2005[8)], so that the load on the bridge can be described as follows :

1. Dead Load (Self Weight)
   a. Weight of Structural Steel The weight of steel is calculated by multiplying the mass of steel with gravitational acceleration g = 9.81

m/dt². Mass Steel is a volume steel product with a mass density γ = 78.5 kN/m³.

b. Concrete Weight Concrete plates carry live concrete in the form of cargo traffic to children's girder. For this reason, heavy concrete loads are considered to work equally among girder children. The mass density for concrete is taken an average of 24.0 kN/m³.

2. Traffic load ("D" Load)
   a. Uniformly Distributed Load (UDL) has an intensity: q kPa with the amount q depending on length.

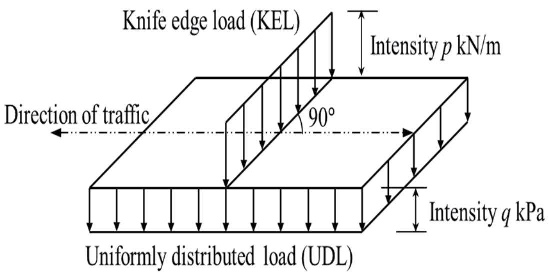

Fig. 7. ‘’D’’ Load

   b. Knife Edge Load (KEL) with the intensity of p kN/m must be placed perpendicular to the direction of traffic on the bridge. The magnitude of the p intensity is 49.0 kN/m. To obtain a maximum negative bending moment for a continuous bridge, an identical second BGT must be placed in the transverse direction of the bridge at the other end.

L = 63 m
q Load = 9.0 (0.5 + 15 / 63.4) kPa
q Load = 6.63 kN/m^2
P load = 49 kN/m.

3.2 Modeling Steel Parts

Steel part modeling is done by using MARC software which starts with entering the material data used and processing the data through connection determination, rod numbering, profile selection etc., In Fig. 8 below will explain the parts of the design.

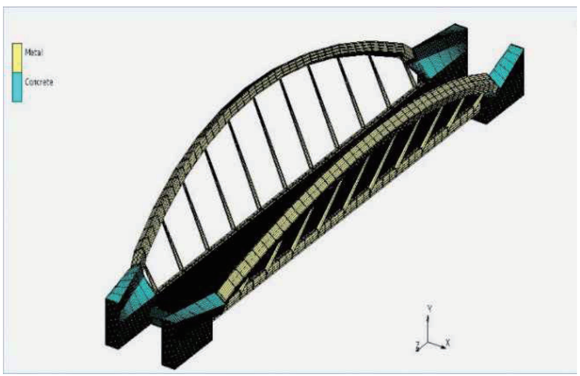

Fig. 8. Modeling using MARC Software

a. Box Girder Modeling

Box Girder Section has 3 parts Outside Box Girder, Inside Box Girder, and Connect Box Girder. The distance of each segment outside the girder is 1,500 mm, while the segment distance for each inside box and connect box girder is 3,000 mm. The amount of mesh in the Box Girder modeling section is 7,796 which consists of Element 3,412 and Nodes 4,384.

b. I Girder

I girder has a distance per segment is 3,000 mm. The amount of Mesh on the I Girder is 29,172 which consists of Element 13,200 and Nodes 15,972.

c. Concrete Floor Deck

Steel floor deck has an Amount of Mesh is 117,594 consisting of Element 46,716 and Nodes 70,878.

d. Arch Bridge Modelling

The Arch Bridge Section has 3 parts Outside, Inside, and Connect Steel. The distance of each segment outside is 1,500 mm, while the segment distance for each inside and connect Steel is 3,000 m. The amount of mesh in the Arch modeling section is 20,412 which consists of Element 9,488 and Nodes 10,924.

e. Profile Poles

The total profile pole used by the butterfly bridge is 21 poles. The amount of mesh in the Profile modeling section is 440 which consists of Element 132 and Nodes 308.

3.3 Modeling Solid Parts

The butterfly bridge has several parts where the main material uses concrete, Bridge abutments function to connect the Box girder, deck or bridge surface to the ground and help support its weight both horizontally and vertically. On this bridge has 4 large abutments which are connected directly to the girder box and arch which have a 63 degrees, and 2 other abutments which are connected directly to the deck.

Abutment that has a length of 8,700 mm, width 1,950 mm and height 4,915 mm. This abutment has a Mesh Number of 29,960 consisting of Element 12,800 and Nodes 17,160.

4. RESULT

3D modeling of material conduct that is modeled on the MARC program in a nonlinear manner. After the input of load data, element specifications and structural modeling using MARC Software, the structure attitude data is acquired after the load has been received after the analysis has been performed. The data of the analysis is in the form of deflection occurring on the butterfly bridge. It was found from the analysis that the butterfly bridge was unable to recognize because of the overall load impact.

In Fig. 9 is the result of a butterfly bridge model design with an angle of 63 degrees using MARC software which will be analyzed using distributed loads. The highest deflection that occurs at an angle of 63 degrees the butterfly bridge has a displacement of 44.3 mm. Based on computational deflection analysis and load distribution, deflection meets deflection requirements because it does not exceed the permissible deflection requirements of $L/800 = 79.25$ mm.

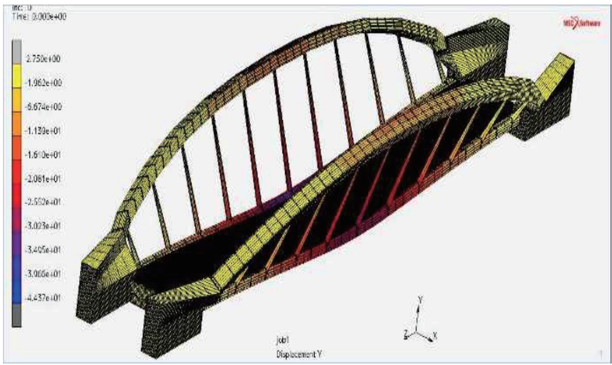

Fig. 9. Modeling Deflection

4.1. Analysis of the results of the load distributed with angle variations and rise span ratio

From the Fig.10 and table above it is clear that from all angles modeled it is still within the service standard limit of under 79 mm. At an angle of 53 degrees gets a result of 53.4 mm, an angle of 63 degrees gets a result of 44.3 mm and an angle of 73 degrees gets a result of 38.3 mm.

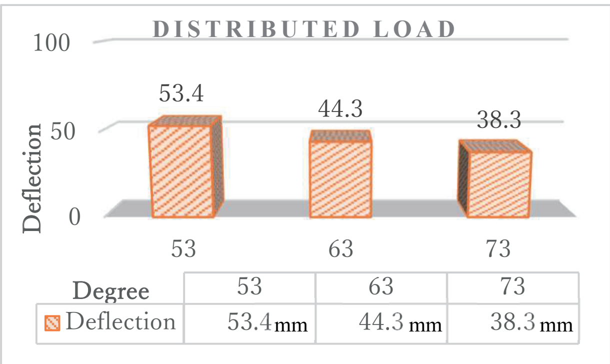

Fig. 10. The results of load analysis are distributed at different angular variations

Basically, the result of deflection analysis at an angle of 63 degrees still has a safe number and does not exceed the standard that has been calculated in accordance with Technical Guidelines for Steel Frame Structure Design at the Directorate General of Highways 2009.

From the results of the analysis of the three models, modeling using an angle of 73 degrees has the smallest deflection rate. It can be concluded that a very good and strong angle of 73 is used rather than 53 degrees and 63 degrees. So, if the bridge design model approaches 90 degrees, the level of security and deflection value will be smaller, better and stronger.

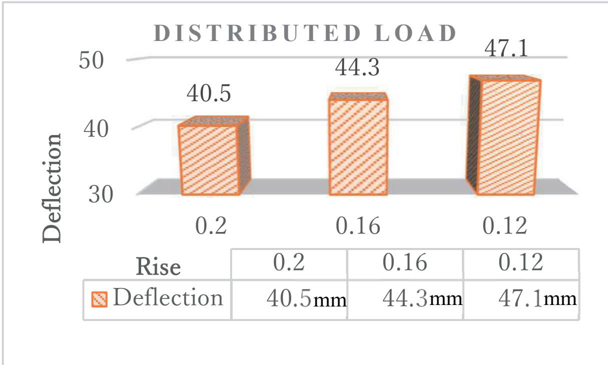

Fig. 11. The results of load analysis are distributed on variations in profile rise

From Fig.11 above, it is clear that from all variations of the profile increase modeled it is still within the service standard limit below 79 mm. On the increase of profile 0.2 got a result of 40.5 mm, on the profile of 0.16 it got a result of 44.3 mm and on the decrease of the profile 0.12 got a result of 47.1 mm. Basically, the results of the deflection analysis on the profile increase of 0.16 still have a safe number and do not exceed standards that have been calculated in accordance with the Technical Guidelines for the Design of Steel Frame Structures at the Directorate General of Highways 2009. From the results of the analysis of the three models, modeling using an increase in profile to 0.2 has the smallest deflection rate. It can be concluded that increasing profile 0.2 is a very good and strong model used from 0.16 and 0.12

4.2 Analysis of the results of Natural Frequency Vibration with angle variations and rise span ratio

In general, structures can have 3 types of core vibration models, namely horizontal, torque, and vertical. From the analysis of capital, it is obtained the shape function in each structural mode analyzed, namely in the horizontal direction.

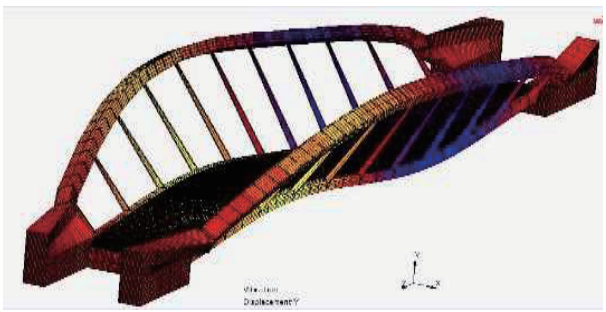

Fig. 12. 1st Mode = 2.78 Hz

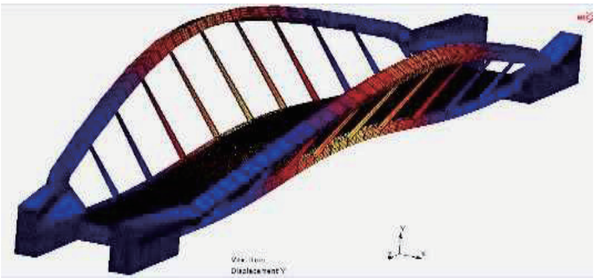

Fig. 13. 2nd Mode = 3.53 Hz

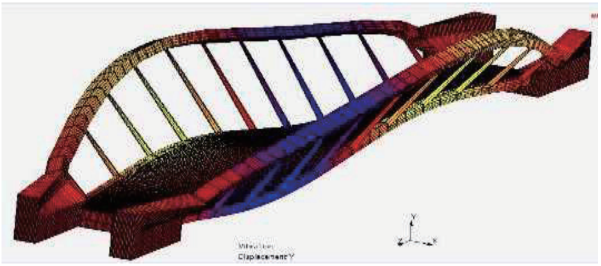

Fig. 14. 3rd Mode = 3.68 Hz

In Fig.12, Fig.13, Fig.14 shows the results of the 63 degree angle analysis, we have obtained the mechanical characteristics of natural frequency vibrations in the form of numerical values in units (Hertz) in each mode, including 1st mode which obtains a number of natural frequency vibrations of 2.78 Hertz, 2nd mode which obtains a number natural frequency vibrations 3.53 Hertz, 3rd mode which gets the amount of natural frequency vibrations 3.68 Hertz.

The overall vibration value is produced from natural frequencies below 5 Hz. At an angle of 73 degrees experiencing a natural frequency vibration in 2nd mode experiences mechanical characteristics that differ from an angle of 53 degrees and 63 degrees, which in 2nd mode a natural frequency vibration that occurs in the form of a twister, a total of 3.68 Hertz, when compared to the results of the natural frequency vibration from an angle of 53 degrees and 63 degrees which gets results below an angle of 73 degrees 3.23 Hertz and 3.53 Hertz. It can be concluded that at an angle of 73 degrees has a very good bending mode and is stronger than at an angle of 53 degrees and 63 degrees. Meanwhile, for the results of the natural frequency vibration value generated by lowering the height of the profile at 0.12 has a very good and strong bending mode.

5. CONCLUSIONS

This study investigates the mechanical characteristics of butterfly bridges in the loading section which are specialized in distributed loading which results from the analysis obtain figures from deflection and this study also investigates the mechanical characteristics of natural frequency vibration. Based on the results of the analysis and discussion, some important points that can be concluded in relation to the research objectives are as follows :

1) The overall deflection that occurs in each model with different angles and height profiles has a deflection rate not exceeding the deflection rate in accordance with Indonesian bridge standard regulations (RSNI T-02-2005 and SNI 1725 - 2016 RSNI)., from the results of the analysis it can be concluded that the important factor of deflection results also depends on the stability of the steel profile.
2) If the degree of the profile pole approaches the angle of 90 degrees, the deflection number will be smaller and if the profile pole is higher, the resulting deflection number will also be smaller.
3) From the comparison of the whole model, it can be concluded that the butterfly bridge with an angle of 73 degrees is the best because it has a much smaller deflection rate than all models.
4) Overall the results of the analysis of natural frequency vibrations obtained less than 5Hz, for angles of 73 degrees and 0.2 have excellent bending modes and are stronger than at angles of 53 degrees, 63 degrees, profile height increases of 0.12 and 0.16.

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