Design of Ciodeng suspension bridge, Indonesia, for pedestrian

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Abstract. Suspension bridge is a type of bridge which have the deck hung below the suspension cables on vertical suspenders. The bridge is commonly used for long spans. One of the longest suspension bridge is Akashi-Kaikyo in Japan. Cost effective, suitable for long span bridge, have more flexibility and less complicated construction are the advantage of suspension bridges. Therefore suspension bridges are not only designed for vehicles but also for pedestrians. Suspension bridges for pedestrian are usually located in rural areas due to obstacles such as rivers, valleys or plantations. This paper presents a design of suspension bridge for pedestrian. The design refers to "Manual for Design and Build of Suspension Bridge for Pedestrian". The suspension bridge is modeled using MIDAS Civil 2019. The output of the software is the internal forces consisting of moments, shear and normal forces used to design section properties and connection models. Based on the analysis and design process, obtained the dimensions of the bridge element; IWF.250.125.9.6 for the main girder, 150.100.9.6 for the cross girder, C.50.45.5.7 for the secondary girder, 250.250.14.14 for the pylon, L.50.50.5 for the bottom bracing, 60 mm for the main cable diameter, 20 mm for the hanging rod diameter, and 20 mm for the wind cable ties diameter.

1. Introduction
Suspension bridge is a type of bridges which has a continuous deck (the load-bearing portion) hung below the suspension cables on vertical suspenders that connect the deck with the main cable [1]. This bridge invented in the early nineteenth century, even bridges without vertical suspenders have already developed and applied in many parts of the world [2]. Until now, the longest suspension bridge in the world is Akashi-Kaikyo in Japan with 1991 meters main span [3-5].

Suspension bridge has some advantages, it spans could be longer than any other bridge, needs less fabrication, needless construction fee, can resist a higher earthquake actions than a heavier and inflexible bridges [2]. And because suspension bridges are relatively light and flexible, they are all susceptible to traffic loads and wind [6]. Some suspension bridges suffered from structural failure in the past. The most famous example is the Tacoma Narrows Bridge built in 1940 and collapsed after 4 months during a windstorm [7-9].

Nowadays, suspension bridges are not only designed for vehicles, but also specific for pedestrians and motorbikes. This type of bridge can be found in villages, connecting two places separated by rivers, rice fields and other obstacles so that the travel time is faster. The design of a pedestrian suspension bridge with a span of 20 meters was done in Pasuruan Regency [10]. In the following year, a design of a 30 meters long span with steel as the main material was done at Bandung Barat Regency [11].
paper will report the design of suspension bridge with 60 meters span at Rancamanyar, Bandung Regency.

2. Methods
Generally, this research methodology is explained by the flow chart on figure 1. The flow chart diagram describe the steps to calculate and determine a section properties and steel connection model. Determined section properties was helped by software, while for the steel connection was calculated manually.

Figure 1. Flowchart diagram of methodology.

There are three stages in operating a program, which consist of input, process and output. At the input stage, the user have to assign the bridge loading, material properties, and section properties. On sectional property, the user have to assume what cross-sectional dimension to be used. Next, the program will process the input parameters that have been assigned. On the last stage, the program will show the output parameter that will be used for the analysis. The output are moment, shear force and axial force.

3. Results and discussion
In this study, the design of a suspension bridge is done by referring to the bridge technical data as shown in table 1. There are several components in the suspension bridge consisting of main beam, secondary beam, main cable, hanger and floor plate. As an example, the following is a cross section capacity calculation for the main beam components with technical data as shown in table 2.

Table 1. Technical data of the bridge.

| Parameter             | Value                          |
|-----------------------|--------------------------------|
| Bridge Type           | Suspension bridge              |
| Bridge function       | Pedestrian and motorbike       |
| Charge class          | Class I                        |
| Bridge span           | 60.00 meter                    |
| Bridge width          | 1.80 meter                     |
| Backstay              | 10.00 meter                    |
| Sag                   | 5.45 meter                     |
| Height of Pylon       | 2 pcs/ 6 meter                 |
| Type of plate         | Perforated steel plate         |
| Size of floor module  | 0.75 x 0.90 meter              |
Table 2. Section property of main beam.

| Property                      | Value       |
|-------------------------------|-------------|
| High H :                      | 250 mm      |
| Width W :                     | 125 mm      |
| Web thicknes t tb :           | 6 mm        |
| Flange thickness tf :         | 9 mm        |
| Sectional area Ag :           | 37,60 cm²   |
| Radius r :                    | 12 mm       |
| Inertia moment lx :           | 4050 cm⁴    |
|                             | ly : 294 cm⁴|
| Radius of gyration ix :       | 10,4 cm     |
|                             | iy : 2,79 cm|
| Plastic sectional modulus Zx :| 324 cm³     |
|                             | Zy : 47 cm³ |

Referring to RSNI T-03 guidelines on steel structure design, each cross section used in the structure required to have a higher nominal strength than the ultimate strength [12]. The main beam have to be considered with flexural strength, shear strength and flexural and shear interactions as showed on equation (1) until equation (3). The following equation is the calculation of the main beam for the three parameters mentioned earlier. The same calculation is applied to other cross sections like secondary beam, diagonal bracing, main cable, hanger cable even to steel joint.

### 3.1. Flexural strength

The cross section is considered "safe" if the ultimate moment is smaller than the nominal moment times by the reduction factor as stated in the equation.

\[
M_u \leq \emptyset M_n
\]

\[
M_u \leq \emptyset Z_x f_y 1,12
\]

\[
33450000 \text{Nmm (output midas)} \leq 0,9 324000 \text{mm}^3 240 \text{N/mm}^2 1,12
\]

\[
33450000 \text{Nmm} \leq 78382080 \text{Nmm} \ldots \text{(safe)}
\]

### 3.2. Shear strength

The main beam is considered "safe" if the ultimate shear is smaller than the nominal shear times by the reduction factor as stated in the equation.

\[
V_u \leq \emptyset V_n
\]

\[
V_u \leq \emptyset 0,6 f_y A_w
\]

\[
8680 \text{N (output midas)} \leq 0,6 240 \text{N/mm}^2 ((250-2,9).6)
\]

\[
8680 \text{N} \leq 308448 \text{N} \ldots \text{(safe)}
\]

### 3.3. Flexural and shear interaction

The main beam is considered "safe" if the interaction of flexural and shear ratio is smaller than the coefficient of flexural and shear interaction.

\[
\frac{M_u}{\emptyset M_n} + 0,625 . \frac{V_u}{\emptyset V_n} \leq 1,375
\]

\[
\frac{33,45 \text{kN.m}}{78,382 \text{kN.m}} + 0,625 . \frac{8,68 \text{kN}}{249,84 \text{kN}} \leq 1,375
\]

\[
0,448 \leq 1,375 \ldots \text{(safe)}
\]
Figure 2. Bridge deflection at the middle of the span.

Figure 3. Detailed engineering drawing of Ciodeng suspension bridge. (a) Top and side view, (b) Detail of deck structure.
Based on "Guidelines for the Design and Build of Suspension Bridges for Pedestrians", the allowed bridge deflection is L / 200 at the middle of the span [13]. The results of the analysis of the bridge structure model with MIDAS Civil software is shown in figure 2. Based on the results of MIDAS Civil program analysis, the deflection of the z-global axis (Dz) at ½ span (30 meters) due to the “envelope” load combination is -276,268 millimetres, it means the deflection that occurs meets the allowed deflection condition (L/200). The same result was performed by Abdullah with a span of 35 meters, obtaining 12 mm deflection in the middle of the span [11]. Likewise Prasetyo who gets a smaller deflection value in the middle of the span which is less than L/200 [10]. As for the deflection of the y-axis (Dy) is 19.76 millimeter. Y-axis direction deflection is caused by wind loads. Futhermore, the suspension bridge is vulnerable to dynamic loads in the form of wind loads. If it does not have stability for the wind loads it can cause flutter phenomena [14-17]. Meanwhile, the deflection of the x-axis bridge is -0.08 millimeters.

After the analysis process, we can get a definite sectional size of each component. So the result of this research is; a detailed engineering design drawing as shown at figure 3. Figure 3(a) shows a side view and top view of a suspension bridge. While figure 3(b) shows the detailed of the bridge deck structure.

4. Conclusion

Based on the analysis and design process, obtained the dimensions of the bridge element; IWF.250.125.9.6 for the main girder, 150.100.9.6 for the cross girder, C.50.45.5.7 for the secondary girder, 250.250.14.14 for the pylon, L.50.50.5 for the bottom bracing, 60 mm for the main cable diameter, 20 mm for the hanging rod diameter, and 20 mm for the wind cable ties diameter.

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