Study on the collapse of the steel bridge due to flooding in Baringin Village of Padang City, Indonesia

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Abstract. Baringin Bridge is a steel bridge that connects between Baringin Village and Koto Lalang Village in Padang City, Indonesia. Baringin Bridge was made of steel frame construction using the Box Caisson type foundation, with 7.6 meters width and 60 meters length. This bridge was built with a semi cantilever method with temporary support using coconut tree trunks. The construction of Baringin Bridge was terminated due to flood in Baringin River on November 2, 2018, which causes the collapse of the temporary scaffolding. The flood made the bridge move away about 300 meters from its foundation. This study aims to find out the cause of the steel bridge collapse. The assessment was carried out to analyze the existing bridge construction, the cause of flooding, and flood discharging that occurred on November 2, 2018. The calculation of forces acting on the scaffold when the bridge collapsed was also conducted. The results of the study show that Baringin River discharge on November 2, 2018, was 407.17 m³/s with a river flow velocity of 1.45 m/s. The calculation results of the scaffold show that the bridge should be able to withstand forces arising from the weight of the steel frame and the flow of the river. However, the collision of the wood logs that hit the scaffold's feet causes the collapse of the steel bridge.

1. Introduction

The construction of the new bridge aims to connect between Baringin and Koto Lalang villages in Padang City, Indonesia. Previously, there was a suspension bridge connecting the two villages, but the suspension bridge was no longer feasible for motorbikes to pass through because there were already many damages on the bridge floors. Therefore, the government plans to build a new steel bridge in this location. The construction of this bridge was funded by the Padang City government, with a total cost of about 8.8 million Indonesian rupiahs. The construction of the bridge was started in May 2018 and planned to be completed in December 2018. However, the construction of the steel bridge was terminated on Nov. 2, 2018, due to the flood that washed away the bridge frame.

Collapse or failure of bridge construction has also occurred in several places due to some factors, such as Tacoma Narrows Bridge collapse due to aeroelastic vibrations caused by wind gusts of 40 miles per hour (64 km/h) [1], Liong River Bridge collapse due to the formwork failure during construction [1], Kutai Kartanagara Bridge collapse due to the errors in compiling operational standards and construction maintenance [2], and Krasak Bridge collapse caused by a fire fuel tank truck in the bridge which raise the temperature on the main beam of the upper structure and finally make the failure of the bridge [3].

In order to know the cause of Baringin Bridge collapse, an assessment was carried out to analyze the existing bridge construction, the cause of flooding, and flood discharging that occurred on November 2, 2018. The calculation of forces acting on the scaffold when the bridge collapsed was also conducted in this study.
2. Causes of flood
The topography of Padang city consists of the slopes of Bukit Barisan section with an area of 1,414.96 km². From this area, only 30% is habitable or residential areas, the remaining 70% is hilly areas. This topography is one of the factors causing flooding. Many of Padang's natural stretches are sloping, where water gathers or low basins. This will be the main cause of the flow and the flood target. Flood-prone districts such as South Padang, Kuranji and Koto Tangah, which are around 3,600-4,000 hectares, are prone to flooding. The low pressure in Samudra Hindia has an impact on the high formation of rain clouds in Mentawai waters, which are drilled to the coastal shores, in which the culmination of the second peak rainfall occurred in November every year.

Referring to Indonesian Meteorological, Climatological, and Geophysical Agency (BMKG) data, the rainfall intensity that occurred on 2 November 2018 was 250 millimeters with a duration of five hours. This was considered extreme, due to the normal conditions of 1,100-1,800 m³ of water. This condition causes the land to hold 2,500 m³ of water per hectare. To hold 2,500 m³ of water, land should be needed as large as a soccer field, and when the intensity of the rain is high, it does not contain drainage so that there is an overflow that results in flooding. In addition, six watersheds in Padang city: Timbalun, Bungus, Arau, Kuranji, Air Dingin, and Kandis areas also triggered the flood on November 2, 2018. This watershed is upstream and empties into Padang, and does not cross other areas. If the rainfall is high on the slopes, floods and landslides are difficult to avoid, such as flooding that occurs in Lubuk Kilangan district [4].

Heavy rains that took place in Padang City on November 2, 2018, caused the overflow of Baringin River in Lubuk Kilangan District, Padang City, West Sumatra. This caused the bridge frame being built on the river to be washed away. The steel bridge framework with a width of 7.6 meters and a height of 6 meters is being built to connect Baringin village with the Koto Tangah village, as shown in Figure 1; however, it was swept away by the swift river water. Based on information from residents, the flood occurred at 3:30 AM, which caused the bridge to move away around 300 m from the initial installation location.

3. Bridge construction analysis
Baringin Bridge was built using steel truss construction. All bridge frame components are in accordance with ASTM A123/ ISO 1461:1999 specifications. Steel structure components on a permanent steel frame bridge are made of steel material that meets the strength standard by referring to the American Association of State Highway and Transport (AASHTO) and the American Standard Testing Material (ASTM).

Bridge work starts from the bridge foundation work then continues with the bridge frame work. The foundation used on this bridge is the Caisson Box, a box-shaped foundation with a large cross-
section. The bridge framework begins with the construction of a bridge scaffold or temporary wooden pedestal (timber crib work), as shown in Figure 2. The temporary wood stack serves to support the steel bridge during the bridge frame assembly with the cantilever system. The coconut tree stems with diameter of ≥ 20 cm were used as the temporary support of the steel bridge. Scaffolding is installed at a distance of 10 to 15 meters.

![Figure 2. Temporary wooden pedestal.](image)

![Figure 3. Assemble of the bridge frame.](image)

After installing the scaffolding, the steel frame was assembled on the top of the scaffold and the riverbank, as shown in Figure 3. The diagonal frame of the bridge on a raft on the river bank is then raised above the scaffold with a mobile crane, which is then assembled with transverse, elongated, and upper girders.

A mobile crane was used in assembling the bridge frame. The mounting and tightening of the bolts are done manually using iron pegs, torque locks and also a wooden clamp. The bridge frames that have been assembled are only placed above the abutments and scaffolding, as shown in figures 4 and 5. The two seat placement bridges on the abutment are supported with temporary wooden shocks.

![Figure 4. Placement of the bridge.](image)

![Figure 5. Pedestal bridges with scaffolding.](image)

The bridge's tip has not been paired with permanent support, because the construction of the bridge has not been fully finished. The mounting pedestal was installed permanently on the bridge when the execution order the bridge has reached across and workmanship casting abutment floor has been completed. The unfinished bridge construction has resulted in the bridge frame not being able to survive when the flood occurs. Bridge scaffolding cannot hold the load of river water flow that is too large, causing the bridge to collapse and be washed away by river currents, as shown in figure 6.
The length of the bridge frame that should be installed is as long as 60 meters, but the installation of the bridge frame is stopped and washed away when the new bridge frame had been installed along 30 meters, as shown in Figure 7 (the red line is a bridge that has been installed).

4. Results and discussion

4.1. Observation
From the results of existing condition evaluation, it was found that the construction work was not carried out by the design consultant guidebooks in the manufacture of scaffolding or wooden pedestals to support the steel frames of the bridge. In the guidebook, the legs of a scaffold that sit at the bottom of the river must first be given concrete block (shoes) which function as ballast so that when the frame installation of the scaffold bridge is not washed away by the river flow, as shown in Figure 8 [5].

The reality in the field, scaffolding is not following the guidebook of the design consultant. In the field, the scaffold legs are only placed at the bottom of the river without any concrete block, as shown in Figure 9. This construction work causes the scaffold unable to hold the river flow so that it collapses and the bridge frame is washed away.

4.2. The calculation of flood discharge and the force that caused the bridge collapse

4.2.1. Catchment area of the river.
The catchment area is obtained through the Google Maps application. The catchment area is observed based on the ridge area that flows from the highest to the lowest elevations. From Figure 10, the catchment of Baringin river area is 34.56 km².

4.2.2. Discharge of Baringin River.

Data required calculating the river discharge:

- River catchment area = 34.56 km²
- Flowing coefficient (C) = 0.50
- Upstream elevation = 800 m
- Downstream elevation = 75 m
- River length = 9.7 km (Figure 11)

Calculation of the discharge:

- Calculate the $S$ (slope of the water track area), using Equation (1) [6]:
  \[ S = \frac{\Delta \text{elevation}}{\text{travel length}} \]  
  \[ S = \frac{800-75}{9700} = 0.075 \]

- Calculate $I$ (rain intensity) using Equation (2):
  \[ I = \left( \frac{R}{24} \right) \cdot \left( \frac{24}{t_c} \right)^{2/3} \]  
  Where:
  - $R$ : Rainfall (taken from highest rainfall data on that day, which is 250 mm)
  - $t_c$ : Time of concentration (hours), using Equation (3):

\[ t_c = \left( \frac{0.87 \times L^2}{1000 \times 0.075} \right)^{0.385} \]  
  \[ t_c = 1.034 \text{ hour} \]

Where:
- $L$ = River length (km)
- $S$ = The slope of the water track area
Then,
\[ I = \left( \frac{250}{24} \right) \times \left( \frac{124}{1.034} \right)^{0.667} \]
\[ I = 84,760 \text{ mm/hour} \]

- Calculate the discharge value

River discharge can be calculated using Equation (4) [7] :

\[ Q = C \times A \times I \]

(4)

\[ Q = 0.50 \times 84.760 \text{ mm/hour} \times 34.56 \text{ km}^2 \times 0.278 \]

\[ Q = 401.173 \text{ m}^3/\text{s} \]

So, Baringin River discharge is 407.17 m³/s

4.2.3. Water level during flood.

Calculation of flood discharge using the Equation (5):

\[ Q = \left( \frac{1}{n} \right) \times (R^{0.667}) \times (S^{0.05}) \times A \] (5)

Where:
\[ Q = \text{River water discharger m}^3/\text{s} \]
\[ R = \text{Hydraulic radius} \]
\[ S = \text{Slope of the water track area} \]
\[ A = \text{Area of wet cross section} \]

Figure 12. Cross section of a river trapezoid.

River Data:
River cross-section (Figure 12)
\[ b (riverebed width) = 30 \text{ m} \]
\[ m (slope of the river) = 5 \]

Calculation of \( h \) (river water level) using Equations (6) – (10):

- Determine \( B \) (length of water surface)

\[ B = b + 2mh \] (6)
\[ B = b + 10h \]

- Determine \( P \) (circumference of wet cross section)
  \[ P = b + 2h\sqrt{1 + m^2} \]  
  \[ P = b + 2h\sqrt{26} \]  

- Determine \( A \) (wet cross-sectional area)
  \[ A = bh + bh^2 \]  
  \[ A = bh + 5h^2 \]  

- Determine \( R \) (cross section hydraulic fingers)
  \[ R = \frac{A}{P} \]  
  \[ R = \frac{bh \times 5h^2}{b + 2h\sqrt{26}} \]  

- \( h \) value was obtained from the trial method n error in the manning formula
  \[ Q = \frac{1}{n} \times \left( \frac{bh \times 5h^2}{b + 2h\sqrt{26}} \right)^{0.667} \times (0.075^{0.5}) \times (bh + 5h^2) \]  
  \[ h = 4m \]  

4.2.4. **Flow of river during flood.**

River velocity was calculated using Equation (11):

\[ V = \frac{Q}{A} \]  

Where:
- \( Q \) = river water discharge
- \( A \) = the area of wet sanding

\[ V = \frac{Q}{bh \times 5h^2} \]  
\[ V = \frac{406.743}{(30 \times 4) \times (5 \times 4)^2} \]  
\[ V = 1.45 \text{ m/s} \]

4.3. **Forced due to flooding.**

To get the balance of the scaffold during a flood, it is necessary to know the weight of the scaffold itself. The scaffold was constructed using coconut tree trunks with a diameter of 0.3 m as many as 8 pieces and a diameter of 0.2 m as many as 6 pieces, the specific gravity of coconut trees is 700 kg/m³.

- Calculate the Scaffold force (\( F_{sc} \)) using Equation (12):
  \[ F_{sc} = [(\pi \times 0.15^2) \times 4.5 \times 700 \times 8] + [(\pi \times 0.10^2) \times 4.5 \times 700 \times 6] \]  
  \[ F_{sc} = 23.75 \text{ kN} \]

- Calculate the drag force from the flood current (\( F_{drag} \)) using Equation (13):
  \[ F_{drag} = 0.35 \times V^2 \times A \]  

Where:
- \( F_{drag} \) = Drag force arising from flood currents
- \( V \) = current velocity
A = the scaffold crossing area that is submerged in water (Figure 13)

Sectional area of the scaffold is exposed to water obtained 11.36 m², with a solid assumption because the garbage was caught in the scaffolding.

\[ F_{\text{drag}} = 0.35 \times 1.45^2 \times 11.36 = 8.35 \text{ kN} \]

The shear stability of the scaffolding to push or drag water using Equation (14) [9]:

\[ s_f = \frac{f \Sigma V}{\Sigma H} > 1.5 \]  

(14)

Where :

\[ \Sigma V = \text{number of vertical forces} \]
\[ \Sigma H = \text{number of horizontal forces} \]
\[ f = \text{shear coefficient} (f = 1) \]

\[ S_f = \frac{1 \times 23.75}{8.35} > 1.5 \]
\[ S_f = 2.84 > 1.5 \ldots \text{OK} \]

Figure 13. Sectional area of inundated the scaffold.

Figure 14. Scaffolding during a flood.

The strong scaffolding holds back the drag force of the river current, as shown in Figure 14, however, the scaffolding that has supported the bridge frame collapses due to the collision of wood washed away during a flood.

The weight of the bridge frame is carried by one scaffold is 80.31 kN. The wooden beam that was swept away the scaffolding have 1.2 m diameter and 4 m length with the density of the wood used was 900 kg/m³, so the weight of wood was:

\[ W_{\text{wood}} = [(\pi \times 0.6^2) \times 4 \times 900] = 40.715 \text{ kN} \]

The magnitude of the collision that occurs according to Hertz’s formula (Equation 15) [10] :

\[ F_H = \gamma p X^{2/5} \left(\frac{5}{4} m\right)^{3/5} VH^{6/5} \]

\[ X = \frac{4 \sqrt{\pi}}{3\pi} \frac{1}{k_1 k_2} ; \quad k = \frac{1-v^2}{\pi E} ; \quad m = \frac{m_1 m_2}{m_1 + m_2} \]

Where :

\[ F_H \quad : \text{collision force} \]
γ_p : constant coefficient
V_H : 1.2th power of the collision speed
m : mass
a : half of the radius of contact face
1,2 : debris and structure
ν : Poisson’s ratio
E : Young’s modulus

\[ k = \frac{1 - 0.33^2}{\pi 10.52} = 0.269 \]
\[ X = \frac{4\sqrt{0.3}}{3\pi} \frac{1}{0.269 + 0.269} = 4.31 \]
\[ F_H = 0.25 \left( 4.31^{2/5} \right) \left( \frac{5}{4} 2034 \right)^{3/5} \left( 1.448^{1.2} \right)^{6/5} = 84.42 \text{ kN} \]

So the scaffold stability of the vertical and horizontal forces is:

\[ \text{scaffold stability} = \frac{1.11}{84.42} > 1.5 \]

\[ S_f = 1.11 < 1.5 \ldots \text{NOT OK} \]

Figure 15 illustrated the forces that occur in the scaffold causing the failure of the scaffold, consequently, the steel bridge was collapsed and the steel frame has moved away from its initial location.

**Figure 15.** Schematic views of the forces that occur in the scaffold.

### 5. Conclusion

From this study, the following conclusions can be drawn:

- The construction of temporary scaffolding or wooden pedestal for the steel bridge frame in the field was not following the design drawings, causing the reduction of the scaffold carrying capacity in the riverbed (bottom of the river).
The temporary support (scaffold) had strong enough capacity to resist the dragging force of the flood. The collapse of the temporary support was mainly due to the additional impact force from the collision of wood that hit the scaffold foot causing the bridge frame moved as far as 300 meters from its original place.

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