Evaluation of the Groundsill’s stability at downstream of “Citorek” Bridge in Cimadur River, Banten Province

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Abstract. Scouring problems faced in the Cimadur River especially near to the Citorek bridge abutments have become the major discussion by the local researchers and the local water resources manager in Banten Province. As an effort in reducing the scouring problem around the abutment of the Citorek bridge, a groundsill structure with specific design is going to be installed in Cimadur River at downstream of Citorek bridge. To make sure the optimal function of the structure, the stability of the groundsill structure in Cimadur River need to be evaluated. This study attempt to evaluate the stability of a groundsill structure from the occurrences of rolling and sliding at both normal and flood conditions. The eccentricity of the groundsill structure is also checked during normal and flood conditions to make sure the stability of the structure. The required data (which are consisting of detail description of the groundsill structure, cross section of the river, rainfall data, topography data and sediment/soil data) are observed in the field and obtained from P.T. Saeba Konsulindo. The data are further analysed to determine: 1) design water discharges for several return period, 2) forces acting to the groundsill structure and 3) stability of the groundsill structure in the river. The results showed that the groundsill structure are stable and safety again rolling and sliding occurrences where the safety factor (SF) for rolling and sliding are higher than critical coefficients of rolling and sliding (1.5). At normal water level, safety factors (SF) for rolling and sliding are 8.07>1.5 and 2.7>1.5, respectively, while at flood water level, SF for rolling and sliding are 5.61>1.5 and 1.88>1.5, respectively. Besides, the results also found that the groundsill is safety from eccentricity at both normal and flood conditions where the calculated coefficients of eccentricities are lower than critical coefficient of eccentricity which could cause rolling and sliding.

Keywords: Citorek Bridge, Cimadur River, Groundsill Stability

Track Name: Land, Water, Forests and Food Security
1. Introduction

River is a natural water body that flows the water from downhill to downstream area due to the force of gravity [1-5]. For the transportation purposes by the local community, a bridge will be constructed to connect the areas separating by the river [6]. In water resources management, scouring problem is the most serious problem in water body which require to pay more attentions [7-13]. Scouring is an enlargement of a flow accompanied by transfer of material through the action of fluid motion. Scouring problem faced in the river can damage river structures and cause bad impact to the river environments. Since the past decades, the scouring problems in the river especially near to the bridge abutments have become the major discussion by the local researchers and the local water resources manager [14-17], while applying the groundsill structure at the downstream of the scouring area in the river is becoming one of promising alternatives [18-20].

There are scouring problems faced in the Cimadur River, Lebak district, Banten Province since the past few years. The scouring problem in Cimadur River especially near to abutment of the bridge take more attention by the local researchers and the local water resources manager in Banten Province due to the safety consideration for the surrounding community. In 2019, a groundsill structure has been constructed at downstream of Bantar Karang bridge. The presence of the groundsill structure in downstream of Bantar Karang bridge was found to give positive impact in slowly reducing the scouring problem around the abutment of the Bantar Karang bridge. The successful of implementing a groundsill structure in reducing the scouring problem around the abutment of Bantar Karang bridge encourage to design one more groundsill structure in Cimadur River, but now, it is going to be installed near to Citorek bridge located at upstream area of Cimadur River, Lebak district, Banten Province. Before the groundsill structure is constructed at downstream of Citorek bridge, the stability of the groundsill structure in Cimadure River need to be evaluated. So, this study attempt to evaluate the stability of the groundsill structure at downstream of Citorek bridge in Cimadur River from the rolling and sliding occurrences. The evaluation is carried out at both normal water level (2 years return period of design flood discharge) and extensive flood water level (50 years return period of design flood discharge). Besides, the eccentricity of the groundsill structure is also checked during normal and flood conditions to make sure the stability of the structure. The evaluation is important to optimize the function of the groundsill structure in maintaining the condition of local sedimentation in Cimadur River.

2. Materials and Methods

2.1 Study Area

This study is carried out at the upstream area of Cimadur River. Cimadur River is located in Lebak district, Banten Province which is geographically situated at latitude of 6° S to 7° S and longitude of 105° 25” E to 106° 30” E as shown in the Figure 1 below. There are scouring problems faced around the abutments of the bridges structure in the Cimadur River since the past few years. Besides of Bantar Karang bridge, the scouring problem is also faced around the abutment of Citorek bridge.

Topographic condition in the upstream part of Cimadur River is characterized with moderately steep slope where the riverbed elevations are approximately from 400 m above MSL to 500 m above MSL. Moderately steep slope of the riverbed in this area also give potential for the local scouring problem in the river.

The climate in the Banten Province is primary subjected to two seasons during the years that are dry season (April to October) and rainy season (November to March). Average amount of yearly rainfall is about 2000 mm to 4000 mm with the temperature of between 24.5 °C and 29.9 °C.
2.2 Data Collections
In this study, the required data are consisting of detail description of the ground sill structure, rainfall data, cross section of Cimadur River, topographic data and soil/sediment data. A ground sill structure has been designed to be installed at downstream of Citorek bridge in Cimadur River. The detail description of the ground sill structure is described in Figure 2 below. The ground sill structure is made by concrete with the specific gravity ($\gamma$) is about 24 kN/m$^3$.

Rainfall data used in this study are obtained from P.T. Saeba Konsulindo. There are two rainfall stations in the watershed of Cimadur River that are Cibeber rainfall station and Bayah rainfall station, while there is another one rainfall station outside of Cimadur watershed. The rainfall data for 10 years period (2011 to 2020) obtained from both rainfall stations are used in the hydrological analyses to calculate the design water discharge for several return period.

The cross sections of Cimadur River are observed in the field by P.T. Saeba Konsulindo, while the topographic data in the study area is obtained from USGS website. Further, the sediment/soil data which is consisting of depth of sediment/soil, sediment specific gravity and type of soil/sediment are obtained from P.T. Saeba Konsulindo.
Figure 2. Detail description of the groundsill structure.
2.3 Data Analyses
In this study, available data is further analysed to determine: 1) design flood discharge for 2, 5, 10, 25, and 50 years return period; 2) forces acting on the groundsill structure and 3) the stability of the groundsill structure. Design flood discharge for 2 years return period is used to represent the condition during normal water level, while design flood for 50 years return period is used to represent the condition during extreme flood condition. HECRAS programme is applied to simulate the water level for the discharges of 2 years and 50 years return periods. The detail descriptions for the analyses are as following:

2.3.1 Analysis of Rainfall, design flood discharge and Water Level
Hydrological analyses are carried out based on maximum daily rainfall data for each year from each rainfall station. The average of maximum daily rainfall for each year is further analysed by adopting theiszen method \([21-22]\), while the calculation is presented in Table 1.

| No | Year | Cibeber Station | Bayah Station | Maximum Rainfall (mm) |
|----|------|-----------------|---------------|-----------------------|
|    |      | Rainfall (mm)   | Catchment Area (A1=159.6 km\(^2\)) | Rainfall (mm) | Catchment Area (A2=50.4 km\(^2\)) | \(P = \frac{(P1*A1+P2*A2)}{(A1+A2)}\) | \(P = \frac{(2+4)}{(A1+A2)}\) |
| 1  | 2011 | 75              | 11970         | 137                   | 6904.8                  | 89.88 |
| 2  | 2012 | 91              | 14523.6       | 128                   | 6451.2                  | 99.88 |
| 3  | 2013 | 112             | 17875.2       | 185                   | 9324                    | 129.52 |
| 4  | 2014 | 97              | 15481.2       | 121                   | 6098.4                  | 102.76 |
| 5  | 2015 | 71              | 11331.6       | 101                   | 5090.4                  | 78.2   |
| 6  | 2016 | 93              | 14842.8       | 115                   | 5796                    | 98.28  |
| 7  | 2017 | 71              | 11331.6       | 120                   | 6048                    | 82.76  |
| 8  | 2018 | 128             | 20428.8       | 131                   | 6602.4                  | 128.72 |
| 9  | 2019 | 201             | 32079.6       | 112                   | 5644.8                  | 179.64 |
| 10 | 2020 | 184             | 29366.4       | 136                   | 6854.4                  | 172.48 |

Design rainfall is computed by adopting log pearson type III method \([21-22]\). Based on calculation, the values of the design rainfall for 5, 10, 25 and 50 years return periods are 128.92 mm, 153.42 mm, 191.19 mm and 224.7 mm, respectively.

Further, design flood discharges are analysed based on results of design rainfall. In this study, design flood discharge for 2 years return period is used to represent the normal condition in the field, while design flood discharge for 50 years return period is used to represent the extreme flood condition in the field. Design flood discharges are computed by adopting Nakayasu Synthetic Hydrograph Unit (SHU) method \([21-22]\) as following:

\[ Q_{\text{max}} = C \cdot A \cdot R_o \cdot \left( \frac{1}{3.6} \cdot (0.3T_p + T_{0.3}) \right) \]

Where: \(T_p\) is peak time (hour)

\(C\) is flow coefficient
Ro is single rainfall (mm)
A is the catchment area (km$^2$)
$T^{0.3}$ is the time of slowdown the discharge (until 30%)

Based on the calculation, the maximum discharge for 2, 5 and 10 years return periods are 398 m$^3$/s, 470.71 m$^3$/s and 560.16 m$^3$/s, respectively, while the maximum discharge for 25 and 50 years return periods are 698 m$^3$/s and 820.4 m$^3$/s (Figure 3).

![Figure 3. Design flood discharges for return periods of 2 to 50 years.](image)

For the calculation of the forces acting on the groundsill structure, water levels during normal and flood conditions are required. In this study, water levels are simulated using HECRAS programme by inputting the cross section of the river; topographic data in the study area; 2 years return period of discharge (represent the normal condition); 50 years return period of discharge (represent the flood condition) and detail description of the groundsill structure.

2.3.2 Analyses of the Forces Acting on the Groundsill Structure under normal and flood conditions

There are several forces that can affect the stability of the groundsill structure in the field which are including the weight of the groundsill itself (dead load), hydrostatics pressure, sediment pressure, uplift pressure and soil pressure. In this study, the forces acting on groundsill structure are analyzed under two conditions (normal and flood conditions). The calculations of those forces are referred to the equations wrote in Hardiyatmo [23], as following:

- Hydrostatic pressure:
  
  $P_u = ((1/2 \times h_u^2) - (1/2 \times h_1^2)) \times \gamma_w$
  
  $P_i = ((1/2 \times h_i^2) - (1/2 \times h_2^2)) \times \gamma_w$

  Where:
  
  $P_u$ is hydrostatics pressure at upstream (kN)
  $P_i$ is hydrostatics pressure at downstream (kN)
  $\gamma_w$ is specific gravity of water (kN/m$^3$)
  $h_u$ is water depth at upstream (m)
  $h_i$ is water depth at downstream (m)
  $h_1$ is the water level at upstream of “mercu” groundsill
  $h_2$ is the water level at downstream of “mercu” groundsill

- Sediment pressure:
Ph = (1/2) * γs * h^2 / (1 + sin θ)

Where:
Ph is forces located at 2/3 depth from the top of the sediment level
θ is the sliding angle (°)
γs is the specific gravity of sediment
h is the depth of the sediment

- Uplift pressure:
  Ux = Hx – Lx/L * ΔH

Ux is water pressure at point x (T/m²)
Hx is the height between point x and the level of water surface (m)
Lx is the water seepage length (m) at point x
L is total of water seepage length (m)
ΔH is the high energy difference

- Soil pressure:
  Kp = tan 2 (45° + θ/2), where θ is the sliding angle (°)

Table 2 describes the calculation results for forces acting on the groundsill structure during normal condition and flood condition.

| No | Type of Forces       | Force (Ton) | Moment (Ton.m) | Force (Ton) | Moment (Ton.m) |
|----|----------------------|-------------|----------------|-------------|----------------|
|    |                      | Vertical    | Horizontal    | Vertical    | Horizontal    |
|    |                      | (R_V)       | (R_H)         | (M_V)       | (M_H)         |
|    |                      |             |                |             |                |
| 1  | Weight (Dead load)   | -74.4       | 11.2           | -291.5      | 21.2           |
| 2  | Hydrostatics Pressure| 0.284       | 1.2            | 0.284       | 1.2            |
| 3  | Sediment Pressure    | 0.5         | 2.2            | 8.0         | 1.5            |
| 4  | Uplift Pressure      | 13.8        | 40.7           | 21.5        | 65.1           |
| 5  | Soil Pressure        | 4.9         | 6.5            | 4.9         | 6.5            |
|    | Total                | -60.6       | 16.8           | -250.8      | 31.1           |
|    |                      | -44.8       | 17.8           | -199.5      | 35.6           |

2.3.3 Analyses of Groundsill Stability under normal and flood conditions
Groundsill stability is analysed during two conditions that are under normal water level (2 years return period of discharge) and extreme flood water level (50 years return period of discharge). Here, we are checking the stability of the groundsill structure from the occurrence of rolling and sliding based on
Suyitno [24] and Sutopo [18]. Besides, we also check the safety and stability of the groundsill structure from the eccentricity based on Suyono [25], Sutopo [18] and Sularno [26].

In this study, we calculate the parameter of safety factor (SF) from rolling and sliding and compare with the critical coefficient of rolling and sliding (which is 1.5). The safety and stable groundsill structure must be refer to the equations below:

\[ SF = \frac{\sum M_V}{\sum M_H} \text{ (must) } > 1.5, \text{ for rolling} \]
\[ SF = \frac{\sum R_V}{\sum R_H} \text{ (must) } > 1.5, \text{ for sliding} \]
\[ e = \left( \frac{B}{2} - \sum M_V - \sum M_H \right) \text{ (must) } \leq \frac{B}{6}, \text{ for eccentricity} \]

The groundsill structure is categorized as safe and stable again rolling and sliding if the safety factor (SF) for rolling and sliding are higher than value of critical coefficient for rolling and sliding (1.5). Besides, the groundsill structure also can be categorized as safety if the calculated eccentricities (for both normal and flood conditions) are smaller than the length of the groundsill structure divided by 6 (B/6).

3. Results and Discussion

Table 3 presents the calculation results of stability analyses for groundsill structure under occurrences of rolling, sliding and eccentricity.

| No | Stability | Normal Condition | Flood Condition |
|----|-----------|------------------|-----------------|
|    | Parameter | Checking         | Parameter       | Checking         |
|    | \( \sum M_V \) | SF critical = 1.5 | \( \sum M_V \) | SF critical = 1.5 |
|    | = 250.8 T.m | SF calculated = 8.07 | = 199.5 T.m | SF calculated = 5.61 |
| 1  | Rolling   | \( \sum M_H \) = 31.1 T.m | The structure is stable (safe) from rolling | \( \sum M_H \) = 35.6 T.m | The structure is stable (safe) from rolling |
|    | SF = \( \frac{\sum M_V}{\sum M_H} \) | \( \sum R_V \) = 60.6 T | SF = \( \frac{\sum R_V}{\sum R_H} \) | SF calculated = 2.70 | SF = \( \frac{\sum R_V}{\sum R_H} \) | SF calculated = 1.88 |
|    | \( \sum R_H \) = 16.8 T | The structure is stable (safe) from sliding | \( \sum R_H \) = 17.8 T | The structure is stable (safe) from sliding |
| 2  | Sliding   | SF = \( \frac{\sum R_V}{\sum R_H} \) | \( \sum M_V \) | SF calculated = 0.97 | \( \sum M_V \) | SF calculated = 0.97 |
|    | \( \sum M_V \) | e critical = 0.97 | \( \sum M_V \) | e calculated = 0.725 | \( \sum M_V \) | e calculated = 0.755 |
|    | = 250.8 T.m | \( \sum M_H \) = 31.1 T.m | \( \sum M_H \) = 35.6 T.m | \( \sum M_H \) = 35.6 T.m | \( \sum M_H \) = 35.6 T.m | \( \sum M_H \) = 35.6 T.m |
| 3  | Eccentricity | \( \sum R_V \) = 60.6 T | \( \sum R_V \) = 44.8 T | B = 5.8 m | B = 5.8 m |
Based on Table 3, the safety factor (SF) for rolling which are about 8.07 during normal condition and 5.61 during flood condition are higher than the critical coefficient of rolling which is 1.5. It demonstrates that the groundsill structure at downstream of Citorek bridge is safe and stable from rolling under both normal and extreme flood water level.

The result analyses also show that the groundsill structure is stable and safe from occurrence of sliding if it is installed at downstream of Citorek bridge, Cimadur River. It is because the safety factor (SF) for sliding which are about 2.7 during normal water level and 1.88 during extreme flood water level are higher that critical coefficient of sliding (which is 1.5). Apart of that, the groundsill structure is also categorised as safe from eccentricity because coefficient eccentricities (e) which are 0.725 under normal condition and 0.755 under flood condition are found to be lower than one-sixth length of the groundsill structure divided by 6. It also demonstrates that the groundsill structure is stable from eccentricity under both normal and flood water level.

4. Conclusion

In optimizing the function of the groundsill structure at downstream of Citorek bridge in Cimadur River, the stability of the groundsill structure need to be checked before its installation in the site. Based on calculation, we can conclude that the groundsill structure is stable and safe from rolling occurrences under both condition that are during normal water level and extreme flood water level. The groundsill structure is also found to be stable and secure against sliding occurrences under normal and flood conditions if the structure is installed downstream of Citorek bridge, Cimadur River. Besides, the groundsill structure can be categorized as secure from eccentricity under both normal and flood conditions where the coefficient eccentricity values (e) is less than B/6.

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