The effect of flood on slope stability along downstream riverbank of MuaraBangkahulu River, Bengkulu City, Indonesia

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Abstract. The flood which occurred due to the rainfall intensity in Bengkulu City of Indonesia could inundate the downstream area of MuaraBangkahulu River, especially TanjungAgung Sub-District. In 2019, a huge flood had occurred in Bengkulu City and triggered the environmental effect to riverbank in TanjungAgung. This environmental effect is a massive slope failure on downstream riverbank in TanjungAgung. This study is therefore conducted to analyze the slope stability in the area during the normal and the critical conditions. A slope stability analysis using finite element method is performed. First, the maximum discharge of MuaraBangkahulu River is estimated. Furthermore, slope stability analyses are conducted by considering the normal condition and the increase of river water level due to the maximum discharge (the critical condition). Mapping of factor of safety for riverbank slope and soil deformation is conducted. The results showed that slope along downstream riverbank of MuaraBangkahulu could undergo slope failure under both normal and critical condition. The results also showed that the factor of safety decreases due to the increase of river water level. The results of this study could be used by local government to consider slope countermeasure in the study area.

1. Introduction
Generally, Bengkulu City is known as the high-seismic activityarea [1]. This is due to the fact that several strong earthquakes had occurred in Bengkulu Province [2]. However, the latent effect of extreme weather could result in the serious damage to Bengkulu City. Bengkulu City is therefore very vulnerable to undergo fast-flood from the high terrain area. Mase [3] mentioned that the impact of fast-flood is not only related to the economical aspect but also the environmental aspect. Afast-flood had also triggered the slope failures along the river bank. On April 28-29, 2019, a huge fast-flood had occurred in Bengkulu Province [4]. The flood was initiated by heavy rainfall in Bengkulu Province (Figure 1a). Several areas, such as Central Bengkulu, Bengkulu City (the capital of Bengkulu Province), and Seluma had inundated for days. The flood had appeared significant loss in terms of economic and social problems, since thousands people should be evacuated to temporary camps. In addition, several slope failures had been found along downstream area of MuaraBangkahulu River, which is the main river in Bengkulu City and frequently overflows once the fast-flood from high-terrain area is coming. The slope failures (Figure 1b) had then become more massive after fast-flood [5]. Therefore, it is important to deeply investigate slope stability in the study area, especially during the flood.
Figure 1. Several impacts of a huge fast-flood on April 28-29, 2019 in Bengkulu City (a) inundation area (b) slope failure at the river bank

One of impacted areas to slope failure during a huge fast-flood in 2019 is TanjungAgung sub-district. This area is located at the riverbank of MuaraBangkahulu River. This area frequently undergo inundation due to the overflows of MuaraBangkahulu River [4]. Several housing areas significantly grow in this area because the sub-district is relatively closed to downtown area [5]. Therefore, the impacts of floods and slope failures become a more serious attention in this area. In line with the impact resulted during the fast-flood in 2019, a study is performed to investigate the impact of flood to the slope stability along riverbank of downstream area of MuaraBangkahulu River. Observation and analysis on soil characteristics, soil shear strength, and slope stability are performed. Several stability parameters, such as factor of safety (FS) and deformation are depicted into zonation maps. In general, the results could help the local government in considering the impact of slope failure during flood in the study area.

2. Method
2.1 Study area and soil properties
This study is focused on the downstream area of MuaraBangkahulu River. An areas called as TanjungAgung Segment is the observed area in this study (Figure 2). As previously elaborated, this area is one of the most impacted areas during the recent fast-flood in Bengkulu City. In the previous study, Mase [3] had mapped slope failures zonation in the neighboring district called Semarang Segment. In Figure 3, the detail of study area is also presented. There are 10 cross-sections investigated in this study, namely TA-1 to TA-10.

The detail of soil properties is summarized in Table 1. It can be seen that sandy soil categorized as poorly graded sand or SP [6] is dominant in the study area. According to Mase et al. [7], the loose saturated sandy soils spreading in the study area, also tend to be vulnerable to liquefaction. The loose density indicates that sand is relatively easy to scrap away during flood. The sandy soils existing in the segment has a high degree of saturation, i.e. about 80% to 90%. It means that the sandy soils are mostly wet. In general, slope failures are triggering by shear strength reduction. This parameter is much related to the increase of pore pressure [8].
2.2 Procedure
This study is initiated by capturing the problem of slope failures along riverbank of Muara Bangkahulu River. Slope failures along the riverbank are also linked with floods occurring in Bengkulu City. Afterwards, the intensive literature review is conducted to study the characteristic of slope failures and floods in the study area. Slope geometry, soil properties, normal condition of river water level, rainfall intensity, topographical map, and land-use map are collected in this study. The rainfall intensity within 20 years (2000 to 2020) is analyzed to estimate the maximum discharge and river water level increase. The increase of river water is noted as the critical groundwater level resulted due to flood.

In this study, a finite element method from Brinkgreve [9] and the Mohr-Coulomb model [10] are employed. From the simulation, several important results, such as FS against slope failure and deformation, are collected.

| No | Soil Properties       | Notation | Unit | 1-1 | 2-2 | 3-3 | 4-4 | 5-5 | 6-6 | 7-7 | 8-8 | 9-9 | 10-10 |
|----|-----------------------|----------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-------|
| 1  | Soil type             | USCS     | SM   | 15.25 | 16.27 | 15.94 | 14.98 | 16.08 | 15.25 | 14.91 | 15.81 | 15.67 | 14.57 |
| 2  | Bulk density          | \( \gamma_b \) | kN/m\(^3\) | 9.82 | 11.20 | 10.75 | 9.64 | 11.12 | 10.07 | 10.53 | 10.87 | 10.44 | 10.44 |
| 3  | Moisture content      | \( w \) | % | 55.30 | 45.27 | 48.28 | 55.39 | 44.60 | 51.44 | 41.60 | 45.45 | 50.10 | 39.56 |
| 4  | Specific gravity      | \( G_s \) | - | 2.76 | 2.78 | 2.60 | 2.89 | 2.77 | 2.69 | 2.53 | 2.82 | 2.53 | 2.58 |
| 5  | Void ratio            | \( e \) | - | 1.76 | 1.43 | 1.37 | 1.94 | 1.44 | 1.62 | 1.36 | 1.55 | 1.38 | 1.42 |
| 6  | Degree of saturation  | \( S \) | % | 86.85 | 87.70 | 91.45 | 82.48 | 85.58 | 85.39 | 77.55 | 82.95 | 92.02 | 71.66 |
| 7  | Consistency limits    |          |      |      |      |      |      |      |      |      |      |      |       |
| 8  | Soil cohesion         | \( c \) | kN/m\(^2\) | 4.85 | 4.20 | 2.91 | 4.98 | 3.88 | 5.17 | 4.52 | 3.55 | 3.88 | 5.17 |
| 9  | Internal friction angle| \( \phi \) | o | 29.82 | 30.24 | 31.29 | 29.60 | 31.49 | 29.16 | 30.24 | 31.49 | 29.17 | 30.44 |
| 10 | Coefficient of permeability | \( k \) | cm/hour | 0.47 | 0.51 | 0.52 | 0.48 | 0.50 | 0.51 | 0.48 | 0.51 | 0.47 | 0.51 |
| 11 | Elastic Modulus       | \( E \) | kN/m\(^2\) | 12216 | 12952 | 14789 | 11840 | 15148 | 11061 | 12952 | 15148 | 11079 | 13310 |

Table 1. Summary of soil properties index in Tanjung Agung Segment
For $FS < 1.5$ indicates unstable slope, whereas the value equal to 1.5 indicates critical slope. For $FS > 1.5$, the slope could be categorized as stable slope which means that slope is not vulnerable to failure [3]. In this study, Krigging interpolating method [11] is employed to generate microzonation maps. The results of this study could describe the effect of water level increase along Muara Bangkahulu downstream area in Tanjung Agung Segment.

3. Results and Discussion

3.1 Hydrological analysis

The rainfall condition is presented in the category of monthly rainfall in Figure 3. In can be seen that the average monthly rainfall during years in Bengkulu City is generally about 200 mm/month. The monthly rainfall show the highest in February and the lowest in March. Based on the average monthly rainfall, the surcharge in Tanjung Agung Segment can be estimated by using discharge analysis [12, 13] (Table 2). Since TA-1 and TA-2 faces each other, the estimation of discharge can be then assumed as the same. This assumption is also adopted for other paired cross-sections. It is shown that runoff discharge on Tanjung Agung Segment is observed to vary from 236 m$^3$/s to 269 m$^3$/s. It was predicted to increase river water level with the variation of 1 to 1.1 m (Table 3).

![Figure 3](image-url)

**Figure 3.** Rainfall intensity in the study area (modified from Mase, 2020)

Figure 4 presents the examples of finite element simulation resulted at TA-6. Figures 4a and 4b presents the sliding plane of TA slope during normal and critical conditions, respectively. It can be seen that circle sliding plane crossing slope toe could occur during both conditions. The results also show that the sliding generally appeared at slope toe. Figure 5 presents the slope deformation zones under both normal and critical conditions. It can be seen that there is no significant different on the slope deformation under both considered conditions. Along Tanjung Agung Segment are dominated by SP, which are relatively sensitive to scrap away due to river flow. Figure 6 presents the zonation of slope severity derived from $FS$. $FS < 1.5$ means that slope could be unstable and vice versa. It can be seen that Tanjung Agung Segment is relatively vulnerable to undergo slope failure even before flood occurred (normal condition). In another word, floods did not significantly influence the slope stability in the study area. However, the impact could be getting worse if the flood effect to the massive erosion during floods has not been well handled. Therefore, the results could be also considered as recommendation to implement slope countermeasure.
### Table 2. Discharge estimation and prediction of water level increase on Tanjung Agung Segment

| Cross Section  | Section Area (m²) | Discharge (m³/s) | Normal Water Level (m) | Estimate Water Level Increase (m) | Critical Water Level (m) |
|----------------|-------------------|------------------|------------------------|-----------------------------------|-------------------------|
| TA-1 and TA-2  | 80.57             | 269              | 2.25                   | 1.020                             | 3.27                    |
| TA-3 and TA-4  | 72.38             | 242              | 2.25                   | 1.094                             | 3.34                    |
| TA-5 and TA-6  | 70.73             | 236              | 2.30                   | 0.999                             | 3.30                    |
| TA-7 and TA-8  | 75.40             | 252              | 2.30                   | 1.025                             | 3.33                    |
| TA-9 and TA-10 | 71.25             | 238              | 2.20                   | 1.020                             | 3.22                    |

#### Figure 4. Sliding plane at TA-6 (a) normal water level, (d) critical water level

#### Figure 5. Slope deformation under condition of (a) normal water level, (b) critical water level

#### Figure 6. Slope severity under condition of (a) normal water level, (b) critical water level
4. Conclusion
During the normal and critical conditions, slope along TanjungAgung Segment is generally unstable ($FS < 1.5$). The results explained that the slope along the segment had been already unstable before the critical condition. However, flood could trigger the worse impact to slope stability. Based on the visual observation, the erosion due to river flow is also massive and it can be getting worse once floods happen. The results show sloping areas, which are indicated as unstable. The results of this study could deliver the recommendation to local government in determining slope countermeasure.

References
[1] Misliniyati R, Mase LZ, Syahbana AJ and Soebowo E 2018 IOP Conference Series: Earth and Environmental Science 212 012004
[2] Farid M and Mase LZ 2020 Int. J. Geomate 18 pp 199-207
[3] Mase, LZ 2019 Final Research Final Report Kurita Water and Environment Foundation (KWEF) Tokyo Japan.
[4] Badan Penanggulangan Bencana Daerah (BPBD) 2019 Badan Penanggulangan Bencana Daerah, Bengkulu, Indonesia (in Indonesian)
[5] Putrie NS, Susilomringtyas D and Pratami M 2019 IOP Conference Series: Earth and Environmental Science 284 012007
[6] Stevens J 1982 CivEng-ASCE 52 pp 61-62
[7] Mase LZ, Refrizon, Rosiana and Anggraini PW 2021 Indian Geotechnical Journal pp 1-15
[8] Al-Karni AA 2011 Arabian J. Geosci 4 7-8
[9] Brinkgreve RBJ, Swolfs WM, Engine E 2011 PLAXIS user’s manual, PLAXIS bv, Delft, Netherlands.
[10] Zhang Q, Shuilin W, Xiurun GE, Hongying W 2010 Min SciTechnol (China) 2 pp 701-706
[11] Meng Q, Liu Z and Borders BE 2013 Cartogr. Geogr. Inf. Sci 40 pp 28-39
[12] Mase LZ 2020 E3S Web of Conferences 148 03002
[13] Paski JAI, Permana DS, Alfuadi N, Handoyo MF, Nurrahmat MH and Makmur EE 2021 AIP Conference Proceedings 2320 040019

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