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# Consideration of costs and factors of safety for landslide mitigation of the housing infrastructure in Sawahlunto

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**Abstract.** The Indonesian government, through the Ministry of Public Works and Public Housing, is conducting a housing infrastructure development to encourage economic growth and improve the quality of Indonesian human life. However, the limitations of proper land in the implementations have resulted in the compulsion to build public houses in disadvantaged areas. On November 2, 2018 there was a landslide in a public residential area in the city of Sawahlunto which resulted in 4 houses which are unable to function anymore and 12 others which are damaged and uncomfortable to occupy. In order to investigate the landslide, the field survey has been carried out and the soil samples have been taken and tested in the laboratory. Then, some remedial methods of landslide remedial work at that location were carried out. Furthermore, a number of possible methods are compared in terms of the value of safety against landslides and the cost of the countermeasures. The main criterion is the costs needed for disaster mitigation for this local landslide, which must be smaller than the value of the affected area. If the cost for disaster mitigation is greater than the value of the affected area, then the relocation option may be a wiser choice. However, in this study, the stone masonry is the right choice to be used in the remedial action.

## 1. Introduction

The Indonesian government through the Ministry of Public Works and Public Housing (PUPR) is trying to carry out housing infrastructure development to encourage economic growth and improve the quality of Indonesian human life. These objectives are contained in the Strategic Plan of the Ministry of Public Works and Public Housing in 2015-2019 [1]. This decision is the latest development in the development of housing adapted to socio-political developments. This has begun with a paradigm shift in the implementation of national development, because of the demands for reform in the housing and settlement sector [2].

However, the limitations of land have resulted in the compulsion to build housing in unprofitable areas, such as those with a lack of clean water, slum areas or those prone to disasters. The national strategy introduces 100-0-100, namely 100% of habitable and sustainable settlements as well as good access to drinking water, 0% of urban slum areas and 100% access to sanitation such as waste water, garbage management and good drainage. Based on available data in 2014, it states that the achievement of drinking water access has only reached 68%, the slum area is 12% and access to sanitation is 60.91%. The Ministry of Public Works and Public Housing estimates that the 100-0-100



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target will be difficult to reach by the end of 2019. The government's strength through the national development budget can only handle access to drinking water at around 80%, overcoming slum areas of only less than 6% and access to healthy sanitation at 77%. For this reason, the Central Government needs support from the Regional Government, infrastructure managers, investors and the public to realize 100-0-100 [3].

Factors that are the main reason for not achieving these targets include lack of funds, lack of division of responsibilities with provinces and private companies and limited available land in accordance with land use. As a result of housing targets that exceed this capability, some housing is built on land that is less profitable from a technical point of view. In addition, the existing problems relating to slum settlements must also be resolved in the provision of housing [4].

Although the construction of rental apartments is one solution to overcome the limitations of this land, it does not answer all the basic problems, that is 'limited land'. In order to pursue the target, the proper land for the site of the houses is paid less attention. The change in the real land use has also not been followed by an appropriate land use plan [5]. Finally, some of the housing that had been built on the land that was technically less advantageous. Then, the built houses eventually suffered from damage both individually and to several houses simultaneously.

This paper describes a field survey at the landslide in Sawahlunto, the test results of soil samples and analysis results of the land are used to give a good idea for better remedial action at the location. The chosen remedial work is selected based on the factor of safety and the construction budget for a number of possible methods. The costs needed for the constructions for this landslide must be smaller than the price of the land.

## 2. Landslide at housing in Sawahlunto

On November 2, 2018 there was land movement in a residential area in the city of Sawahlunto, West Sumatra, Indonesia. This landslide resulted in 4 houses being unable to function and 12 others damaged so that it was very uncomfortable and dangerous to be occupied, and there was road cracks (figure 1). The event of the landslide in Sawahlunto did not occur suddenly. In fact, before a major movement occurred on November 2, 2018, there had been a crack in the road since October 11, 2018 [6]. The cracks were reported following extreme rain on October 11, 2018. It is estimated that there has been infiltration of rainwater into the underneath soil through the cracks that already existed before. This infiltration resulted in saturation and reduced the strength of the soil.



**Figure 1.** Road damaged by land movement after heavy rains in Santur Village, Sawahlunto, West Sumatra, 2 November 2018. (Photo by BNPB in [6]).

In order to understand the incident, a field survey was carried out to visually observe the events that occurred. In this field visit the crest of the landslide is determined as well as the toe of the land movement. Furthermore, soil samples were taken and tested in the laboratory to obtain engineering properties. Based on the data obtained, an analysis of the land movements in that location was carried out. Some remedial methods were also simulated in the location of Sawahlunto. The increasing factors of safety and the construction budget for a number of possible methods are estimated.

The criteria for selecting the appropriate mitigation method are based on factors of safety and the cost of construction. These criteria are adopted because the area is experiencing land movement is public housing areas and did not result in casualties. Thus, the costs needed for the constructions for this land movement must be smaller than the value of the land. If the costs incurred for disaster management are greater than the value of the housing area, then the relocation option is a wiser choice. Even from the reality in the field, the people affected by this landslide have evacuated (relocated) independently (figure 2) [7].



**Figure 2.** Residents dismantle their houses independently [7].

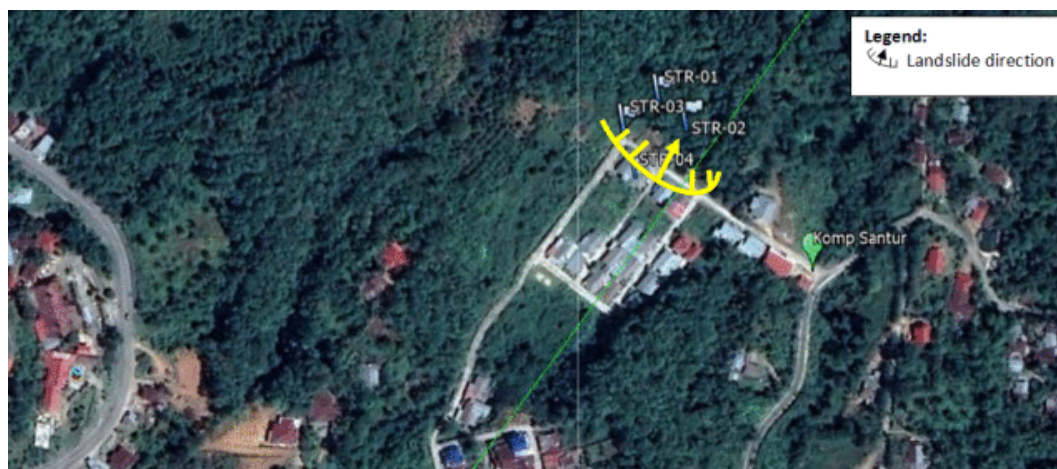
### 3. Field survey results

The location of this landslide is precisely in the global coordinates of E: 100° 45' 03.4", S: 0° 38' 48.0" (figure 3). The location is in the form of housing with the name "Perumnas Lembah Santur" in Karanganyar Village, Santur - Barangin District, in Sawahlunto City of West Sumatra - Indonesia. The Santur landslide has caused 4 (four) housing units to be seriously damaged, 12 (twelve) units of houses were slightly damaged and 40 meters of land cracks which damaged roads and drainage. The morphology of the Perumnas Lembah Santur area is part of the Batang Ombilin Basin, the slope is a moderate to medium steep slope (15° - 50°) and elevations range from 250 - 400 meters above sea level. The Perumnas Lembah Santur area of Barangin District and its surroundings is quite close to the fault structure with a relative north-south direction. The types of rocks in the Perumnas Lembah Santur area and surrounding areas are [8] are Lower Member Formations of Ombilin (Tmol) in the form of quartz sandstones containing archaic mica inserts, clay flakes, quartz conglomerates and coal.

Field observations found that the dominant type of rock was medium-strong weathered clay shale. The nature of the slab shale is impermeable so that it tends to hold water and directly reduce the shear resistance of the soil. In high rainfall a few days before the landslide, slip was created which resulted in the disaster of this land movement.



The land use for the Perumnas Lembah Santur area and its surroundings consists of settlements and plantations. The top of the slope is a highway and residential housing, while the lower part of the slope is a community-owned plantation (rubber). Hydrogeology of the Perumnas Lembah Santur area and surrounding areas includes rare groundwater zones [9] with bedrock that has a low graduation rate (porosity). On November 2, 2018 there was land movement in a residential area in the city of Sawahlunto, West Sumatra, Indonesia. This landslide resulted in 4 houses being unable to function and 12 others damaged so that it was very uncomfortable and dangerous to be occupied, and there were road cracks (figure 1). The event of the landslide in Sawahlunto did not occur suddenly. In fact, a few days before a major landslids, there was high rainfall which might create a slip line that resulted in the disaster of this landslide.



**Figure 3.** Bird eye Sanur landslides.

According to the Forecast Map of the Potential Land Movement in West Sumatra Province [10], the Perumnas Lembah Santur area and its surroundings are classified as "High Soil Movement Vulnerability Potential" where soil movements often occur. The old and new land movements still actively occur due to high rainfall and strong erosion, some efforts and measures to prevent and overcome landslides in the context of landslide mitigation may include the following:

- ✓ Stop the flow of water on the slope to reduce the potential for aftershocks.
- ✓ Installing an extensometer (ground movement monitoring device) in the lower part of the housing area (rubber plantation) in order to monitor the potential of aftershocks. This tool can be a part of an early warning system.
- ✓ The houses that have been damaged due to the land movement may be adopted as a green zone and be planted with strong rooted plants / trees.
- ✓ Disseminate to all levels of society about the potential and mitigation of landslides.

#### 4. Landslide analysis

Landslides that occur include movement of creeping [11]. Landslides are triggered by high rainfall before the event that causes soil conditions to become saturated and unstable so that landslides occur [12]. Creeping type of land movement generally occurs slowly due to clay shale rocks that are water-resistant (low porosity) and do not have strong rooted cover vegetation. In general, landslides are caused by a combination of natural factors, namely geological factors and rainfall plus human activity factors. The results of the evaluation of landslides in the Perumnas Lembah Santur area and surrounding areas are as follows:

- ✓ Geological factors, The Perumnas Lembah Santur and its surroundings are above the Lower Member Formation Ombilin (Tmol) which is soft and labile when saturated with water.

- ✓ The steep slope factor is  $15^\circ - 50^\circ$ .
- ✓ The factor of liquidity is high rainfall during the incident.
- ✓ Factors of human activity in the form of land use changes that were previously rubber plantations into residential areas as it is today.

The estimation of the value of safety factors for landslides at the Santur location is carried out by following the Mohr-Coulomb equilibrium equation (figure 4) below:

$$\tau = c + \sigma \tan \phi \quad (1)$$

Furthermore, slope stability analysis is carried out using a generally accepted and very popular method of slices. By using numerical applications, the calculation of stability with this method is easier to be done. Stability is expressed in the form of a safety factor which compares the overall value of  $T_{\max}$  with the number of  $T$  values as follows:

$$SF = \frac{\sum T_{\max}}{\sum T} \quad (2)$$

where:  $T_{\max} = c \Delta A + N \tan \phi$  (see figure 5)

$T = W \sin \alpha$

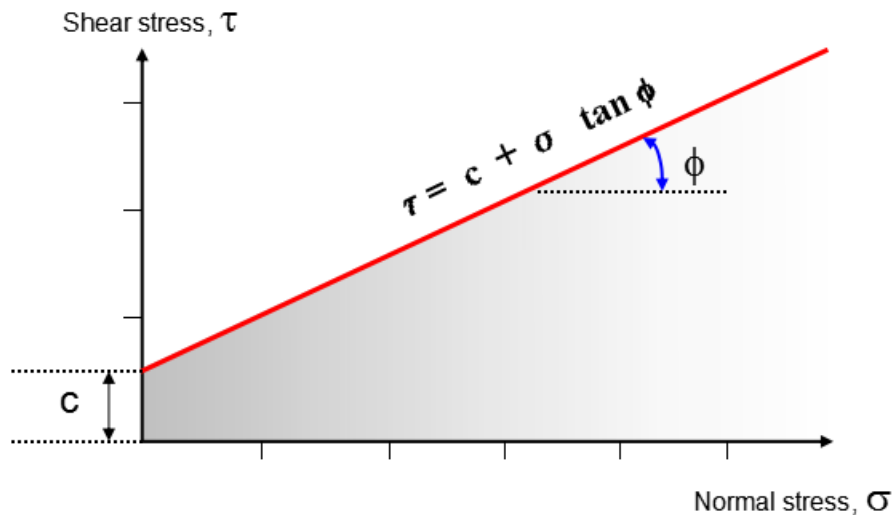
$N = W \cos \alpha$

$\Delta A = \Delta L / \cos \alpha$

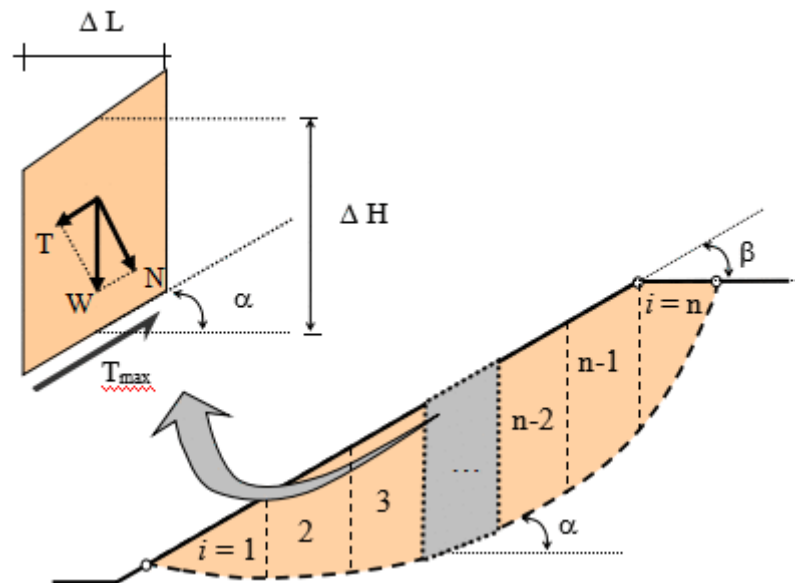
$\Delta H$  and  $\Delta L$  are the height and the length of the soil mass

$\alpha$  is the angel of the soil mass in respect to the horizontal axes

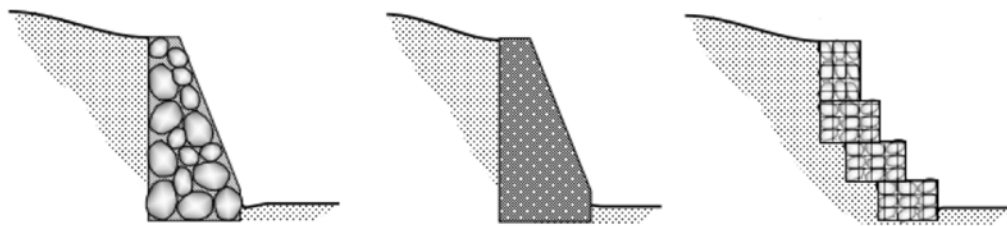
Slope stabilization is done by using several types of gravity retaining walls that are masonry retaining wall, concrete retaining wall and gabions (figure 6). This is done on the site since this type of wall is easily to be carried out in terms of materials, expertise of workers and the site conditions. Sheet pile or spun piles will be difficult to adopt by the limited area for equipment manoeuvring.



**Figure 4.** Soil strength for slope analysis.



**Figure 5.** Slice Method.



**Figure 6.** Gravity wall types for Santur Landslide.

The laboratory test results of soil gave the soil property data as follows: the moisture content of 28%, weight volume of  $1.62 \text{ t/m}^3$ ,  $S_u$  of  $1.1 \text{ kg/cm}^2$  and the sensitivity of 1,28. These values are then used in the stability analysis in terms of factors of safety. Based on the results of the slope stability analysis and chosen construction for stability countermeasure, the summarized results can be shown in Table 1 together with the cost estimation:

**Table 1.** Safety factors (SF) and estimated cost.

Type of retaining wall	SF	Volume	Cost (IDR)	Total Cost/SF
Just slope (no-wall)	2.45	0	n/a	n/a
Stone masonry wall	2.51	$4 \text{ m}^2/\text{m}$	800.000	1.275.000
Concrete wall	2.53	$4 \text{ m}^2/\text{m}$	1.500.000	2.372.000
Gabion	2.6	$6 \text{ m}^2/\text{m}$	600.000	1.385.000

Based on these results, to determine the right choice based on two main factors, namely slope safety and construction costs, the cost values are compared with factor of safety (SF) (table 1). It can be seen that without using a retaining wall, the factor is zero, but this value does not actually provide security since it collapses in reality. The comparison value for the construction of concrete walls is greater than the others which means it is very expensive and does not have good economic value. Whereas the stone masonry wall has the smallest value that indicates this construction can be chosen as the right option to be used in the Sanur area.

## 5. Conclusions

The government of Indonesia is dealing with economic growth development and trying to improve the quality of Indonesian human resources. The Strategic Plan of the Ministry of Public Works and Public Housing provides the goals for years 2015 to 2019. However the limitations of good land have resulted in new problems such as lack of water, unhygienic or prone to disasters. The Sawahlunto landslide resulted in disaster which destroyed 4 houses and damaged 12 others. Based on the observed data, including laboratory test obtained, the analyses of remedial work are simulated for the Sawahlunto landslide. The possible methods are compared in terms of the value of safety against landslide and the cost of the countermeasures. The chosen appropriate mitigation is based on the better comparison values. For this local landslide, the stone masonry wall has the smallest value that indicates this construction is the right option to be used in the Sanur.

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