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# The stability analysis study of conventional retaining walls variation design in vertical slope

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**Abstract**. One of the hazards that usually occur in slope is landslide. This disaster can occur due to various factors, such as soil material, load on the slope, and the presence of groundwater. Retaining wall is one of the reinforcements that can be applied in slope. This reinforcement is expected to overcome the landslide hazard that can possible to occur. For the conventional retaining wall in kind of gravity wall, the weight of structure influences the stability to retain the slope. Moreover, the weight of retaining wall is determined by its dimension. The assumptions of retaining wall dimension is determined by trial and error. If retaining wall is not enough to bear the load, the dimension of the retaining wall must be changed. In this study, analysing conventional gravity type of retaining walls with several variation designs in 3 meters vertical slope. As the limitation of this study, there are two layers cohesive soil behind the retaining wall. The retaining wall only relies on the weight of the structure as the basis of its design. Therefore, the relation between weight of retaining wall with stability of the structure itself can be known. Thus, the design of the suitable retaining wall that is used on the vertical slope in this study can be obtained. Results show that the greater the retaining wall, the value of the safety factor will increase. The design of the retaining wall with sloping wall on the front of the retaining wall gives greater safety factor than the design of the retaining wall with the slender shape.

## 1. Introduction

In the slope there is a landslide hazard to wary. Besides declivity of slope, this landslide can occur due to the condition of the soil material, load on the slope, and the presence of groundwater. For this reason, soil stabilization and soil reinforcement on the slopes are needed. Soil stabilization is the alteration of soils to enhance their physical properties. There are several methods in framework of soil stabilization, by using physical, chemical, mechanical, biological or combined method. Moreover, soil reinforcement is a technique used to improve the stiffness and strength of soil using geo-engineering methods. On the other hand, mechanically stabilized earth wall using artificial reinforcing to overcome landslide.

However, the common solution which is widely used for slope is retaining walls. Coduto (2011) stated that retaining wall is a structure designed to maintain two faces of different soil elevations [1]. There are two types of retaining walls, conventional retaining walls and mechanically stabilized earth walls [2]. For the conventional retaining wall, it can be formed by masonry stone, concrete, etc. In this soil retaining wall concept, the weight of the structure is very influential in resisting slope avalanches.

Stability analysis on the conventional retaining walls design can be viewed from various factors, overturning, sliding, bearing capacity, and deep-seated shear failure. The overturning and sliding failure are review of the retaining wall in holding the load that works. In addition, an analysis of bearing capacity failure is influenced by soil parameters. Moreover, deep-seated shear failure can occur along a cylindrical surface. The critical cylindrical failure surface which must be determined by trial and error, using various centers. The failure surface along which the minimum safety factor is obtained is the critical surface of sliding [2].

The main cause of landslides is the presence of gravitational force affecting a steep slope [3]. Thus, the safety factor of slope is influenced by the slope geometry itself where the steeper the slope the occurrence of landslide will be more potential. Moreover, the material parameters also can affect the landslide. For the cohesive soil will be more potential than non-cohesive soil. As the example, the existence of friction angle, for the cohesive soil the value of friction angle will be smaller than non-cohesive soil. The strength of sand is usually characterized by the peak friction angle $\varphi_p$ and the critical state friction angle $\varphi_{cv}$ [4]. In addition, water can also affect the stability of slope. As it is known that the soil submerged in water under saturated conditions will further reduce the strength of the soil to withstand the load above it.

In the gravity wall as conventional retaining wall, the stability depends on the weight of structure. Moreover, the assumptions of retaining wall dimension is determined by trial and error. If retaining wall is not enough to bear the load, the dimension of the retaining wall can be changed. Therefore, in this study, the relation between weight of retaining wall with stability of the structure itself can be known. Thus, the design of the suitable retaining wall that is used on the 3 meters high of vertical slope can be obtained. The height of gravity retaining wall used is 4 meters. As the limitation of this study, there are two layers of soil behind the retaining wall.

In this study, modeling simulation was performed using PLAXIS 2D. This numerical method has the advantage of considering more accurately the soil behavior, the soil-wall interface and also the ability to consider multiple hydraulic conditions and various options for modeling support conditions [5]. However, the result of Chogueur (2018) showed that, in terms of distribution and magnitude of active earth pressure, Rankine's theory possesses the highest match to the PLAXIS analysis and also it has the highest compatibility to finite element analysis among all theories [5].

## 2. Retaining Wall

The conventional retaining walls can be divided into four type, gravity, semi-gravity, cantilever, and counterfort retaining walls. The gravity retaining wall type is formed by concrete, stone, or a combination of both. Moreover, semi-gravity wall is constructed by modifying gravity wall. The semi-gravity walls use steel so that can minimize the size of wall sections. On the other hand, cantilever retaining wall is formed of reinforced concrete that consist of thin stem and a base slab. Moreover, the type of counterfort retaining wall has similar shape with cantilever but at some intervals, they have counterforts that tie the wall and the base slab together. The counterforts mean thin vertical concrete slabs. Each type of retaining walls can be seen in figure. 1

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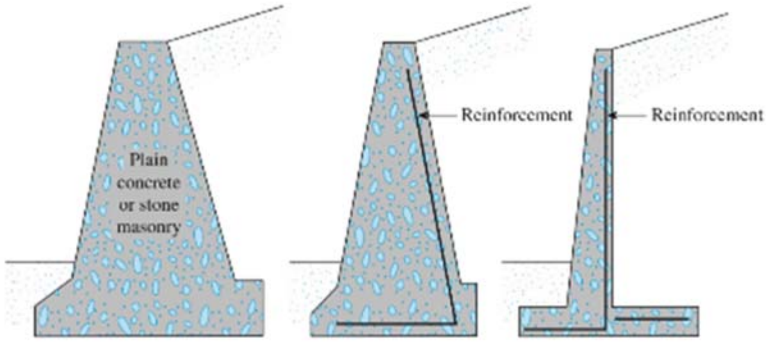
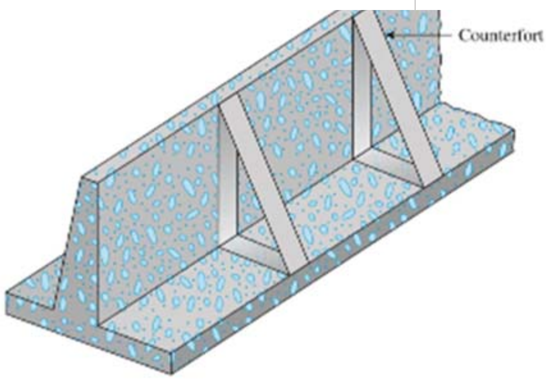



(a) Gravity wall (b) Semi-Gravity wall (c) Cantilever wall




(d) Counterfort wall

**Figure 1.** Types of retaining wall [2]

Stability analysis of retaining wall is influenced by loads which burden the structures. This load in the mechanic analysis can be known as force. This force mainly can be divided into two kind, lateral pressure and vertical pressure, that can be seen in Fig. 2. Lateral pressure itself comprises of soil and water pressure. There are two type of lateral soil pressure, namely active and passive pressure. The active pressure commonly located behind the retaining wall as the slope which want to retain. On the other hand, the passive pressure in front of the retaining wall is an additional force on the retaining wall to maintain the slope from collapse. If there is not soil in front of retaining wall, there will not any passive pressure. Moreover, the lateral pressure also includes water pressure if there is water existence in slope.

Furthermore, vertical pressure of retaining wall structure is influenced by load above the slope. The load can be house, vehicle, and huge tree. It will add load of retaining wall to retain the slope itself. Due to the load in structure, there are failures that possible to happen, overturning, sliding, bearing capacity, and deep-seated shear failures. The vertical forces also comprise of weight of retaining wall and weight of soil above it.

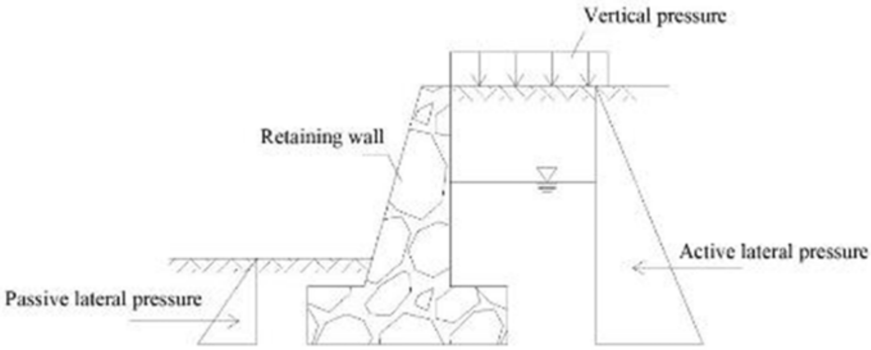



**Figure 2**. Forces distribution in retaining wall structure

Deep shear failure can occur along a cylindrical surface (abc) which can be seen in figure. 3 [2]. Moreover, in such cases, the critical failure surface can be determined by trial and error method. This method is done by giving various centres shown point O in figure. 3.

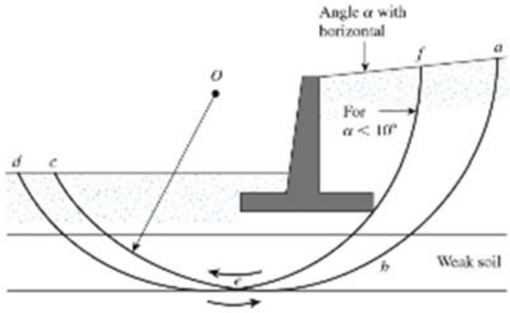



**Figure 3.** Deep-seated shear failure

In the gravity retaining walls, the stability depends on their own weight and any soil resting on the masonry. Weight in retaining wall is determined by its dimension. The assumptions of retaining wall dimension is determined by trial and error. If retaining wall is not enough to bear the load, the dimension of the retaining wall can be changed. Das (2014) gave the general proportions of various retaining-wall components that can be used for initial checks, as seen in figure. 4 [2]. The depth, which is denoted by D, should be minimum of 0.6 meters [2].

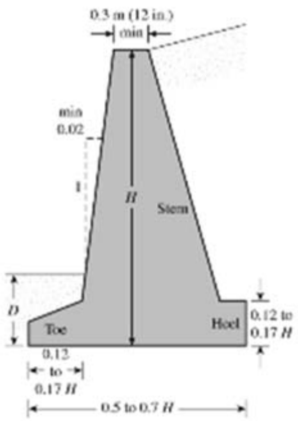



**Figure 4.** Approximate dimensions of retaining wall for initial stability checks [2]

## 3. Research Method

Failure surface of retaining wall can be reviewed with its safety factor. Calculating the safety factor can be used not only by empirical equation but also modeling simulation. In this study, the case study was modeling by PLAXIS 2D simulation. Preference using PLAXIS due to it applies finite element method where the calculated soil parameters are numerous and mutually continuous so that it is expected it can approach actual behavior. Very fine meshing was used to perform the model. In this case study, the slope was assumed to be 3 meters high perpendicular to the ground (the angle was $90^0$). According to Look (2007), slope which has 90 degree is classified as vertical slope [6]. Depicting in figure. 5, the slope geometry as case study.

Based on figure 5, there were two soil layers behind retaining wall as active pressure. Both of soil layers were cohesive soil. Cohesive soils potentially cause landslides than granular soil, so that it could be extreme condition which will happen. Clay belongs to cohesive soil which less dense soil. This type of soil has the potential for landslides, especially if there is rain. In addition, this soil is very susceptible to soil movement because it becomes soft when exposed to water and breaks when it gets too hot. As passive pressure in front of retaining wall has similarly with soil layer 2 which was located behind retaining wall.

In this case study was determined that height of gravity retaining wall was 4 meters. Design of retaining wall used can be seen in figure. 6. They were 8 designs in this case study. For design (a) until design (f) were determined based on same area value. Moreover, retaining wall (g) and (h) were designed with the design of retaining walls in general. The design still refers to approximate dimensions for initial stability checks of retaining wall by Das (2014) (figure. 4). Nevertheless, there are several modifications that were adapted to variations in this design so that can have same area value.

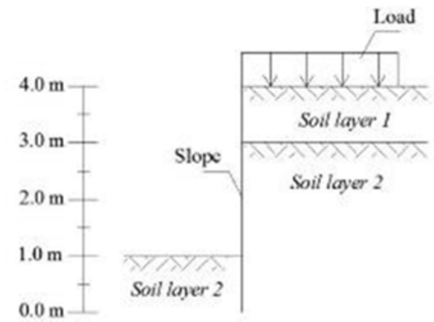
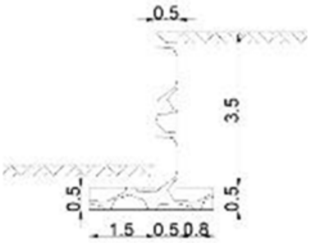
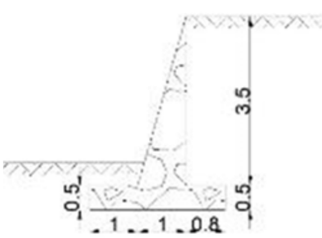



**Figure 5.** Slope geometry as case study

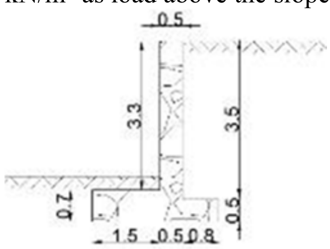
The surcharge values of 0, 10, 20, 30, and 40 kN/m$^2$ (Fethi, 2000) and Dicleli (2001) were used as design practical values for uniform loads and based on minimum design surcharge of 10 kN/m2 recommended by code of practice [7]. Therefore, in this study used 10 kN/m$^2$ as load above the slope.



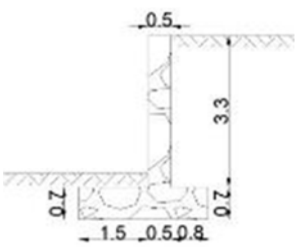

(a) Design a

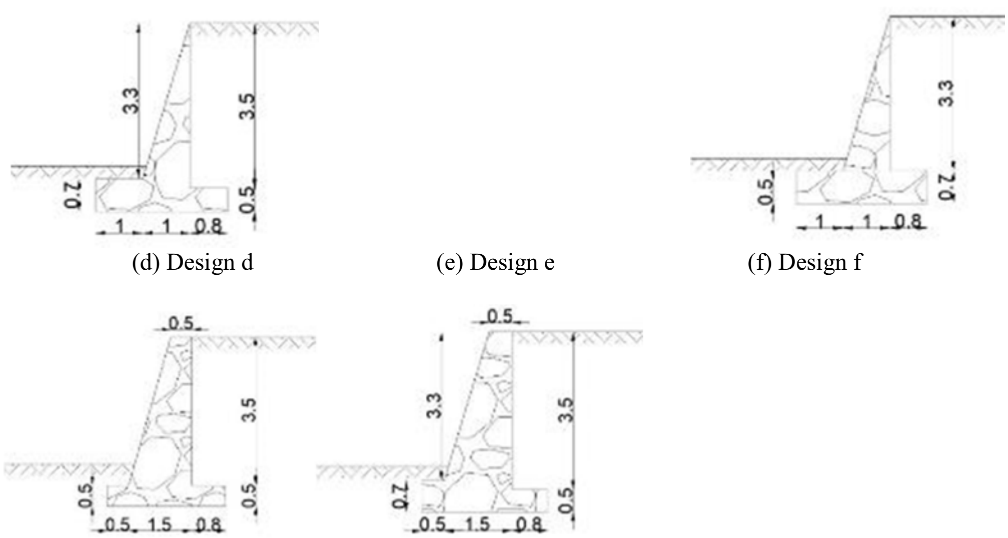



(b) Design b




(c) Design c






(d) Design d (e) Design e (f) Design f

(d) Design g (e) Design h

**Figure 6.** Variation design of retaining wall

In the PLAXIS modeling, the soil was modeled as Mohr-Coulomb and retaining wall as linear elastic with material type non-porous. The Mohr-Coulomb (MC) model is recommended to use for a first analysis of the problem considered [5]. Furthermore, material parameters of soil and retaining wall used in PLAXIS modeling can be seen in table 1. The stages of calculation were plastic calculation for slope analysis and phi/c reduction for safety factor analysis.

**Table 1.** Material parameters of soil and retaining wall

| Material Parameter | Soil 1 | Soil 2 | Retaining Wall |
|---|---|---|---|
| Material model | Mohr-Coulomb | | Linear elastic |
| Type of material behaviour | Undrained | | Non-porous |
| Dry unit weight (kN/m$^3$) | 14.715 | 15,206 | 22 |
| Saturated unit weight (kN/m$^3$) | 15.715 | 15,510 | |
| Permeability coefficient (m/day) | 1x $10^{-6}$ | 1x $10^{-6}$ | - |
| Cohesion (kN/m$^2$) | 13.734 | 14.715 | - |
| Friction angle ($^0$) | 13 | 15 | - |
| Young Mod. (kN/m$^2$) | 2x $10^5$ | 2x $10^5$ | 2,574x $10^7$ |
| Poisson ratio ( - ) | 0.40 | 0.40 | 0.15 |

## 4. Results and Discussion

Based on the modeling simulation that has been done, the safety factor for the geometry slope without load in figure. 5 was 1.8149. Furthermore, for the geometry slope safety factor with a load of 10 kN/m$^2$ reduced to 1.264. This load can be due to the existence of buildings, traffic which can exist over time in the development of a land. The low value of the safety factor is because the type of soil in the case study is clay soil. Clay with a very small friction angle causes a large active soil pressure. As said by Pratama (2014) Lateral soil pressure behind the retaining wall depends on the friction angle in the soil and cohesion [1].

Refers to GEO (1984) in Look (2007), safety factor of slope is 1.3 for high risk type [6]. Moreover, refers to Bolton (1993) in Osman and Bolton (2004) which illustrates the mixture of definitions of factor of safety in the Code of practice for earth retaining structures (CP2) (British Standards

Institution 1994), for a deep circular slip, a factor of safety of 1.25 is used [8]. Safety factors on slopes that do not comply with the safety factor requirements can cause slope collapse or landslide.

Mass movement is a movement of large soil masses along the critical landslide field [9]. The movement is a downward movement of slope-forming material that can be in the form of soil, rock, landfill or a mixture of other materials, if the movement is very excessive then it is a landslide. Therefore, a retaining wall as one of the landslide preventions is needed on the slopes of this study case.

There were 8 types of retaining wall various designs which had been modeling in PLAXIS. The weight of retaining wall can be calculated as multiplying the volume per meter with the weight of the volume of the stone. The weight of each retaining wall design shown in table 2 with weight of stone is 22 kN/m$^3$.

As has been explained in the research method, from each design, there are two retaining walls which have the same area, that is in design (a) and (b), design (c) and (d), and design (e) and (f). Moreover, for the designs of (g) and (h) were the design of the retaining wall which were generally used. The main feature is the sloping wall on the front of the retaining wall. The gravity wall must be retained and prevent sliding that may occur. This landslide is viewed from the safety factor modeled with PLAXIS in this case study. The value of safety factor obtained based on each design can be seen in table 2.

**Table 2.** Safety factor of retaining wall in each design

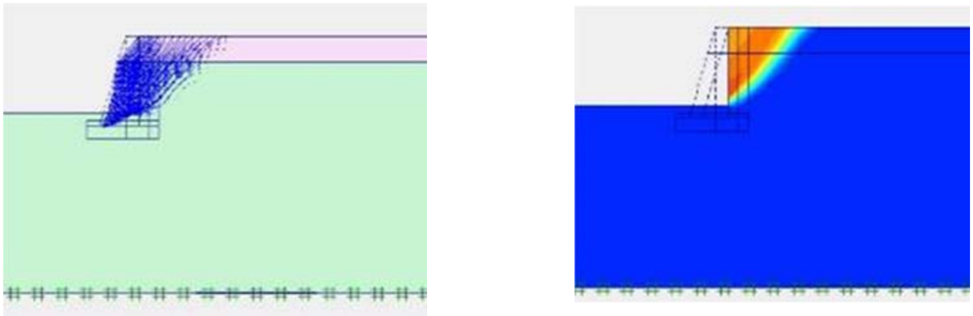
| No | Type | Area (m$^2$) | Weight (kN) | Perimeter (m) | Safety Factor | Note |
|---|---|---|---|---|---|---|
| 1 | Design a | 3.15 | 69.30 | 13.60 | 2.3209 | Has same area value |
| 2 | Design b | 3.15 | 69.30 | 12.74 | 2.3294 | |
| 3 | Design c | 3.45 | 75.90 | 13.60 | 2.3321 | Has same area value |
| 4 | Design d | 3.45 | 75.90 | 12.75 | 2.3466 | |
| 5 | Design e | 3.61 | 79.42 | 13.60 | 2.3308 | Has same area value |
| 6 | Design f | 3.61 | 79.42 | 12.75 | 2.3475 | |
| 7 | Design g | 4.90 | 107.8 | 12.74 | 2.1943 | General design |
| 8 | Design h | 5.10 | 112.2 | 12.75 | 2.2103 | |

The results obtained show that in the case of designs (a) to (f), the greater the area of the retaining wall which results in greater the weight, the greater the safety factor. The smallest safety factor is 2.3209 in design (a) with weight of 69.30 kN and the largest safety factor of 2.3475 in design (f) by weighing 79.42 kN. This result like as in Nurrohman's study (2016) which showed that the dimensions of the retaining wall affect the safe number (SF) value, the larger the dimensions of the retaining wall, the slope safe value (SF) value is also greater [10]. Furthermore, from design (a) to (f) can be seen that for designs that have larger perimeter it turns out to provide a smaller safety factor even with the same area and weight. This is because the form of the retaining wall in the designs (a), (c), and (e) is slenderer like cantilever retaining wall. As known, that for cantilever retaining wall is needed reinforcement as retrofitting. Whereas, designs (b), (d), and (f), although they are smaller in weight but are more proportional in terms of design in terms of toe and heel dimensions. They have also sloping wall on the front of the retaining wall which gives more force to retain the active pressure.

Moreover, for the general design used, design (g) and (h) give the same results where the greater the weight, the greater the value of the safety factor. Although when compared with designs (a) to (f), the safety factor does not increase sequentially with design (a) to (f) because they are only 2.1943 and 2.2103 respectively for the (g) and (h) designs with weight of 107.8 kN and 112.2 kN.

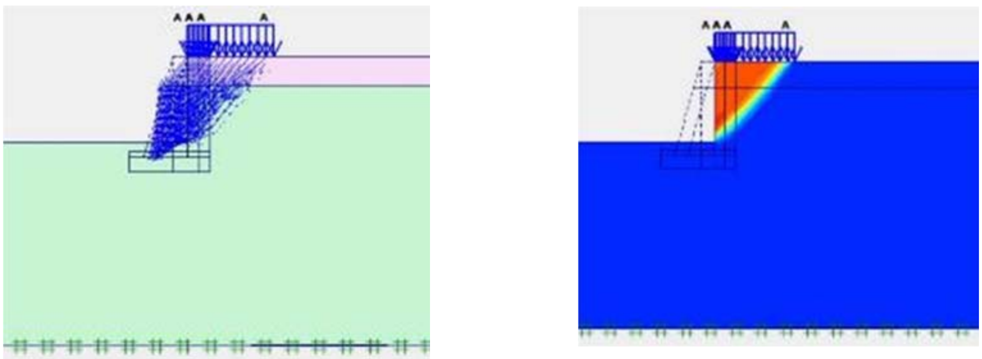
Furthermore, the pattern of landslide on the slope before being given a load and after being given a load can be seen in figure. 7 and figure. 8. The direction of movement shows diagonal sliding occurs.

In addition, even though the arrows in the conditions before and after being given the slope are almost the same, the shading of displacement that occurs is greater after the load is given, resulting in slope failure.



(a) Landslide arrows (b) Landslide shadings

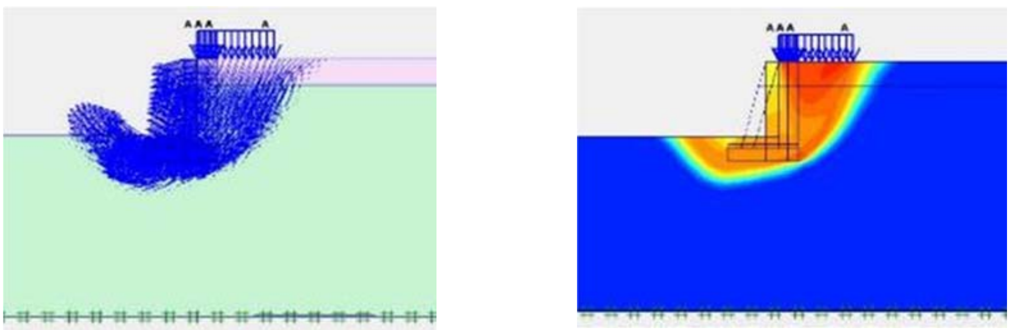
**Figure 7.** Load-free slope failure



(a) Landslide arrows (b) Landslide shadings

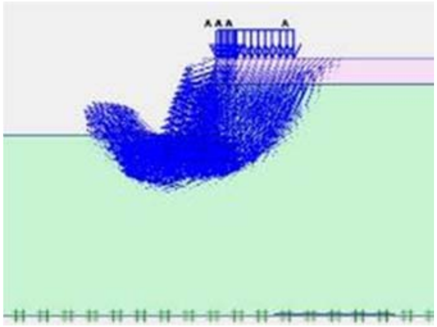
**Figure 8**. Slope landslide with load

The pattern of landslide on the retaining wall was taken in design (a) to (f) which had the lowest and highest safety factors, designs (a) and (f). The pattern of landslide can be seen in figure. 9 and figure 10 for designs (a) and (f), respectively.

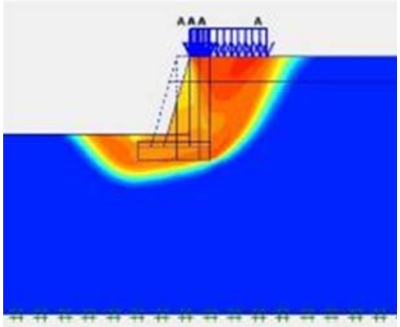


(a) Landslide arrows (b) Landslide shadings

**Figure 9.** Landslide on retaining wall design (a)



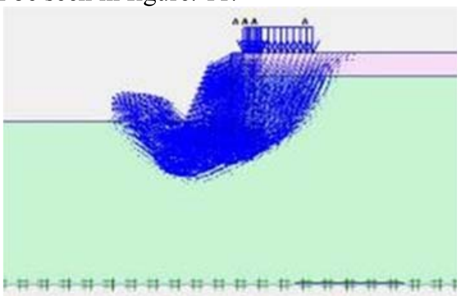

(a) Landslide arrows



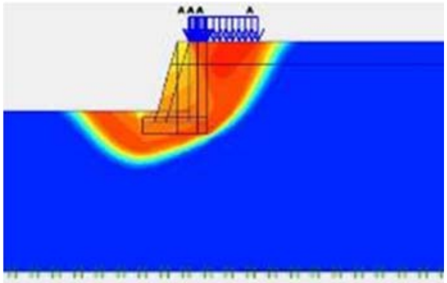

(b) Landslide shadings

**Figure 10**. Landslide on retaining wall design (f)

From figure. 9 and figure. 10, although the arrows in both designs are almost the same but can be seen in the shading that the displacement that occurs in the design (f) is greater than the design a. This is because the retaining wall in the design (f) has a greater weight than retaining wall designs (a). Meanwhile, in the (h) design where it has a more compact form of retaining wall, its sliding pattern can be seen in figure. 11.




(a) Landslide arrows




(b) Landslide shadings

**Figure 11.** Landslide on retaining wall design (h)

Thus, it can be seen from the results that have been obtained, the heavier the retaining wall is used, the higher the value of the safety factor. However, for displacement in the landslide, it will result in a large displacement. This is because gravity retaining walls are constructed with plain concrete or stone masonry. They depend on their own weight and soil resting on the masonry for stability. So that, the weight of the retaining wall will affect the magnitude of the displacement that occurs. Moreover, understanding the type of soil on the slope is also very necessary. This is due to knowing the properties of the soil behind the wall enables to determine the lateral pressure distribution that must be designed for.

## 5. Conclusion

The retaining wall is one of the concepts of soil reinforcement that is used to hold ground loads vertically or to certain slopes. The steep slopes or cliffs will increase the driving force. The steep slopes are formed due to the erosion of rivers, springs, sea water and wind. In addition, there are additional burdens such as building loads on the slopes, and vehicles will increase the driving force for landslides.

High failure of retaining wall will cause a catastrophic and will affect surrounding areas. Therefore, the right design of retaining wall on the slope is needed. Based on the results of this research, it can be concluded that in the vertical slope with the cohesive soil type, the greater the retaining wall, the value of the safety factor will increase even though the increase is only small. The design of the retaining wall with sloping wall on the front of the retaining wall gives more force to retain the active pressure.

So that it gives a greater safety factor than the design of the retaining wall with the slender shape. However, it is necessary to consider the aspect of displacement, because the weight of the retaining wall adds to the load that must be borne by the slope.

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