Multi-storey precast retaining walls to prevent landslides: derivation of the basic formula

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Abstract. Landslides can involve both large and small soil masses. Many geotechnical researchers focus on large-scale landslide problems. The retaining walls required for large landslides also involve large dimensions. The national standards also only cover the dimension of retaining needed to prevent large landslides. There are landslides that only involve small masses of soil. For this reason, the needed retaining walls are also in small dimensions. Small retaining wall dimensions do not need to follow national standards for maintaining the efficiency and effectiveness of application. In this paper, a precast retaining wall is designed which is used to retain soil on a relatively small scale. The designed retaining wall can be used also in multi-level to restrain the larger landslide. There are three main elements of the retaining wall: base plate, wall plate, and connector beam. The retaining wall elements are made of concrete material with bar reinforcement and wire mesh. The weight of each wall element is less than 50kg so it is portable. The wall prototype has been made and is ready to be applied in the areas with potential landslides.

1 Introduction

Landslides are geological disasters that often occur in hilly areas. This disaster can result in huge losses, both in terms of material, loss of human life, and environmental damage. In West Sumatra Province, on July 1 2023 alone, more than 10 landslides were reported [1]. More than 2000 landslide disasters in Indonesia in 2021-2023 have been reported.

Specifically in West Sumatra, the incident that is of concern is the landslide in Kubang Tangah Village - Sawah Lunto City. This village is located in a hilly area. This landslide occurred in April and May 2023. Apart from blocking the main access road, this incident resulted in several houses being buried in the ground. From observations made, this area is covered by a layer of sandstone. This sandstone layer was the one that collapsed. At several points, landslides also carried weathered limestone rock material.

The use of retaining walls to overcome landslides is still the choice of engineers. Reinforced concrete cantilever retaining walls to prevent landslides in difficult areas need to be specially constructed [2]. The use of retaining walls in areas with poor slopes must be designed to remain safe and meet specified criteria. This takes into account the various types of failure that may occur. The stability of the retaining wall is primarily against overturning and slipping. The results of the design are wall dimensions and the shape of special elements to resist wall movement. This study also concluded that of the various types of retaining walls, the cantilever retaining wall type is more feasible to solve the case being handled.

Landslides also may involve large and small soil masses. Many geotechnical researchers focus on large-scale landslide problems. The retaining walls required for large landslides also involve large dimensions. Further, the national standards also only cover the dimension of retaining needed to prevent large landslides. There are many landslides that only involve small masses of soil. For this reason, the needed retaining walls are also in small dimensions. Small retaining wall dimensions then do not need to follow national standards for maintaining the efficiency and effectiveness of application.

Based on experience in cases of Retaining Wall failure, a study of the height that is still feasible for certain types of retaining walls was carried out [3]. The results of this study show that the gravity-type retaining wall will easily fail if it is made more than 8. Meanwhile, the cantilever-type retaining wall can still stand in a stable
series up to a height of 14m. This study suggests optimization for retaining wall planning.

Optimization studies of retaining wall type cantilever and gravity and sheet pile were successfully carried out [4]. The results show that for a limited height of up to 7 m, the gravity-type retaining wall still provides optimum values. But for higher heights, a retaining wall cantilever is cheaper. Compared to retaining walls, sheet piles provide the most expensive costs.

Retaining walls are useful in protecting against landslides by increasing security in areas that have the potential to landslide. Retaining wall construction often takes a long time. For the need to combine innovative technology with the principles of landslide resistance to protect the environment and human life. The technology referred to here is precast technology.

Retaining walls made on-site require access to transport materials to the location. Meanwhile, precast retaining walls require access to transport the wall pieces to the installation location. Hard-to-reach locations require special access or special equipment to transport wall materials. This special tool is needed especially for transporting heavy wall materials. For this reason, in locations where access is difficult, the wall material must be made as light as possible so that it can be moved only by workers.

2 Methodology

Retaining wall design is a study that is always interesting in the field of geotechnical engineering. Reviews of retaining wall planning procedures have been published by several researchers.

The study describes the analysis and design of a cantilever-type retaining wall with varying heights from 3m to 10m and surface loads have been done [5]. In the study, a comparative study was also carried out on cantilever retaining walls and stepped platforms on costs, bending moments, overturning, and shear stability. The best option which is cheaper and more stable is for a wall with a stepped platform behind the wall compared to a regular cantilever.

It has been confirmed that the stability of the retaining wall is primarily against overturning and slipping [6]. This stability must take into account the main force, namely the lateral earth pressure of the soil behind the wall. Determining the working load and the point of action of the force is important in designing a retaining wall. Apart from that, specifically for gravity retaining walls, it has been concluded that the construction sequence is also an important factor that needs to be considered in the design.

The stability of retaining walls due to overturning and sliding is limited in the form of the following safety factors:

Safety factor for overturning, SFo:

\[ SFo > 1.5 \]

Safety Factor for sliding, SFs:

\[ SFs > 1.2 \]

The safety factor for foundation bearing capacity, SFq is:

\[ SFq > 2.5 \]

The soil parameters used for retaining wall planning are self-weight and soil strength. These two parameters must be determined in such a way as to guarantee the safety of the foundation, namely the fulfillment of the minimum safety factor limit [7]. This study makes a comparison between the parameters used during design and at certain times. The results show that there is a decrease in service from the retaining wall when the current parameters are used. For this reason, it is recommended that parameters be adjusted if necessary so that retaining wall services can be guaranteed for a certain time.

3 Results

From various references that have been put forward, it has been revealed that the stability of retaining walls is mainly in the form of overturning, shearing, and the bearing capacity of the foundation. Meanwhile, the working load is due to the lateral pressure of the soil behind the wall. The lateral load \( P \) causes a moment \( Mo \) at the front end and causes shear \( T \) at the base of the foundation (Fig. 2).

![Fig. 2. Main loads on retaining walls.](image)

The overturning moment is:

\[ Mo = P \left( \frac{1}{3}, H \right) \]  

where:

\[ P = \frac{1}{2} \cdot p \cdot H \]  

\[ p = Ka \cdot H \cdot g \]

Ka is the active lateral coefficient

Meanwhile, to support the workload, retaining walls rely on the self-weight of the soil behind the wall \( W \). This load produces a moment of resistance \( Mr \) which acts on the front end of the retaining wall (Figure 3).

![Fig. 3. Resistant moment of retaining walls.](image)
The moment of resistance can be calculated using the following formula:

\[ Mo = W \left( \frac{1}{2} \cdot B \right) \]  
\[ W = w \cdot B \]  
\[ w = B \gamma \]  

Further, the bearing capacity of the foundation on the retaining wall must be greater than the soil reaction (max) due to the vertical loads and moments that occur (Fig. 4). Assuming that the soil reaction due to the active load \( P \) (in the form of \( Mo \)) is triangular, the soil reaction is:

\[ q_{max} = \frac{W}{B} + \frac{Mo}{2/3 \cdot B} \]  
\[ q_{min} = \frac{W}{B} = w \]  

The maximum moment is:

\[ M = \max (M_w, M_p) \]  
\[ M_w = \frac{1}{8} w' L^2 \]  
\[ M_p = \frac{1}{8} p' L^2 \]  

The maximum shear force is:

\[ L = \max (L_w, L_p) \]  
\[ L_w = \frac{1}{2} w' L \]  
\[ L_p = \frac{1}{2} p' L \]  
\[ p' = \left( \frac{2}{3} \right) H \cdot g \cdot K_a \]  

Specifically for precast retaining walls in this study, the internal stability is achieved by installing steel at the top and bottom ends (Figure 7). The stress that occurs in the steel is caused by the loads acting on the retaining wall. The tensile value of steel for design is determined from the maximum stress that may occur due to horizontal or vertical loads:

\[ S = \max (S_w, S_p) \]  
\[ S_w = \frac{S_w'(B^2 + H^2)^{1/2}}{H} \]  
\[ S_p = \frac{S_p'(B^2 + H^2)^{1/2}}{B} \]  
\[ S_w' = \frac{M_r}{B} \]  
\[ S_p' = \frac{M_o}{H} \]
Based on the formulation described above, in this study, a prototype of a precast retaining wall has been created. The weight of each element is less than 50 kg. Pre-chasting has already on separate locations (Figure 8). The assembling process of the retaining wall will be carried out soon at the landslide location in Kubang Tangan Village - Sawah Lunto City.

**Fig. 8.** Precast element of the retaining wall.

4 Conclusions

The design procedure for precast retaining wall elements to prevent landslides has been described. This design procedure follows the basic design of retaining walls in general. Retaining wall elements are designed to withstand working loads due to soil pressure.

Based on those procedures, the element of the retaining wall has been successfully designed. Then, elements of the retaining wall have also already precasted. Each retaining wall element then is ready to be lifted moved and assembled at the installation location.

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References