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doi:10.5937/jaes0-29558

Cite article:

Yoga Purnama A., Oktaviana Latif D., Wahyu Kurniawan A., Adriyati M. (2022) IMPLEMENTATION OF BUILDING INFORMATION MODELING ON SLOPE STABILITY AND MITIGATION ANALYSIS IN ACEH, INDONESIA, *Journal of Applied Engineering Science*, 20(1), 293 - 299, DOI:10.5937/ jaes0-29558

Online aceess *of full paper is available at: www.engineeringscience.rs/browse-issues* doi:10.5937/jaes0-29558

Paper number: 20(2022)1, 931, 293-299

IMPLEMENTATION OF BUILDING INFORMATION MODELING ON SLOPE STABILITY AND MITIGATION ANALYSIS IN ACEH, INDONESIA

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Slope failure in the well site area in Aceh, Indonesia caused the termination of gas distribution and resulted in financial loss. Based on the visual observation, the slope failed due to the high intensity of rainfall, which influenced the reduction of soil shear strength of the slope embankment. Moreover, the slope reinforcement has been damaged due to the collapsed trees on the slope embankment. Slope stability analysis was carried out by using a two-dimensional (2D) numerical method in several section areas to determine the appropriate slope reinforcement or countermeasures. Based on the 2D slope stability analysis, the Building Information Modeling (BIM) was performed by using a 3D projection drawing to evaluate the detailed information of the area which was applied by the countermeasures system. This method describes the total area and material quantity covered by the countermeasure system to determine the information material quantity and land acquisition area. Furthermore, the implementation of BIM in this study provides detailed information during the construction process to ensure comprehensive landslide mitigation.

Key words: slope failure, numerical analysis, 3D projection drawing, BIM

INTRODUCTION

Slope failure occurred in the well site area in Aceh Province, Indonesia after heavy rainfall, and it affected the stability of the building in the facility area near the slope. The location of the landslide was close to the air cooler system and the gas pipeline, which forced the gas distribution to stop, and it caused a lot of financial loss. Based on the visual observation, the landslide occurred due to the high intensity of rainfall, which affected the reduction of soil shear strength on the slope embankment. The effect of high rainfall causes the soil to become saturated, and water is trapped inside the soil voids. This condition increases the degree of saturation and decreases soil shear strength drastically [1]. In addition, the collapsed trees on the surface of the slope caused excessive loads and ruined the combi-grid as a slope reinforcement system. The additional load at the top of the slope can increase the gravity load and it can cause slope failure [2]. The condition of the well site area after the landslide is shown in Fig. 1. This research was conducted to determine the appropriate slope reinforcement/countermeasure to increase the slope stability, thereby allowing the building in the facility area to be normally operated, including the effect of earthquakes and rainfall that might occur in the future. Analysis of the slope failure countermeasures was carried out to determine the safety factor and displacement to evaluate the appropriate recommendations for landslide mitigation. Based on the preliminary analysis, there are several problems that can be identified, such as the condition of the embankment, which is located in a high-risk area, erosion on the slope surface, contour changes, and the additional load due to collapsed trees. Therefore, it is necessary to analyze the slope failure in an integrated system to determine the safety factor of the design recommendations. In addition, the Building Information Modeling (BIM) method was carried out to integrate the mitigation analysis between design and construction to get comprehensive landslide mitigation.

Figure 1: Slope failure area

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BUILDING INFORMATION MODELING (BIM)

Building Information Modeling (BIM) has become popular in recent years. The National BIM Standard-United States® (NBIMS-USTM) defines BIM as a digital representation of physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life cycle from inception onwards [3]. The implementation of BIM in structural aspects is already well implemented. However, for the geotechnical aspects, it remains uncommon. Infrastructure projects usually consist of geotechnical and structural aspects which may be implemented by BIM, but it seems to be neglected for the geotechnical aspect. This condition can lead to costly mistakes [4]. BIM allows AEC professionals, operations management, and owners to manage an asset more wisely and cost-effectively. Geotechnical BIM is becoming an inevitable component of BIM [5]. Three-dimensional visualization models have been widely utilized by structural engineers, geologists [6], hydrogeologists [7], [8], [9], and petroleum engineers [10]. However, it did not attract the attention of geotechnical engineers [11]. According to [12], BIM is classified into three main principles and digital data (3D) when applied to geotechnical engineering, as shown in Fig.2. BIM needs agreed repeatable procedures, methods, and workflows to access, capture, process, and share data and information easily. BIM can also visualize and analyze data from other disciplines to ensure engineers and make decisions more precise. By managing data and information, it can be used for future projects. Digital data (3D) is the principal thing to obtain the advantages of BIM. So, in this paper, Building Information Modeling (BIM) is carried out to determine the information about the material quantity and land acquisition area covered by the countermeasure system.

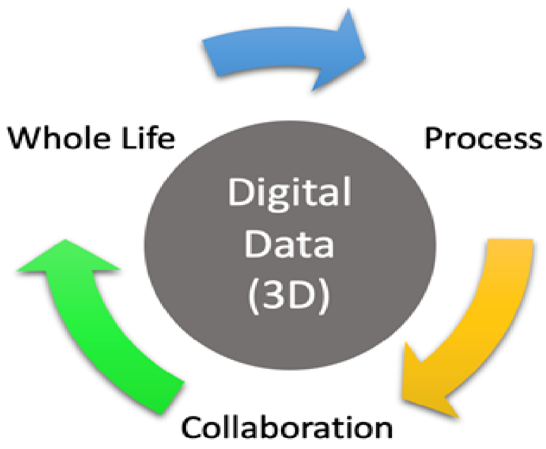

Figure 2 : BIM principles [12]

METHODOLOGY

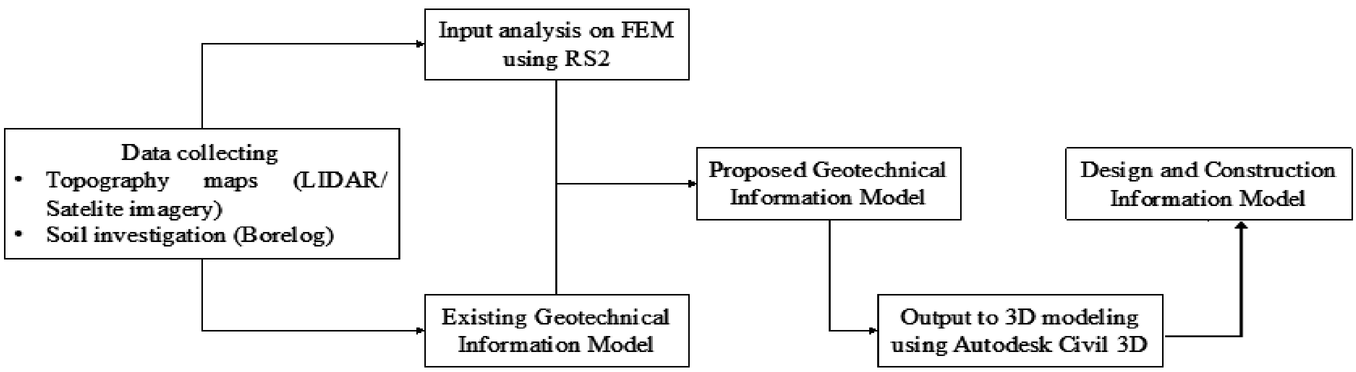

Figure 3: Flowchart of the analysis

The flowchart of the analysis is shown in Fig.3. The data such as topography and soil investigation were collected and analyzed to get the existing geotechnical information model and input into 2D numerical analysis using RS2. Based on the design, the proposed model was projected into a 3D drawing, so it can obtain the design information modeling for slope stability analysis and mitigation.The numerical analysis was carried out using the 2D finite element method on Rocscience software (RS2). Theoretically, the minimum safety factor for a stable slope is 1,00. However, to cover the uncertainty in the construction process, the value of the safety factor should fulfill the minimum requirement based on Indonesian standard [13], which is 1,50 for permanent condition and 1,10 for temporary condition. The plain strain model that assumes homogeneous isotropic layers with 2D mesh should meet the requirements of the boundary condition [14]. The width of the model is four times larger than the length of the embankment, and the depth of the model is at least 5 times the height of the embankment or until the hard soil due to the maximum stress area corresponds to the loading of the embankment. Earthquake analysis is determined by the value of the peak ground acceleration (PGA), where the results are obtained based on the earthquake map of Indonesia. Based on [13], the horizontal seismic coefficient, kh, is determined to be 0.5 of the horizontal peak ground acceleration by determining the location and amplification factor, which has a PGA of 0.30g in the Aceh area.

RESULTS AND DISCUSSIONS

Site Investigation

Based on the regional geological aspect conditions, the slope failure area is included in the Meulaboh geological map [15] and, from the rock formations or lithology, it consists of coastal and river deposits which include gravel, sand, and clay. To determine the soil layer in detail, the evaluation of the soil investigation data is carried out in this area. Fig. 4 shows the 3D visualization of the existing conditions based on LIDAR and satellite imagery. Fig. 5 shows the contour map of the well site area and the location of soil investigation points. Three bore holes, BH-01, BH-02 and BH-03, were conducted to find out the detailed soil layers. The contour map used for analysis is based on the field survey, soil investigation, and laboratory test results which are used as a reference in conducting analysis and evaluation based on [13]. Fig. 6 shows the soil stratigraphy based on the value of N-SPT with soil conditions consisting of soft clay, medium clay and hard clay. According to Fig. 4 and Fig. 5, the slope slice for every section can be determined on Autodesk CIVIL 3D and converted to a 2D model as input for numerical analysis by using RS2.

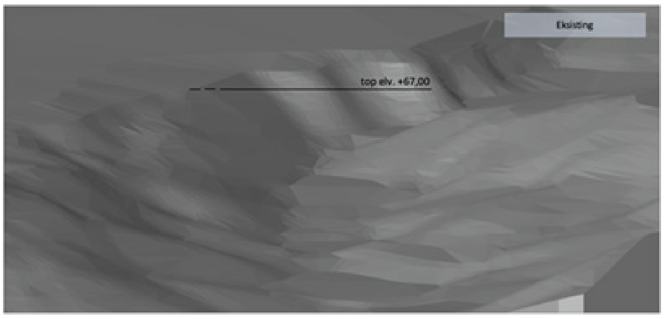

Figure 4: Topography map based on LIDAR and satellite imagery in 3D view.

Figure 5: Topography map based on LIDAR and satellite imagery in 2D view

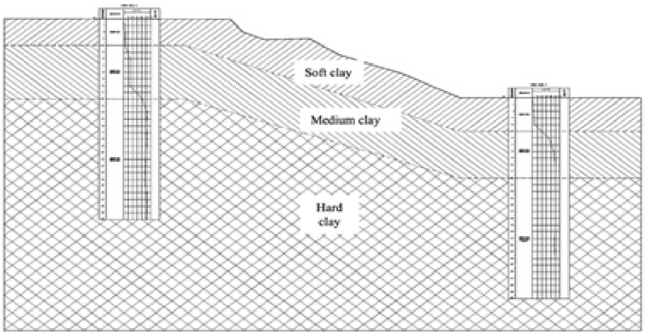

Figure 6: Soil layers based on soil investigation

Table 1: Engineering properties of soil

Soil type	γb (kNm^3)	E (kN/m^2)	c (kN/m^2)	ø (˚)
Soft clay	16	5000	10	10
Medium clay	18	10000	20	10
Hard clay	20	20000	30	10
Embankment	18	40000	15	30

Engineering properties used as an input on numerical analysis are obtained from the results of stratigraphic observations based on BH-01, BH-02, and BH-03, both from laboratory test results and field test results. The input parameters in the numerical analysis model are obtained based on laboratory tests. The approach value is adjusted by reference according to [16], [17], [18], [19], [20]. The soil parameters are shown in Table 1.

Two-dimensional numerical analysis

The two-dimensional numerical analysis was performed using a plain strain model on 4 sections of slope (section A-A, section B-B, section C-C and section D-D) which are located in the critical area as shown in Fig. 5. Engineering properties as an input for numerical analysis are the results of stratigraphic observations of data BH-01, BH-02, and BH-03 as shown in Table 1. In addition to increasing the slope stability, the additional embankment was applied as a countermeasure to the slope. This embankment option was selected to put a distance between the building in the facility area and the edge of the slope. Moreover, the additional embankment could be useful as a countermeasure and is easy to implement in construction.

Table 2: Summary of slope safety factor

Section	Static/ Permanent	Dynamic/ Temporary
Section A-A	2.30	1.34
Section B-B	2.34	1.25
Section C-C	2.09	1.29
Section D-D	2.19	1.37

The numerical analysis is continued with the additional embankment method, which has a slope ratio of 1H: 2.5V for all sections. The recommended slope ratio was selected to obtain results which qualified the safety conditions and design based on the minimum safety factor value requirements [13]. The results of numerical analysis for static and dynamic loading for section A-A can be seen in Fig. 7 for static condition and Fig. 8 for dynamic condition. Table 2 shows the summary of slope safety factors based on 2D numerical analysis for all sections.

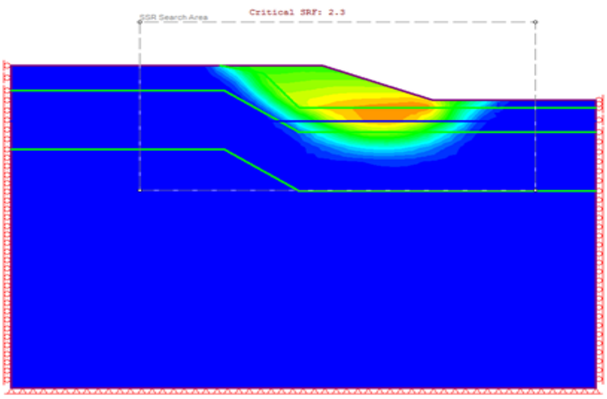

Figure 7: Two-dimensional numerical analysis result for section A-A in static condition

Based on the numerical analysis, it can be informed that the additional embankment can increase the safety factor of the slope for both static and dynamic loading conditions in all sections. It means that the additional embankment could represent a countermeasure to the landslide which occurred in the facilities area. The value of the safety factor for all sections also satisfies the minimum requirement of the standard [13] for both permanent and temporary loading by using earthquake load. Thereafter, the 2D model from numerical analysis was plotted into the 2D visualization referring to the existing topography condition. The results for all critical sections are shown in Fig. 9.

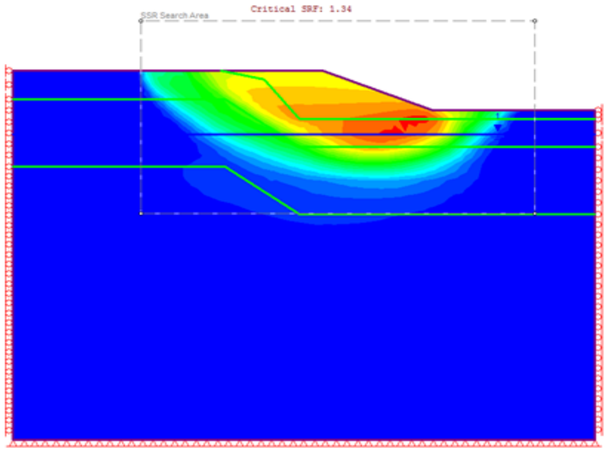

Figure 8: Two-dimensional numerical analysis result for section A-A in dynamic condition

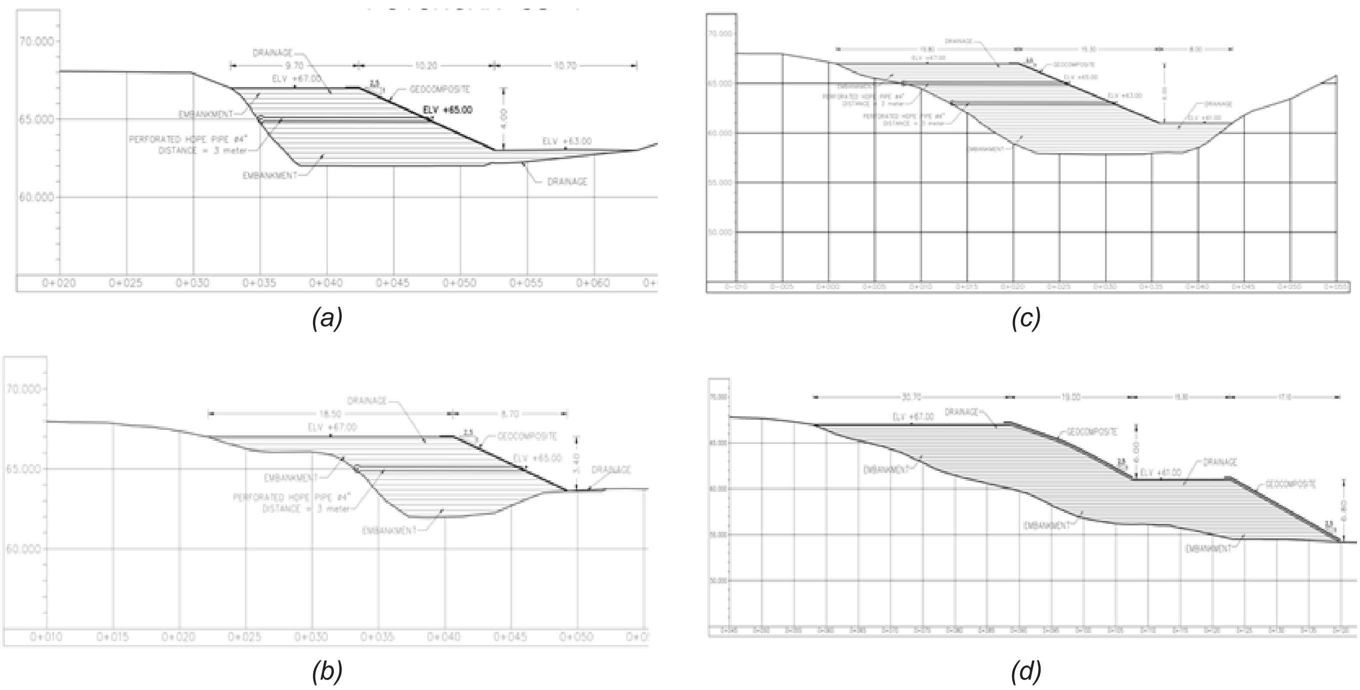

Figure 9: Geometry for slope after countermeasures applied (a) Section A-A (b) Section B-B (c) Section C-C (d) Section D-D

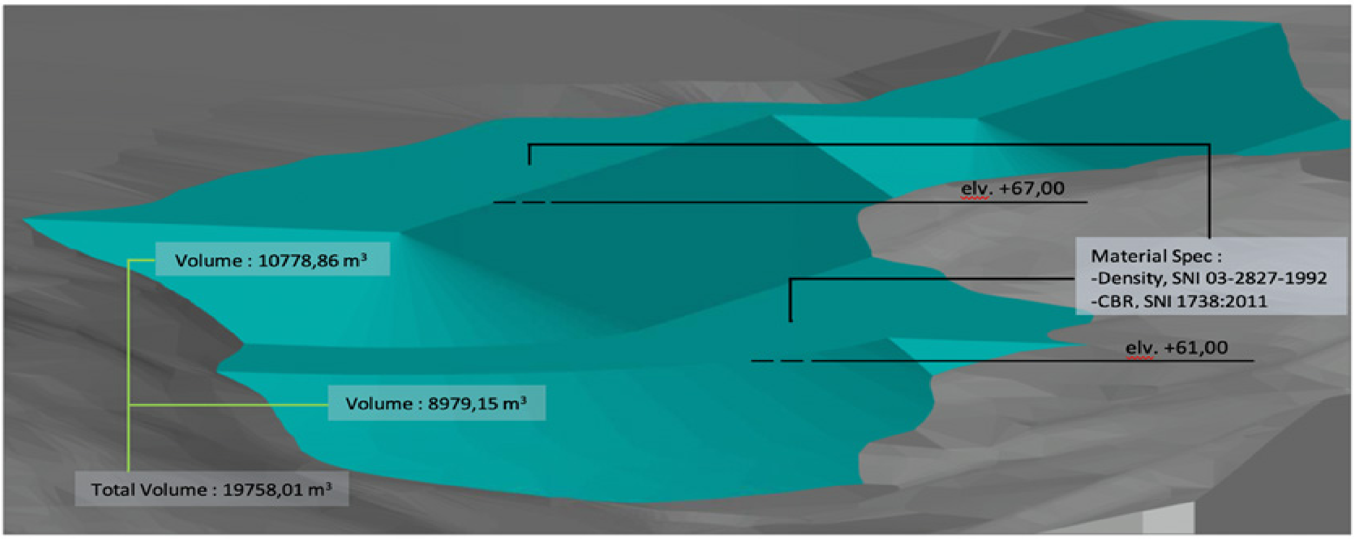

Figure 10: Final design for slope in 3D visualization

Three-dimensional projection

Each section provides a different volume of additional embankment due to the different geometry and condition of the slope. In addition, it needs to make a lot of sections to ensure the detailed volume of embankment that is needed as a countermeasure in the 2D model. Therefore, in the 3D visualization model, the whole embankment can be plotted according to the 4 sections which already analyzed and generalized the whole embankment in the countermeasure area as shown in Fig. 10. Based on the results of the 3D projection, it can be seen the whole area that needs to be repaired and determine the required quantity of embankment material. If 2D visualization is done, it takes a lot of sectional slices to find out the detailed dimensions of each point. By using a 3D visualization model, each sectional slice can be determined and checked automatically when necessary. The stages of each construction can also be modeled according to the field conditions as shown in Fig. 11.

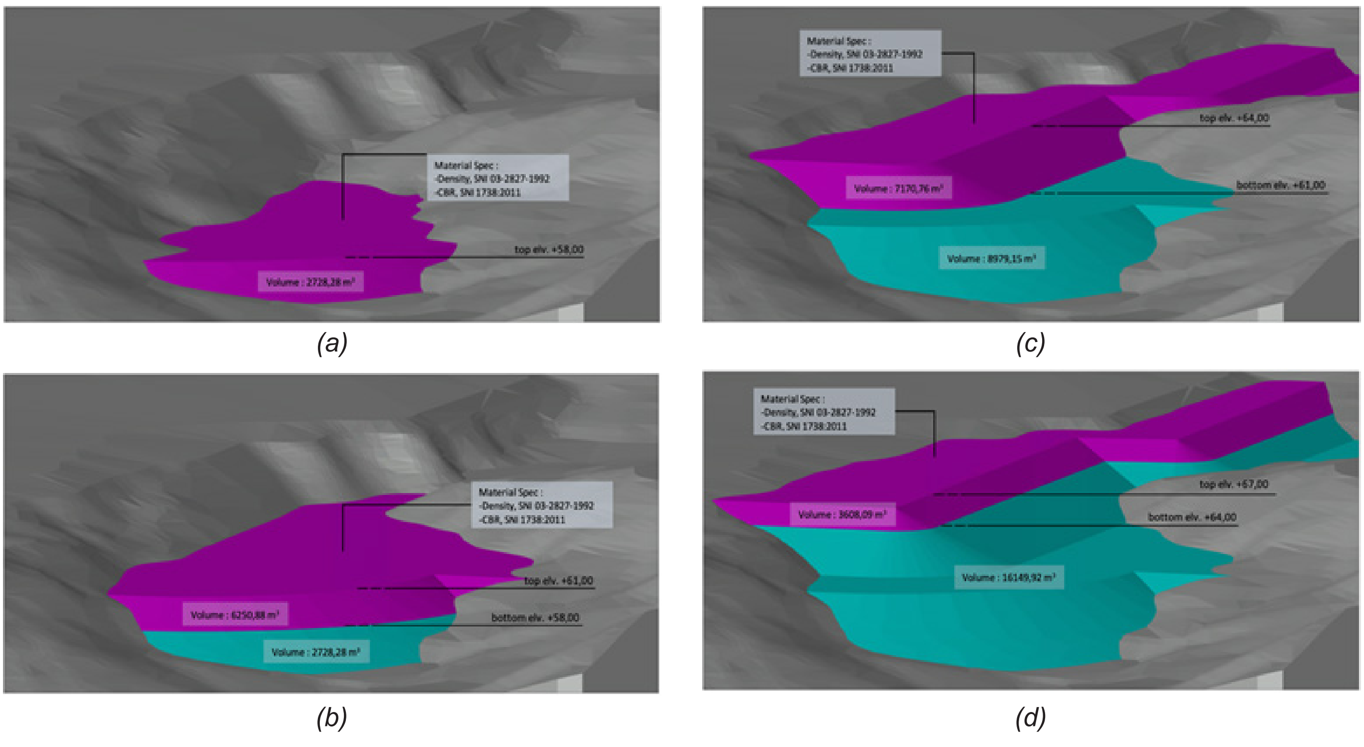

Figure 11: 3D visualization for each elevation of embankment (a) Embankment until elv. +58,00 (b) Embankment until elv. +61,00 (c) Embankment until elv. +64,00 (d) Embankment until elv. +67,00

Design information model

In the 3D visualization model, the information about elevation, distance, and volume of the embankment can be seen on the model. The information about the general specification of embankment materials and testing standards can also be provided according to [21] and [22]. In addition, the 3D visualization model can determine the area that has to be covered by the countermeasure system, so it can accurately obtain the amount of required embankment material considering land acquisition in the surrounding area. Moreover, it can make it easier for site engineers to manage the amount of embankment that needs to be provided for every step of the construction period. The 3D visualization model can be shown in several conditions according to the field conditions. In this paper, 3D visualization is divided into 4 stages of the embankment process based on the final elevation of each stage which can be seen in Table 3.

Table 3: Summary of embankment volume

Bottom elevation (m)	Top elevation (m)	Volume of embankment (m^3)
Base	+58,00	2728,28
+58,00	+61,00	6250,88
+61,00	+64,00	7170,76
+64,00	+67,00	3608,09
Total volume		19758,01

CONCLUSIONS

Based on the results of analysis and modeling, the additional embankments can increase the safety factor value and they can be used as a countermeasure to resist landslides. 2D modeling has limitations in providing information related to conditions in the field. By using the BIM concept, all data from site investigation to analysis results can be integrated and visualized according to actual conditions in the field. This can make it easier for the site engineer to adjust related to the volume of embankment material and to determine effective and efficient construction procedures. The 3D visualization model can provide information regarding the elevation of the embankment, the volume of embankment material required, and the area that needs to be filled by the embankment as a consideration for land acquisition in the construction area. The use of the BIM concept can help to integrate the data from LIDAR/satellite imagery as an input model in 2D numerical analysis and the results can be projected directly into a 3D model. This can simplify the analysis process and increase accuracy in analyzing a model. The implementation of the BIM concept in geotechnical engineering is still rarely used due to the lack of tools that can integrate all the data. However, this can be overcome in various ways, so the modeling can be carried out quickly and precisely to produce a comprehensive model that can be executed easily in the field.

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Paper submitted: 24.11.2020.
Paper accepted: 28.08.2021.
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