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Geotechnical and Geological Engineering

Engineering Geology Consideration for Low-Wall Stability Analysis in Open-Pit Coal Mine

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Abstract:	<p>Open-pit mining will form low-wall and high-wall. Low-wall stability has typical characteristics, which have not been much studied, and continue to change based on field phenomena. Many factors need to be considered in low-wall stability analysis, including condition of the location because different region has different geological characteristic. This paper examines what factors need to be considered in low-wall stability analysis, including condition of study area. Back analysis was carried out on landslides occurred at a low-wall in an open-pit coal mine. This method is expected to provide detailed information about geological condition that may be a contributing factor to slope stability analysis. The variables studied include conditions of geological structure, bedding rock structure, geohydrology, as well as physical and mechanical properties. Limit equilibrium method and finite element method were performed with consideration of detailed geological condition. The result showed that physical and mechanical properties, slope length, layer thickness, bedding ratio, lithology type, and aquifer type need to be considered. These considered conditions become important factors in the analysis, especially in determining suitable slope stability method as well as evaluating reasonable results of low-wall stability analysis. Comprehensive slope stability analysis may help improving quality of slope to be optimal.</p>
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Engineering Geology Consideration for Low-Wall Stability Analysis in Open-Pit Coal Mine

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Abstract: In low-wall stability analysis, there are many geological factors that must be considered; therefore, in determining the method and parameters, real conditions in field must be taken into consideration. This paper examines what factors need to be considered in low-wall stability analysis, including condition of the study area. The analysis method used in this study was back analysis on a low-wall slope where failure occurred, by collecting all the details of geological conditions and performing finite-element-based stability analysis to break down the contribution of each factor. This method is expected to provide detailed information about geological condition that may be a contributing factor to slope stability analysis. The result showed that physical and mechanical properties, slope length, bed thickness, bedding ratio, lithology type, and aquifer type need to be considered. These considered conditions become important factors in the analysis, especially in determining suitable slope stability method as well as evaluating reasonable results of low-wall stability analysis. Comprehensive slope stability analysis may help improving quality of slope to be optimal. The result of this analysis can be implemented for layered sedimentary rocks with low mechanical properties.

Keywords: Low-wall, Coal Mining, Bedding Ratio, Bedding Contact, Depressurization

1. Introduction

Coal deposits, especially in back-arc basin and fore-arc basin, usually form successive layers with specific bedding position. The dip of coal bedding varies from gently sloping to perpendicular forming a vertical bedding. In several locations of the study area, folding structures were found in either micro or macro scales. Based on the geological condition, mining activity will form high-wall and low-wall sections. High-wall is a part of mine slope that is perpendicular to the dip of rock bedding, while low-wall is the dip of mine slope that is in the same direction as the dip of rock bedding (Fig.1).

Many practices of slope stability analysis are carried out using limit equilibrium method with slip surface as normal circular which intersects the bedding plane. Some detailed geological conditions such as bedding ratio, bed thickness, and geohydrological condition have not been included in the parameters of slope stability analysis. Landslides are controlled by material heterogeneity due to structure of bedding plane and fracture in surface deformation zone (Cheng, et al., 2018) which form a weak layer. This layer will control the occurrence of landslide at weak zone (Stead & Eberhardt, 1997); (Alejano & Juncal, 2009); (Ning, et. al., 2011); (Havaej, et.al., 2014); (Hertelé, et.al., 2015); (Yu, et.al., 2015); (Sun, et.al, 2019). Landslide mechanism is formed due to kinematics of structural plane (Imber, et. al., 2003); (Uenishi, 2015); (Smith, 2018). Landslides will depend on friction in slip surface that passes through weak layer (Bahrani & Tannant, 2011). Fluid can cause a complication through hydrogeological processes and mineralization (Carter, et al. 2015). This study discusses in detail the factors that affect low-wall slope stability based on exploring the details of geological conditions in the landslide occurred at low-wall.

Coal deposits are associated with sedimentary rocks that have rock bedding. In fore-arc basin, coal deposits and rock lithology have low mechanical properties. Contact between beds is a weak zone, and at the contact of rock bedding, it is usually found a thin layer that can trigger instability of slope. Slope stability of low-wall is affected by bedding contact between two rocks (Supandi, 2014). Bedding contact is usually in the form of clay which has high plasticity, thus it will separate two different beds. Because it separates two different parts, the cohesion value becomes zero and the internal friction angle becomes 13° , which were obtained based on back analysis result (Supandi, 2014). When a weak plane is formed at contact of two rocks, it is assumed that the upper bed only relies on the bed below it, so, with the concept of stress, the smaller the lower part, the greater the stress received, leading

to potential for overstress at the toe. Overstress occurs due to difference in bedding ratio between the top and the bottom. The smaller the bedding ratio, the smaller the safety factor produced, as shown in Fig.2 (Supandi and Hidayat, 2013). Since the rock bedding has a weak zone, it may cause failure at the toe. The toe failure is one of the contributing factors that leads to landslide at low-wall (Fig.3) (Sulistijo and Kusumo, 2013).

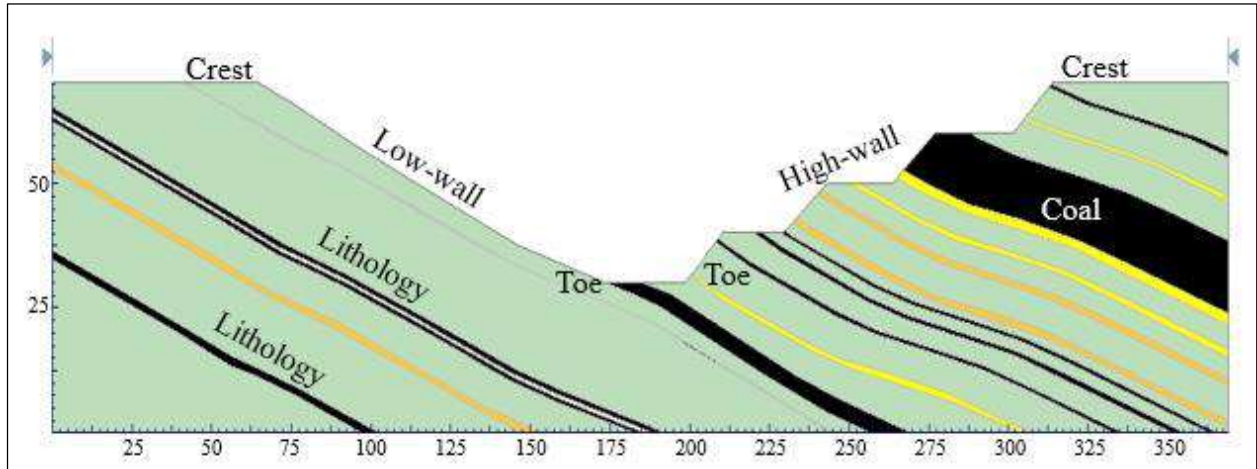


Figure 1. Low-wall and high-wall of coal open-pit mine.

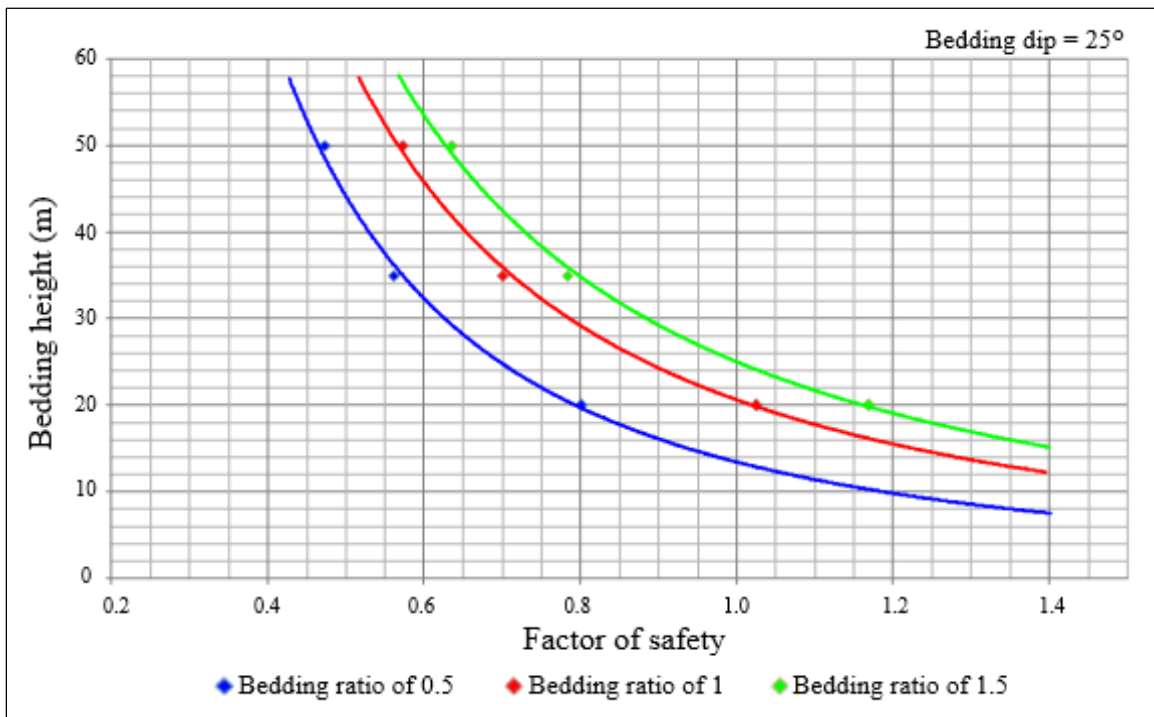


Figure 2. Relationship between factor of safety and bedding ratio in the same slope geometry (Supandi and Hidayat, 2013).

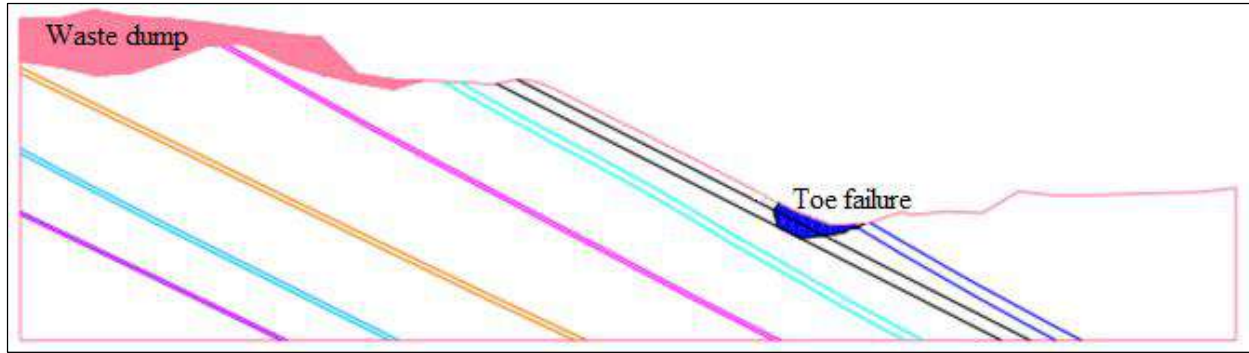


Figure 3. Landslide at low-wall due to toe failure.

Slope stability analysis is closely related to the existing structure pattern, especially discontinuous plane. In this analysis, rock was assumed to be a rigid plane separated by weak plane that is cut by joints making the bed look like being cut into pieces; thus, the movement is purely due to frictional force at the bottom of the slope. When driving force gets bigger, buckling will potentially occur (Fig.4).

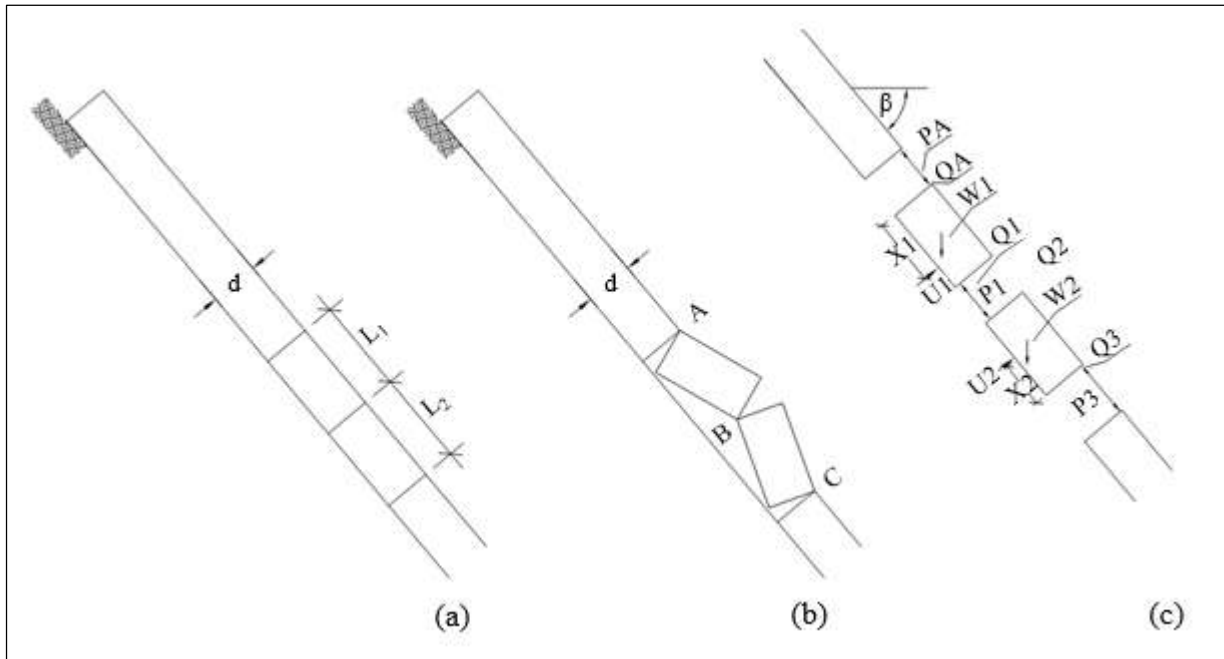


Figure 4. Inaccurate application of rigid-and-jointed bed for low-wall stability (Giani, 1992).

Analysis of landslide due to buckling is carried out with assumption that at the toe of slope there are joints receiving pressure along the slope, and additional assumption of Young's modulus (Fig.5). As a result of the pressure, buckling occurs. The shorter buckling (L), the greater the force required for the buckling process to occur. Water flowing in sandstone pore and impermeable mudstone cause a decrease in values of cohesion and internal friction angle.

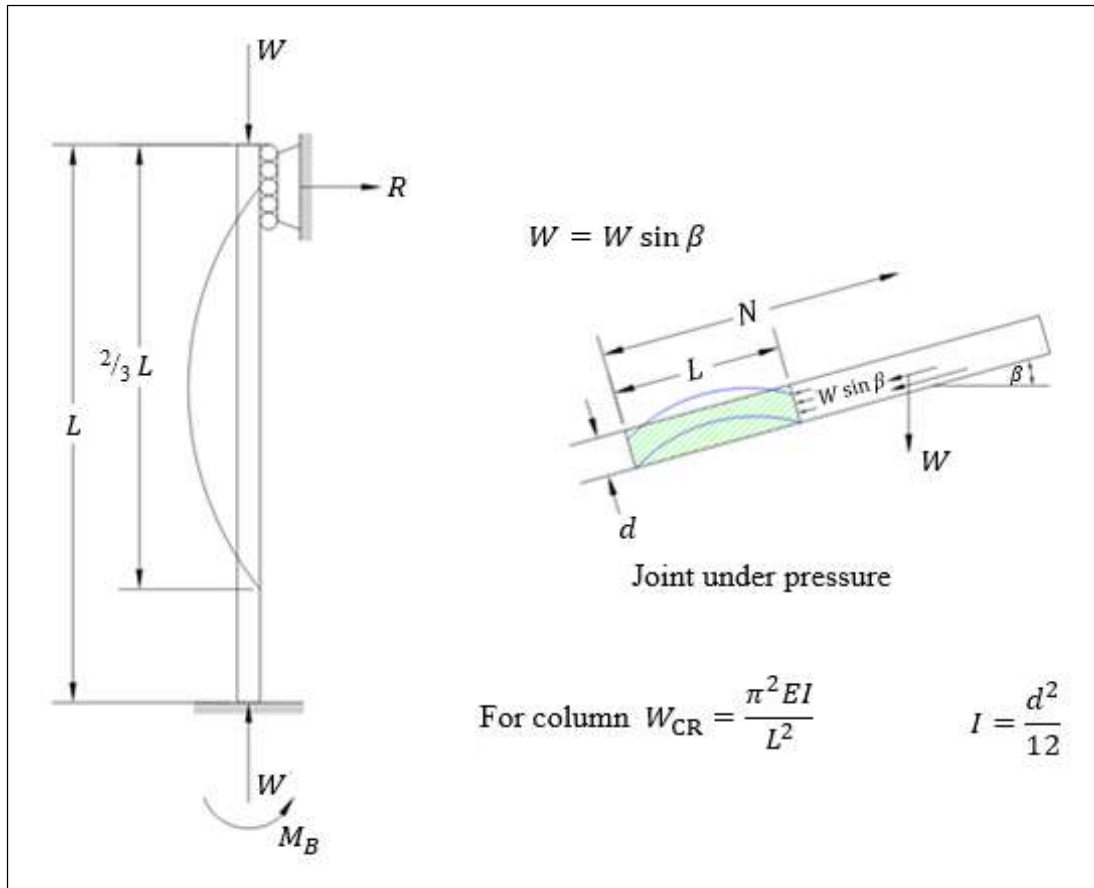


Figure 5. Buckling concept at low-wall (Giani, 1992).

Analysis of low-wall stability uses concept of toe failure that occurs very quickly without showing any indication of instability. This type of landslide is triggered by low angle joint at the base of excavation. The low angle joint often cannot be detected from drilling, so field observation is very important in determining the possibility of low angle joint.

In some cases, landslide at low-wall is affected by pile load at the top of slope, which is considered to provide a significant burden to the low-wall slope. Loose pile material will put the load fully at the base which is passed on to the slope. Placement of overburden must be spaced from the slope to reduce load on the slope surface (Sulistijo and Kusumo, 2013). Landslide at low-wall can also be triggered by weathered rock on the slope surface. This type of landslide usually occurs in tropics which have very high weathering rate. The landslide is relatively thin and only on surface.

Joint pattern plays a very important role for instability because there are some joints that are key to all joint systems. This type of instability is triggered by joint or fracture that cuts each other forming a shape of "X". Under normal condition, instability of natural slope is generally in stable condition. However, if a part of the "X" formation is taken due to slope forming, then instability may occur due to reduced horizontal force and increased groundwater level in joint area that results in increased hydrostatic pressure either vertically or horizontally (Fig.6). Instability will occur when resisting force is smaller than driving force. If this mechanism can be known from the beginning, then instability can be anticipated early.

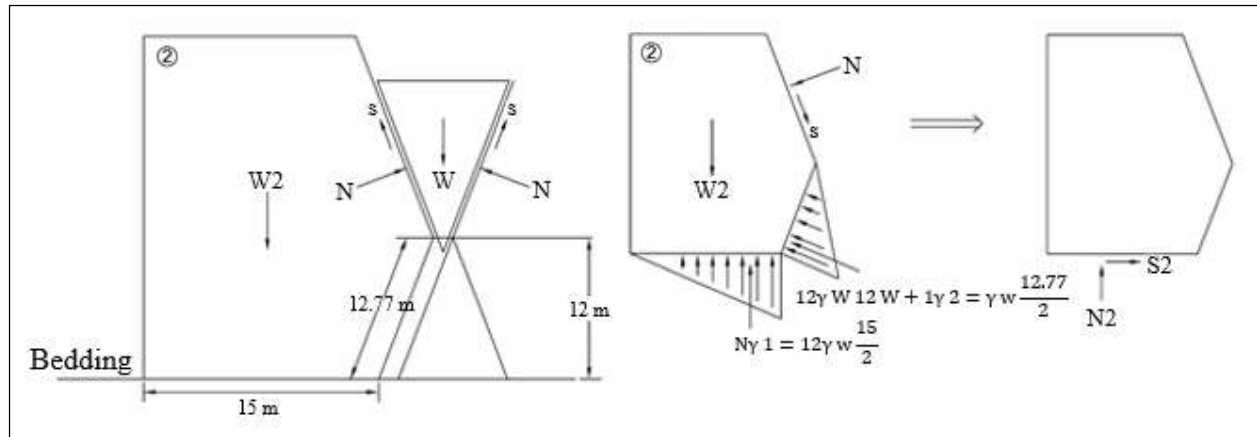


Figure 6. Unfavorable joint mechanism (Giani, 1992).

Increasing in safety factor of 'closed' joint ends cases compared with the 'open' counterparts on small scale slopes shows that support measures such as bolting and wire meshes, which essentially force exposed joint ends to move together, are effective (Hammah et al., 2009). The modelling in Hammah et al. (2009) also shows that the efficiency of such support decreases as slope height increases and suggests to consider other stabilization methods for large slope. Buckling failure may be reproduced by considering this variability. Back analyses of failure mechanism that were carried out by Silva and Lana (2014) shows that it leads to representative values of the in-situ stress state and the normal and shear stiffness modulus of the foliation discontinuities. Alejano and Juncal (2010) analyzed different failure mechanisms to evaluate footwall slopes stability using the numeric code UDEC. These results were then contrasted against limit equilibrium method (LEM) to determine the use of UDEC as a valid tool in analysis of footwall slope. For cases where the footwall slope failure took place through complex mechanisms, UDEC was performed. Seeing that the rock mechanical behavior obeys the statistical damage model, Liu et al. (2016) studied the effect of the rock mechanical parameters n and ϵ_0 on the slope CBH (critical buckling height). Results of the study confirms the effectiveness of rock strength on the slope CBH. Maximum of the slope CBH will be resulted if the rock is supposed to be a linear elastic body without failure in Euler's method. Proper application of empirical methods begins with a step of reviewing the failure mode of laboratory testing samples and using the real intact rock uniaxial compressive strength value. The most critical and challenging step for rock mass strength estimation is understanding the pit floor rock mass characterization. It is easy to miss identification of floor shear and weak ground due to sparsely spaced exploration holes and limited floor trenches in coal mines. Concisely, the default material strength values should not be blindly applied to any rock mass condition from aspects of either safety or cost reduction and productivity increase (Li et al., 2016). Clastic sedimentary rocks in the Warukin Formation have low hardness (Supandi and Hartono, 2020) and the rocks will degrade when exposed to the surface (Supandi et al., 2018). With this condition, clastic sedimentary rocks, especially claystone, have limited engineering properties, and type of clay mineral must be considered before choosing construction material (Supandi et al., 2019; Ballantyne, 2003). Large scale low-wall failure causes considerable disruptions to mining associated with a loss of production, damaged infrastructure, and the potential loss of life (Vangsnæs, 2020). Depressurization is indispensable in pit optimization and pit design (Waterhouse et al., 2008). Numerical modeling in slope stability analysis for optimizing mine slope is more convincing in the result of slope stability analysis (Suratha, 2007).

2. Materials and Methods

The method used in this study is back analysis on landslide that occurred at low-wall of a coal mine. Back analysis was carried out by identifying all geological and geohydrological conditions as well as physical and mechanical properties of slope rock, then evaluating slope stability analysis that had been carried out before the landslide occurred. Geological condition was identified by detailing slope material, identifying contact zone, calculating bedding ratio, and mapping structure seen after the landslide; while geohydrological component was identified by identifying slope bedding to obtain the type of aquifer. Structure was mapped to determine the

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4 orientation of joint pattern found on the slope and identify the existence of low angle joint. Field observation
5 includes identification of failure zone found in the landslide area as an indication of release point of force from rock
6 bedding. Physical and mechanical properties were evaluated by comparing sampling position to the results of
7 laboratory tests that have been carried out. Additional number of samples required for further analysis was added for
8 detailing back analysis later. Laboratory tests such as hardness test, triaxial test, and uniaxial test were carried out by
9 following the ASTM standards.

10
11 Back analysis was carried out by collecting all the details of geological condition in the landslide to model its
12 mechanism during the analysis. Some of the concerned geological conditions are not limited to stratigraphy, bedding
13 contact, bedding ratio, geohydrology, rock mass, and slope geometry. Mechanical properties were determined based
14 on laboratory tests or the result of back analysis on the landslide. The analysis used a method that can adjust to the
15 behavior of the landslide. The SRF, stress, and strain, as well as the slip surface pattern were evaluated according to
16 the actual conditions in the field. The analysis diagram can be seen in Fig.7 below.

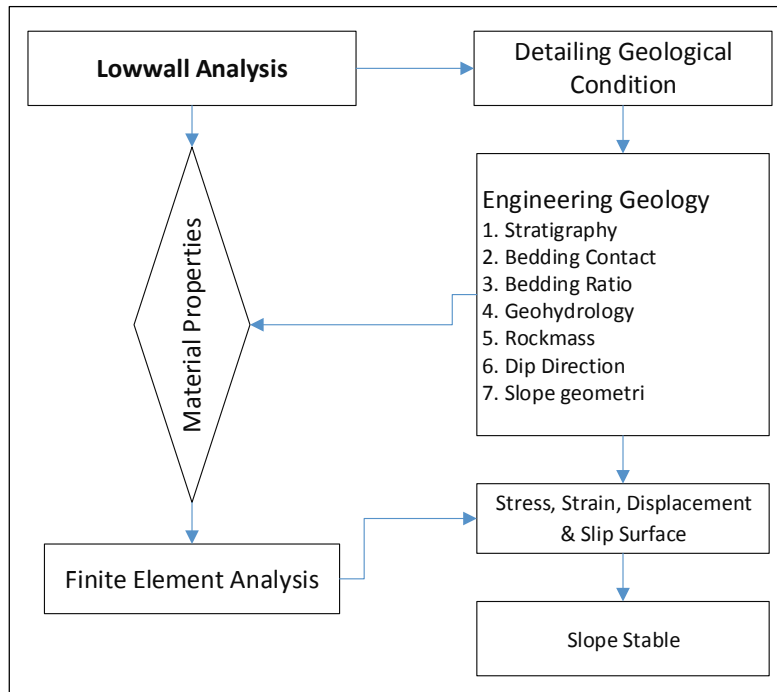


Figure 7. Diagram of analysis

Study area

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46 The study area was in Batulaki Block, Tanah Bumbu Regency, South Kalimantan, Indonesia. Landslide at the
47 low-wall of Batulaki pit had slope geometry of 28°, height of 65 m, and lithology dominated by mudstone. The toe
48 of the slope was used as a sump for draining mine water with water depth of about 9 m from final elevation (Fig.8).



Figure 8. Failure at low-wall of an open-pit mine.

The result of laboratory analysis on the stratigraphy of slope rock is shown in Table 1. Samples were obtained based on drilling that had been carried out before mining activity. The drilling activity reached a depth of 150 m with a core size of HQ (70 mm).

Table 1. Material properties for low-wall stability analysis in open pit coal mine.

No	Properties	Claystone	Mudstone	Sandstone	Soil	Coal	Weak zone
1	Friction angle (°)	45.31	27.792	40.96	13.55	24.57	13.00
2	Cohesion (kPa)	189.32	114.334	354.534	25.04	154.70	3.00
3	Tensile strength (kPa)	5.703E+03	7.676E+04	2.430E+04	2.635+03	8.604E+03	2.312+3
4	Young modulus (kPa)	6.823E+03	4.871E+04	1.848E+04	1.736+02	3.179E+04	2.341+03
5	Poisson's ratio	0.314	0.297	0.382	0.231	0.271	0.423

3. Result & Discussion

Based on the method that has been described, geotechnical analysis was carried out in detail, from geotechnical exploration, logging, sampling, mapping of discontinuous plane, aquifer identification, stability analysis, to geological concern related to the slope stability. The analysis was able to:

1. Identify the details of slope rock bedding

Planning geotechnical investigation, especially for low-wall area, requires more detailed planning. Full core drilling was carried out to determine the slope stratigraphy, to do sampling for laboratory tests, and to depressurize the area planned for low-wall formation. The drilling point should be placed at 2 points, near the subcrop and in the down dip direction according to the pit depth plan. With this method, it is expected to obtain the bed correlation and the detailed geometry of slope bedding (Fig.9). Samples for laboratory testing was taken for every variation of lithology, including for thin layer that was possible for laboratory testing. Laboratory testing was performed at least by triaxial test and uniaxial test.

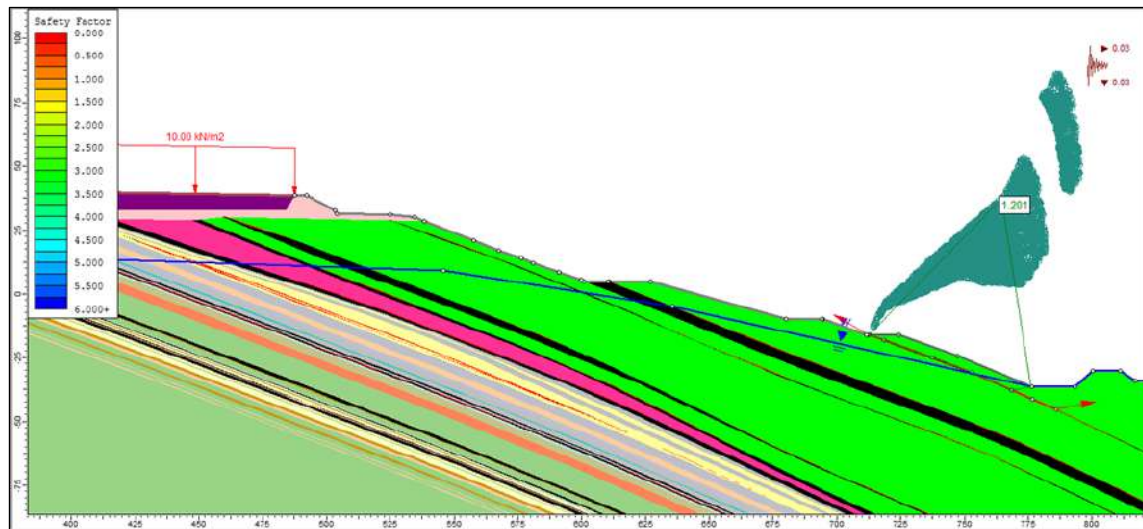


Figure 9. Detailed stratigraphic model including weak layer. The thin black line is a weak layer in bedding contact.

2. Identify the weak zone

Rocks identification must be done in detail, including the identification of thin layers which have high plasticity. The thin layer is a weak zone that can trigger slip surface presence. This weak zone was used as a basis in calculating bedding ratio where the thickness of rock bedding was calculated based on the perpendicular distance between a weak zone and the next weak zone. Physical and mechanical properties of weak zone were determined by carrying out laboratory tests based on samples that were possible to be taken or performing back analysis. The layer must be identified because although it has a thickness of only a few centimeters, it has a considerable influence. Fig.10 shows the weak zone of mudstone bed that has a relatively high plasticity and the block where plane failure occurred at low-wall that was controlled by weak plane which is the contact between rock bedding.



Figure 10. Slip surface on weak plane (left) and landslide at low-wall controlled by weak plane (right).

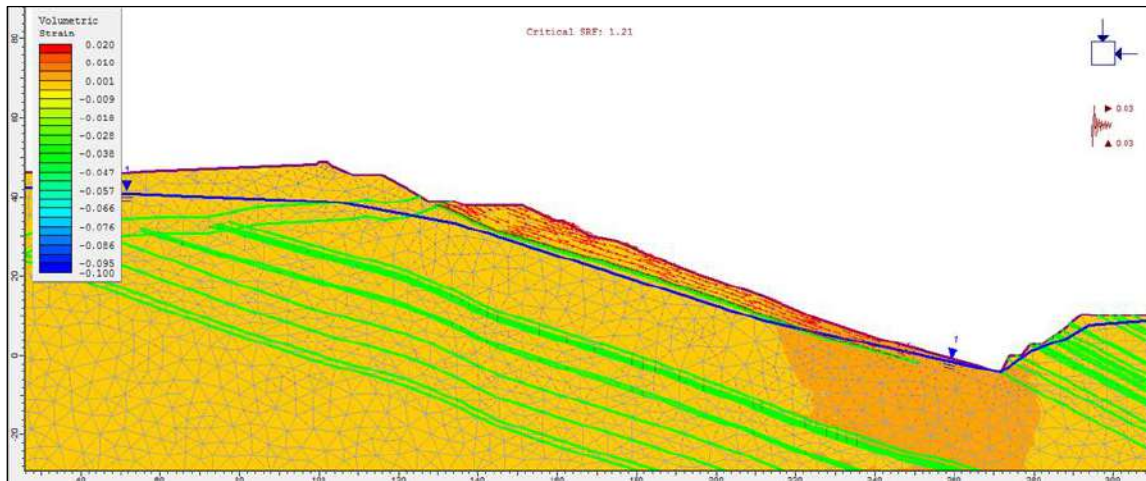
3. Describe the bedding dip including weak zone control

Identifying weak plane must be continued by identifying continuity of the weak plane. Continuity in direction of strike and continuity in direction of dip can be used for detailed analysis on the correlation with the patterns of weak plane. Weak plane pattern in the form of rock bedding contact can also correlate with weak plane

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4 pattern due to joint or geological structure activity. In sedimentary rocks, continuity of weak plane follows
5 distribution of rock bedding. Although the thickness is limited, it is necessary to do more detailed mapping.
6

7 4. Calculate the bedding ratio of rock bedding

8 Calculation of bedding ratio can be done after identification of weak plane done and well modeled. Bedding
9 ratio was calculated perpendicularly between two weak planes and was calculated for the very top (crest) and
10 the very bottom of the pit plan. Bedding ratio is a comparison between top bed thickness and bottom bed
11 thickness. Bedding ratio is equal to 1 if the thicknesses of the top and the bottom are the same; less than 1 if the
12 bottom is thinner than the top; and greater than 1 if the bottom is thicker than the top. The thicker the bottom,
13 the more stable the low-wall because of the increasing stress. The thinner the bottom, the greater the stress
14 received, thus, it may disturb the stability. Fig.11 shows a bed with a bedding ratio of less than 1 where the
15 thickness of the toe was smaller than the crest, so the stress increased at the toe. This condition reduced the
16 value of slope safety factor.
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18



35
36 **Figure 11.** Bedding ratio and strain behavior at low-wall cross section.
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39 5. Map the pattern of discontinuous plane

40 Mapping of discontinuous plane is more emphasized in the discontinuous plane in the form of geological
41 structure which can be joint or fault. Measurement of discontinuous plane must be done in detail in terms of its
42 density or position. Describing rock mass or discontinuous plane must also be done in detail which cannot be
43 separated from the filling material, roughness, and water condition. Identification of discontinuous plane was
44 carried out on all slope sections from the top to the bottom. The bottom part must get more attention because the
45 accumulation of stress occurs in that zone, so a little of discontinuous plane can trigger stability. Fig.12 shows
46 the existence of a weak plane on rock contact in the form of a thin layer of mudstone which is a controller in the
47 occurrence of plane failure at low-wall. The block above the weak plane moved down the slope along the weak
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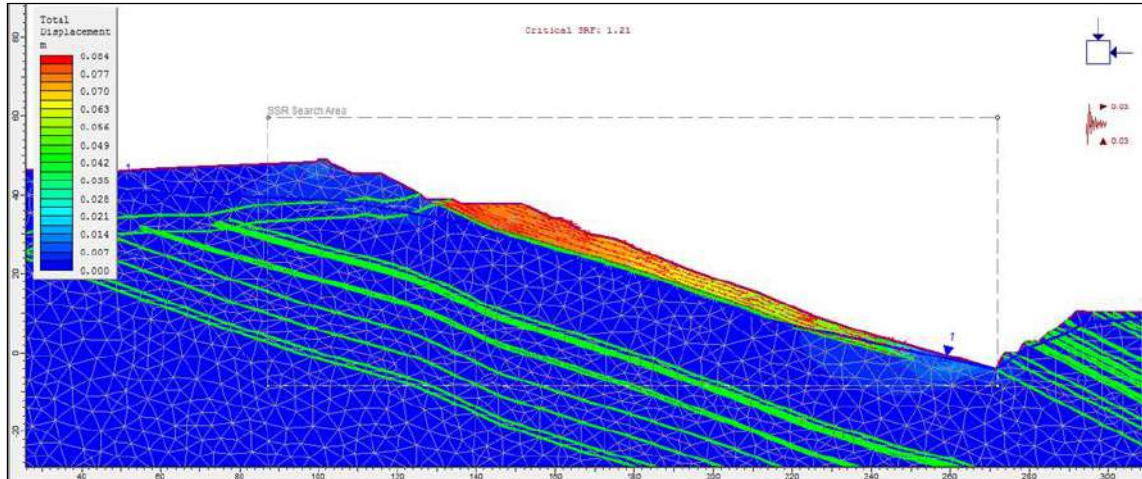


Figure 12. A discontinuous plane on contact plane that controlled displacement in rock bedding.

6. Identify the type of aquifer found on the slope

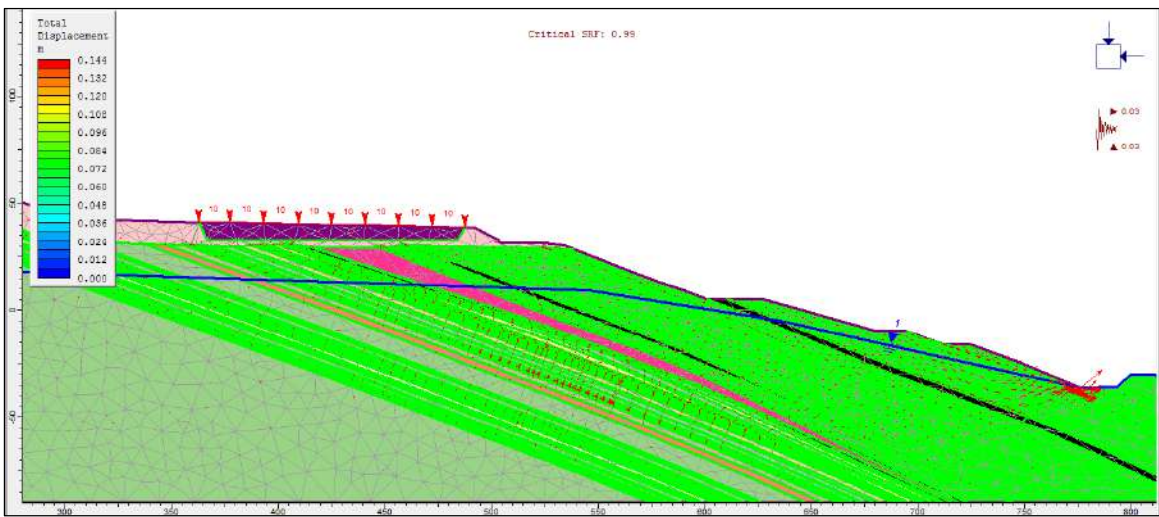
In analysis of low-wall stability, it is a must to identify the rock bedding especially which have high porosity. Vigilance needs to be increased if a bed that has high porosity is found between impermeable layers or distressed aquifer is found. The distressed aquifer can have aquifer stress in the form of water or air. If the impermeable layer at the top has a limited thickness and pressure continues to increase, buckling will occur. To avoid this, depressurization may be carried out before forming low-wall slope. Depressurization can be done at several points at low-wall with target of distressed aquifer layer. When there is pressure from the distressed aquifer, it will release pressure from the formation which usually appears artesian water pressure. Water will continue to come out of the formation until the pressure in the formation decreases (Fig.13). The more the depressurization point, the faster the formation pressure will decrease.



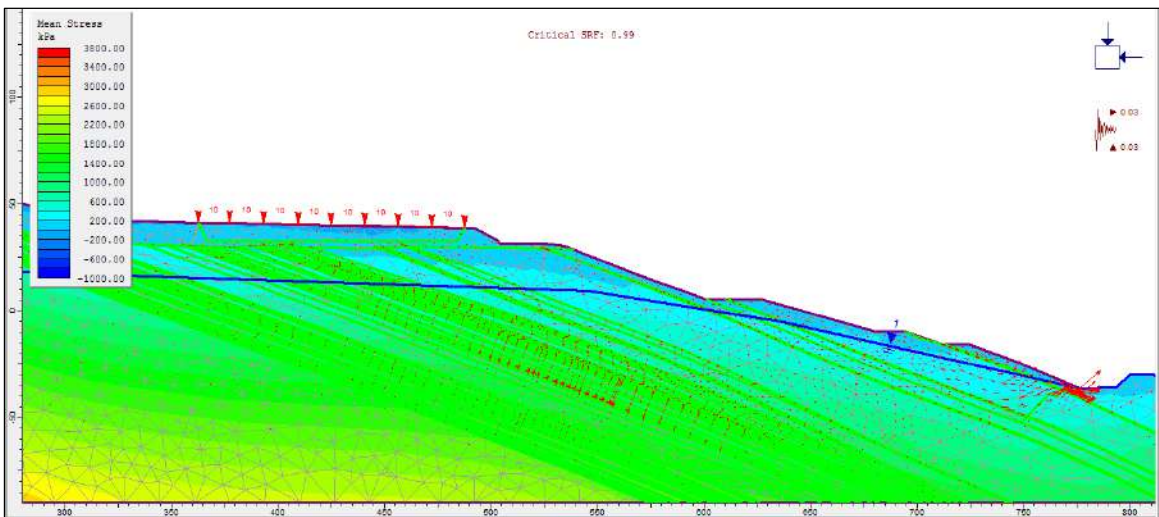
Figure 13. Depressurization (red dot) and the aquifer stress causing artesian (bottom left).

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4 7. In analysis

5 Based on the consideration of geological conditions previously described, the low-wall stability analysis must
6 be carried out by using finite element method or plane model for limit equilibrium method. Fig.14 shows the
7 result of back analysis on the landslide at low-wall using finite element method with the movement towards the
8 toe. This can be corroborated by the distribution of stress pattern occurred in rock mass which shows the stress
9 pattern leading to the toe (Fig.15). Limit equilibrium method can be carried out as long as the thickness of slope
10 bed is homogeneous or the equilibrium plane only occurs in one bed. Calculation of stress especially at the toe
11 area must be done to ensure that the concept of stress occurs in the analysis process. Weak zone determination
12 at the time of analysis must be done with parameters that can refer to the results of the laboratory analysis or
13 based on back analysis. Even though the thickness is thin and only a few centimeters, separate layer must be
14 made. Identification of aquifer stress needs to be done to ensure that the bed thickness is able to withstand the
15 stress from the bed as well as from the aquifer. When all parameters have been considered, the optimum slope
16 height is modelled for each bed, so formation of the low-wall slope geometry can be performed.
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38 **Figure 14.** Displacement pattern on the low-wall cross section after stabilization. The direction of displacement was
39 still at the toe.
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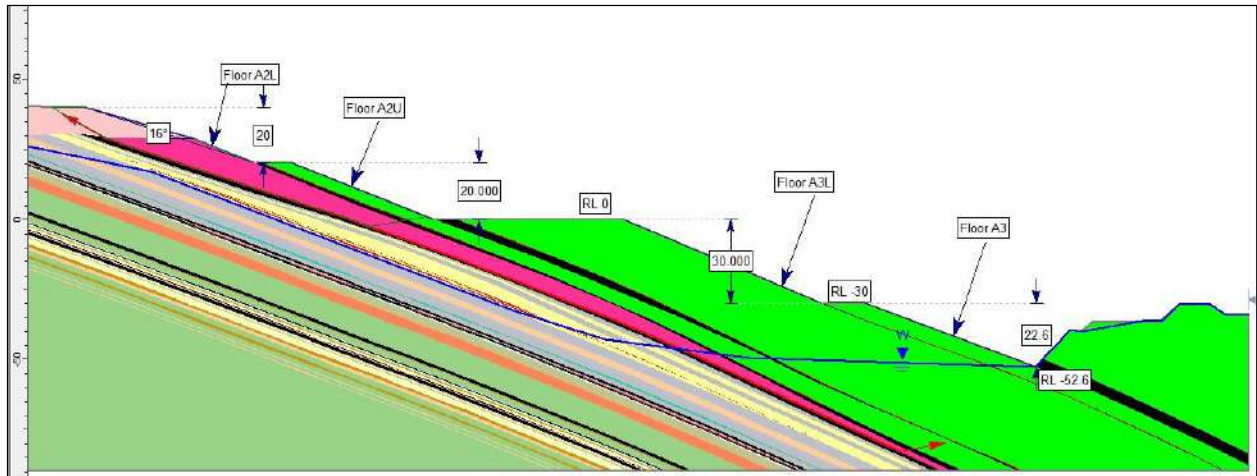
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59 **Figure 15.** Stress pattern on the low-wall cross section with the direction of stress at the toe.
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4 8. Optimization

5 With the geological conditions in mind, analysis of low-wall can be done using finite element method by
6 considering the weak zone and bedding ratio. Low-wall height modelling for each bed with a specific dip can be
7 done to get the optimum low-wall geometry. If there is a distressed aquifer on low-wall, then depressurization
8 must be done to reduce the aquifer stress on the bed above it.
9

- 10 a. Analysis using finite element method
11 b. Simulating bedding ratio
12 c. Simulating the effect of bedding dip on the rock bedding
13 d. In connection with the point c above, the length of the bed is simulated to obtain the optimum height of the
14 low-wall geometry in each bed
15 e. Depressurization needs to be done especially to release aquifer stress which has the potential to trigger
16 buckling
17

18 Based on the explanation above, for the low-wall geometry, it is a must to pay attention to the detailed
19 geological aspects and the dip of single slope at the low-wall following the dip of bedding contact or rock bedding.
20 To obtain the optimum geometry, it can be done by using the optimum height of each bed, so the optimum height
21 will be different for each bed. Fig.16 shows the optimum geometry of the low-wall based on back analysis result
22 where the bed thickness has a different geometry.
23
24



41 **Figure 16.** Geometry of the low-wall slope after being analyzed by considering the geological aspects.
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43
44 4. Conclusion

45 In geotechnical analysis, it is mandatory to consider the geological conditions at each location starting from
46 lithology, bedding contact, bedding, structures, and geohydrology. The analysis method must also be chosen
47 relevant to the rock mass behavior, so the landslide mechanism can be analyzed according to the actual conditions.
48 Based on the result and discussion, analysis of low-wall must be carried out with detailed planning so that it is able
49 to identify the geological conditions. Geological conditions cannot be separated from the condition of lithology,
50 stratigraphy, aquifer, and weak plane between beds. Identification of discontinuous plane pattern must be done to
51 ensure the kinematics of a bed. In high stress zones, condition of discontinuous plane has a significant role in
52 stability of low-wall slope. Calculation of bedding ratio after modelling a weak plane is highly recommended so that
53 at the time of analysis, it will be close to the real field condition. Finite element method is recommended for low-
54 wall stability analysis even though limit equilibrium method is still possible if circular pattern only occurs in one
55 bed. Depressurization is required to reduce aquifer stress due to the presence of distressed aquifer. The dip of single
56 slope on low-wall is the same as the dip of rock bedding, but the height of the slope can adjust to the height of each
57 bed.
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9 for-profit sectors.

10
11 **Competing Interests:** The authors declare that they have no known competing financial interests or personal
12 relationships that could have appeared to influence the work reported in this paper.
13

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[Click here to view linked References](#)**Response by Authors to Reviewer's Remarks/Comments****ENGINEERING GEOLOGY CONSIDERATION FOR LOW-WALL
STABILITY ANALYSIS IN OPEN-PIT COAL MINE****Authors: Supandi**

The authors have summarized their replies to the Reviewers' comments in this response letter in a two column format. A revised manuscript is submitted addressing all the comments to the Journal of Open Geoscience for possible publication.

No	<i>Editor's Comments</i>	<i>Authors Response</i>
Reviewer #1		
1	The abstract should state briefly the purpose of the research, the principal results and major conclusions. An abstract is often presented separately from the article, so it must be able to stand alone.	Abstract has been improved by rewriting and completing the background, purpose, variable and material, location, as well as results and discussion.
2	The introduction section needs revision. It is not clear what is already known about this topic. More relative, recent literature should be included in this section. Also, look into this section length.	The introduction has been improved by rewriting the background of this research. Many cases of low-wall stability analysis are carried out using limit equilibrium method with slip surface as normal circular which is not relevant to the real condition in the field. Several references have been mentioned in the manuscript, and the difference between the current and previous research have been described.
3	The major defect of this study is the debate or Argument is not clearly stated in the introduction session. Hence, the contribution is weak in this manuscript. I would suggest the author enhance your theoretical discussion and arrives your debate or argument.	This research describes in detail many factors that must be considered in low-wall stability analysis, while the previous research discussed it partial and not comprehensive. The current research details previous research by incorporating the factors that contribute to low-wall stability. To prove the validity, a numerical analysis was performed with the concept of finite element. Indeed, this research does not discuss the details for the numerical method, how mathematical it is, because this can be a separate research. This research shows all the factors that need attention when conducting analysis on low-wall, therefore, it is hoped that the result of this research can become a guideline for geotechnical engineers in conducting analysis.
4	The necessity and innovation of the article should be presented to the introduction.	It has been stated in the manuscript that all factors mentioned in the manuscript must be considered when performing analysis on low-wall. The analysis method has also been demonstrated using finite element method.
5	A flowchart should be added to the article to show the research methodology.	Flowchart has been added to the manuscript, which explains the analysis process from gathering the data to evaluating the result.
6	The "Materials and Methods" section needs revision. Add a subsection about the study area considered in this paper, its name, location, country, the soil characteristics, and coordinates.	Subsection about study area has been added to the manuscript which contains an explanation of the study area, soil characteristic, and other information.
7	It is suggested to replace figure 7 with more accurate and clearer photo.	The figure has been changed with better picture.

8	The paper language needs revision by an expert.	Language improvement have been made.
9	It is suggested to compare the results of the present research with some similar studies which is done before.	Similar studies, namely Supandi et al. (2019), Ballantyne (2003), Suratha (2007), Supandi and Hidayat (2013), and Sulistijo and Kusumo (2013), have discussed the variables of low-wall stability analysis; however, the discussions are limited to each variable, not comprehensive for all variables related to low-wall stability. The current research has added several factors that can have an impact on low-wall slope stability, such as aquifer type, depressurization, and pit optimization. In this research, the contributing factors to stability of low-wall slope have been discussed in detail and analyzed in a complete numerical analysis up to the pit design of low-wall section which is a novelty in this analysis.
10	The authors should add a discussion to "Results" section to become "Results and Discussion" to explain the paper findings, clarify the novelty of the paper and compare the results with recent studies.	The result section has been combined into one with the result and discussion.
11	It is suggested to organize the Conclusion section much better. This section should present in one 250-300 words paragraph and should contain unique results and findings.	The conclusion has been redrafted by adding sentences without reducing the substance.
12	The number of references is Few, as the author has chosen references from excellent sources, and there is the possibility to use them better than it is. However, most references need to be re-written for the following reasons: (please review the file): * GEGE style should be used carefully for writing the references. * Add the DOI for all references. * Many references are not available online. * Add the Abbreviation of Journal. * Increase the number of references in the manuscript because it is few.	DOI has been added to some references.
13	A good plagiarism rate 5%, but don't let it go above this threshold when you increase the references.	Thanks.
Reviewer #2		
1	Plagiarism check must be carried out and shall be submitted together with manuscript revision.	Plagiarism check has been added.
2	The literature review is not complete. The journal papers relevant to the author's work should be addressed. Introduction can be extended and MORE and NEWEST references should be added	Some recent references have been added, including the explanation of what is new in this research.

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5	A better description of the target area is needed. Furthermore, the technical characteristics of investigated area should be clarified, incorporating the geological information. The in pit dumping data need to be better explained.	Detailed description of the location and the condition of geological characteristics has been added to the study area subsection in the materials and methods.
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7	Check this parameter, I would like to say that it's wrong parameter since number modulus elasticity is equal to all material. A further interpretation of the results is needed. The results are not clearly related to the geotechnical analysis. In addition, the results need to be discussed in relation to the parameters of the slope stability analysis.	Thank you for the carefulness in reviewing the parameters. The parameters have been corrected and only in the draft because the analysis has used the correct parameters.
8	The author should clearly mention weaknesses and limitations of the proposed method.	This research can be carried out on sedimentary rock with low mechanical properties. If it has different mechanical properties, then this model can be reviewed again.

The authors appreciate the valuable comments from the reviewers.

Yours sincerely,

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Response by Authors to Reviewer's Remarks/Comments

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Authors: Supandi

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