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AASEC 2021

The 6th Annual Applied Science and Engineering Conference
Online Virtual conference, 18-19 August 2021
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Date: 16 August 2021

Letter of Acceptance for Abstract

Dear Authors: A Y Siregar (a), M A Azizi (a*), I Marwanza (a), W Dahani (a), R Yulianti (a)

We are pleased to inform you that your abstract (ABS-259, Oral Presentation), entitled:

"The Effect of Tolerance Value Variation to Slope Stability Analysis Results Using 3 Dimensional Finite Element Method"

has been reviewed and accepted to be presented at AASEC 2021 conference to be held on 18-19 August 2021 in Bandung, Indonesia.

Please submit your full paper and make the payment for registration fee before the deadlines, visit our website for more information.

Thank You.

Best regards,

Prof. Dr. Ade Gafar Abdullah, M.Si.
AASEC 2021 Chairperson

The Effect of Tolerance Value Variation to Slope Stability Analysis Results Using 3 Dimensional Finite Element Method

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Abstract. In the subject of mine slope stability analysis there are many analysis method available, especially with the rapid enhancement of computational technology. Finite Element Method is one of the most applied method amongst practitioners dan academics in the field of mining engineering. The method involves dividing 3 Dimensional model into small parts called elements. In this method, Shear Strength Reduction is adopted to determine the Factor of Safety, which in the terms of Finite Element Method also known as the Strength Reduction Factor. This research is intended to better understand one of the parameters in the Finite Element Method which is the tolerance value. The test is done by performing Finite Element Method analysis with a set of tolerance value variations. The result then used to generate graphs to determine the effect of tolerance variations to Factor of Safety and Total displacement. The result indicates a trend in the increase of Factor of Safety and total displacement with the increase of tolerance value. From the Factor of Safety and displacement chart it is found that the total displacement of 4.7 meters tends to stabilize when the tolerance value is 1×10^{-5} as it has insignificant difference from total displacement generated with tolerance value of 1×10^{-6} with the SRF of 1.2..

1. Introduction

Slope stability analysis is an integral part the mining process to ensure safety and fluency in coal and minerals production. In present days there are many methods available regarding the broad enhancement in computational analysis tools. Finite element method is one of the most known method amongst practitioners and academics in the field of mining engineering. Available in 2 dimension, and 3 dimension this method involves a technique in which the model is divided into small fragments called elements. The Finite Element method is used alongside with the Shear Strength Reduction technique to determine the Factor of Safety.

The shear strength reduction is a technique in which the materials shear strength parameter, cohesion and internal friction angle, is gradually reduced with a specified until the material is at the brink of failure. In this method failure occur when the analysis does not come to a solution to satisfy both Mohr-Coulomb failure criterion and global equilibrium condition. The strength reduction factor (SRF) just beyond failure is the critical failure, in the case of shear strength reduction also known as the Factor of Safety value. As the material strength reduced, movement within the slope occur as the respond to the shear strength reduction. These movement then projected by the nodal movement in each element generated, also known as the nodal displacement.

The Finite Element Method results provide information regarding the Factor of Safety, total displacement, and the position of the critical area along the 3 dimensional pit model. In the 3 dimensional SSR Finite Element Method, there are several factor affecting the accuracy and computing time. Mesh type, the amount of nodes, maximum number of iteration, and the 3D model quality are few of them. From previous researches, usage of bigger element size will result in less accurate Factor of Safety Result, but the computation time needed is less than smaller element mesh type. In terms of maximum iteration number, smaller Factor of Safety value generated with lesser iteration ceiling. These factor need to be conservatively considered in the use of Finite Element Method to yield optimum results. This research is intended to better understand and knowing the influence of factoring parameter in the SSR Finite Element Method, namely the tolerance value. The tolerance value is referred to as the material ability to tolerate energy imbalance that could cause displacement (strain), before the material collapses. The aim of this research is to understand the influence of tolerance value to SSR Finite Element Analysis results. Specifically, the effect of tolerance value variations to the Factor of Safety value, and the total displacement when critical.

1.1 Finite Element Method

In engineering problems, there are unknown values that if are found, the characteristics of the entire structure can be determine (Bhavikatti, 2005). The Finite Element analysis is a numerical problem solving method. In principal, the method involves diving the model into small fractions called elements. These elements provide solution continuum to estimate the unknown values in engineering problems. These elements are attached to one another by nodes. In its application to slope stability analysis, Shear Strength Reduction (SSR) technique are applied to each elements. The deformation caused by the strength reduction are the projected by nodes attached at each elements, to generate the displacement in the form of nodal displacement (Griffiths, 1999).

1.2 Shear Strength Reduction

In the Finite Element Method, the SSR technique is utilized as a tool to determine the value of FoS and the Total Displacement. The shear strength is a parameter that defines the strength of a material. In the SSR method the shear strength parameters of a material, cohesion and internal friction angle, are gradually reduced by a reducing factor called the Strength Reduction Factor (Matsui and San, 1992). This process is repeated until the strength of the material is at critical condition or just beyond failure. The SRF at this point is called the critical SRF and represents the actual value of FoS. According to Matsui and San, the SSR technique can be mathematically defined as follows

$$c_R = \frac{c}{SRF}, \tan^{-1}\varphi_r = \frac{\tan\varphi}{SRF} \qquad (1)$$

1.3 Mohr-Coulomb Failure Criterion

The Mohr-Coulomb Failure criterion is a set of linear equation, in the dimension of principal stresses (Labuz and Zang, 2012) to determine a condition which a material fails based on its shear strength. According to Mohr and Coulomb, material strength is best defined by its shear strength parameters (Cohesion and Internal Friction Angle). In this criterion, failure occur when the Mohr circle formed by the minimum and maximum principal stress exceeds the failure envelope. The Mohr-Coulomb failure criterion is mathematically represented by

$$\tau = c + \sigma . tan\varphi \qquad (2)$$

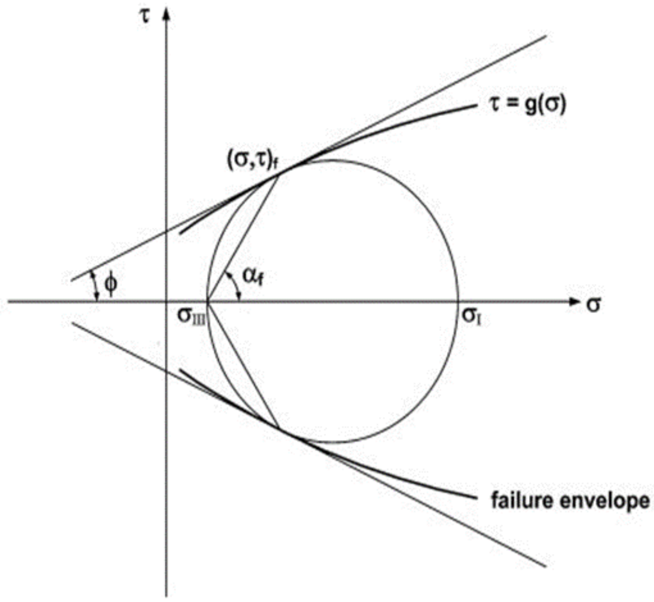

Figure 1 Mohr - Coulomb Failure Criterion Diagram (Labuz & Zang, 2012)

2. Methodology

This research is adopting the Finite Element numerical analysis method, using 3 dimensional FEM software by rocscience Inc, Roc and Soil 3 (RS3). In this method, prior step are taken to develop 3 dimensional model of a slope. Input parameter consisting the strength parameter, cohesion and angle of internal friction, elasticity parameter the Young's Modulus (E) and Poisson's Ratio (V) was applied to define the material strength and stiffness characteristics. The next step is to divide the model into small elements. This process is called meshing. The mesh type of graded and uniform are two types of mesh that is available in the RS3 software. After the meshing process is done, a form of retaining forces are applied to the edge of the model, so the displacement would happen inside the pit area. This process was done by applying restraints to the model. Before computing, adjustment need to be make to a set of criteria, which govern the SSR iterations stopping time. This set of criteria is known as the convergence criteria, consisting maximum number of iteration and the tolerance value. The maximum number of iteration in this research is set in the default number of 500. On the other hand, the tolerance number used in this experiment is varied in each of the computation. The tolerance variations used are 1, 1 x10-1, 1 x 10-2, 1 x 10-3, 1 x 10-4, 1 x 10-5, and 1 x 10-6. Each analysis performed with different value of tolerance will generate different values of SRF and total displacement. The results obtained are then observed to understand the effect of tolerance value variations to Factor of Safety and Total Displacement. These results are defined in the form of X Y graphics to make the observation. From the SRF and total displacement graph, an optimum value of tolerance number was determined with an indicator of which tolerance number generates stable value of Total displacement. This research is a continuity of a prior research. The 3D model analysed in this research is the same 3D model pit from the research by Kemal et al (2019). Therefore, the input parameters of physical and mechanical properties of the materials are also the same from the prior research. To better understand the approach, the framework of the research is provided in the next page.

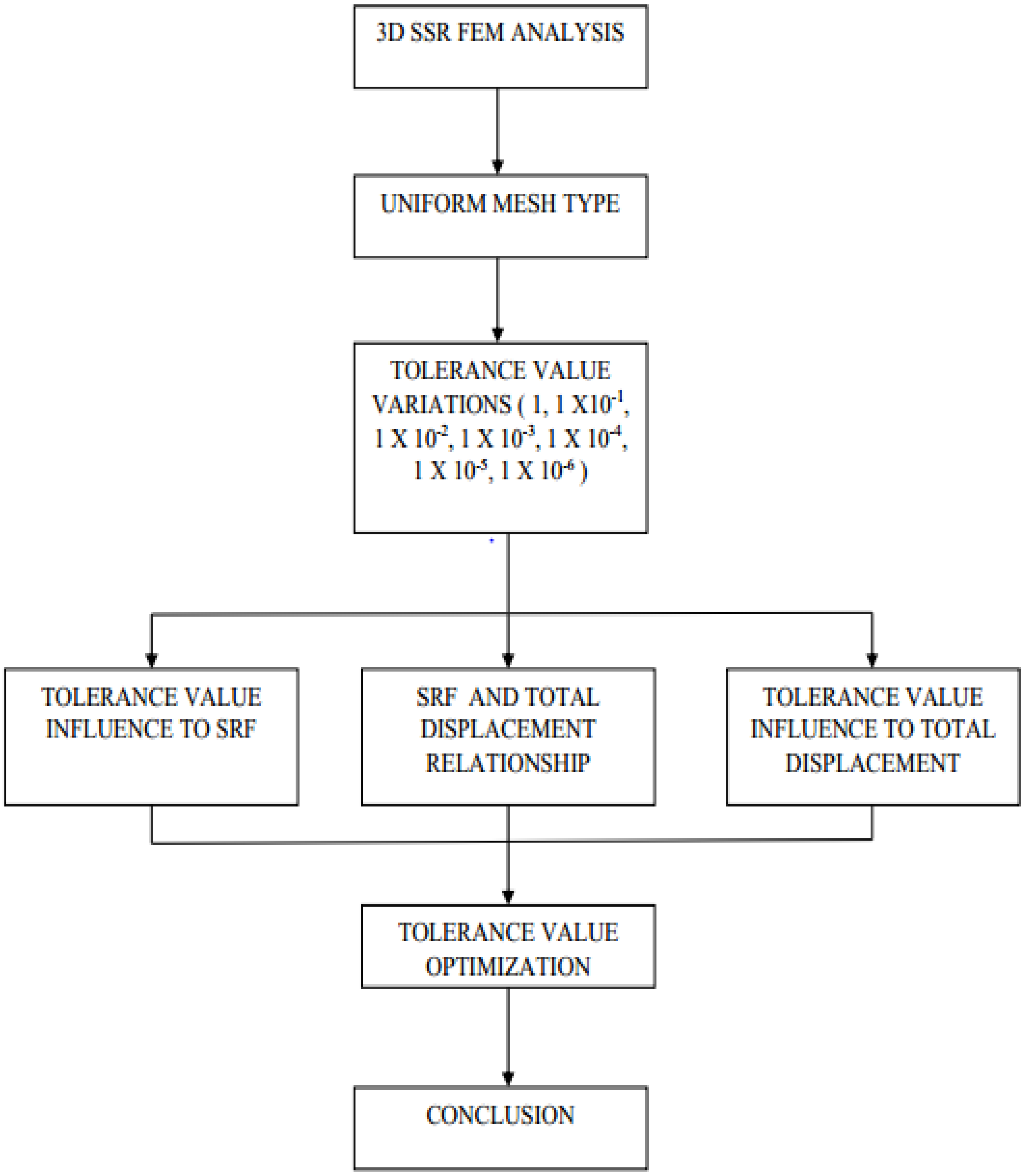

Figure 2 Research Framework

3. Result And Discussion

Results generated from computation with adjusted tolerance value is used for analysis to determine how the tolerance influence SRF and displacement, also to determine the optimum value of tolerance.

3.1. Result

From the computation using uniform mesh type with the adjusted element size of 100 Meters, the results obtained with different value of tolerance are as follows

Table 1 3D SSR Finite Element Computation Result

Mesh Type	Tolerance Value	SRF	Total Displacement (Meters)
4 Nodded	1	9,6	588,362
Uniform 100	1×10^{-1}	2,49	151,234
	1×10^{-2}	2,12	55,4421
	1×10^{-3}	1,93	35,4112
	1×10^{-4}	1,6	7,66136
	1×10^{-5}	1,2	4,71012
	1×10^{-6}	1	4,71011

3.2. Discussion

This paper mainly discusses the influence of tolerance value in the 3 Dimensional SSR Finite Element analysis method. The aim of the discussion is to better understand the role of tolerance parameter in this analysis method.

3.2.1 The Influence of Tolerance Value of FoS

Strength Reduction Factor (SRF) is the reducing factor referring to how many times the strength reduction reduced. The SRF computed in this method is the SRF at which point the failure occur. In the SSR method, the SRF value represent the actual value of FoS. The shear strength of the material is gradually decreased with a specified increment by a reducing factor called SRF. The shear strength reduction is done continuously until the slope is at the brink of collapse, or until the slope is in a critical condition. Failure happens when the analysis no longer able to come to a solution or non-convergence, and there no solution to satisfy the Mohr-Coulomb failure criterion (Griffiths, 1999). The reduction factor when the slope is at a critical condition is called the Critical Strength Reduction Factor or at this point, the Factor of Safety Value. According to rocscience, in its correlation with SRF, tolerance value determines the end of analysis or convergence. Tolerance value governs the step size (difference of SRF between two iterations) in the SSR method. Iteration will stop when the step size is less than the tolerance value. Therefore, the tolerance value plays an important role in the SSR Finite Element Method. Based on fig. 2 the chart indicates a clear trend of the increase of FoS value with the increase of tolerance value. The same SRF trend also shown in research by (Shen & Karaskus, 2014). This is due to the fact that tolerance is the minimum limit of the step size allowed in the SSR method. In iterations with lower tolerance value, convergence can be achieved without significant increase of the SRF. Therefore, the SRF just beyond non-convergence (failure) tends to have smaller value. On the other hand, analysis with higher tolerance value, the strength reduction needs much greater amount of reduction factor to reach the tolerance value, in which achieved with higher value of SRF.

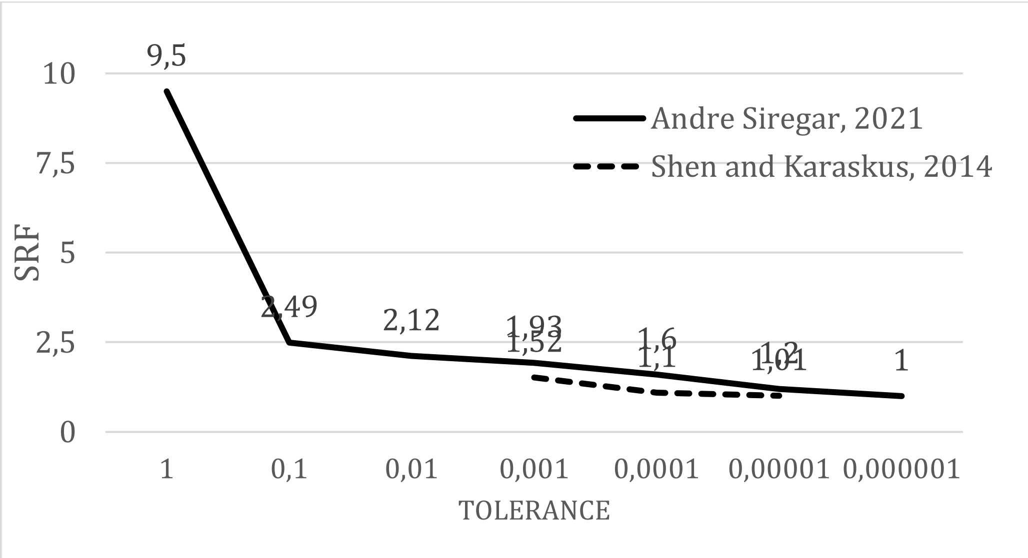

Figure 3 Relationship Between Tolerance and SRF

3.2.2 The Influence of Tolerance Value to Total Displacement

Results computed with 3 Dimensional SSR Finite Element Method give a set of information regarding the condition of the pit or slope at critical. One of the information is the Total Displacement. In this research the displacement recorded is the displacement occur when the slope is in a critical condition. According to Griffiths et al (1999) the displacement from computed results of the FE method Is the displacement occurred prior to displacement. In the SSR Finite Element Method, displacement is the respond of the to the strength reduction. The strength reduction caused a decrease in the material strength in the terms of cohesion and internal friction angle. At the critical point the material strength reaches its limit of the amount of force from the material self-weighted it can withstand. From fig. 3 it is clear that the relationship between tolerance displacement indicates a trend of the increase of Total Displacement with the increase of tolerance value. The explanation of this condition is, at higher tolerance value means that the material has the ability to hold greater amount of force caused by the strength reduction. Therefore the displacement prior to failure, generated by higher value of tolerance is greater because it needs large amount of deformation to bring the slope to its critical point.

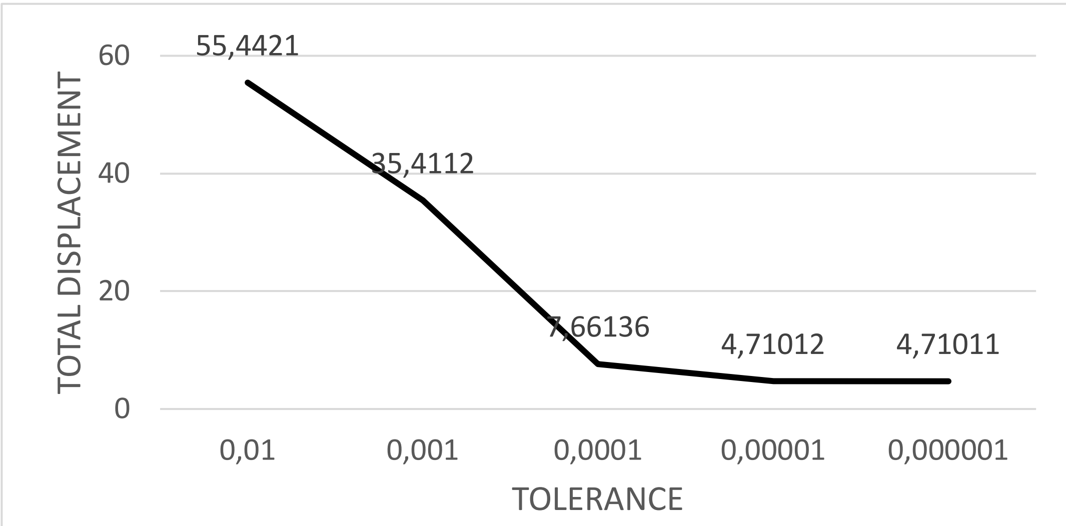

Figure 4 Relationship Between Tolerance and Total Displacement

3.2.3 Strength Reduction Factor and Total Displacement

The Strength Reduction Factor (SRF) is a reducing factor that shows the state of the reduction applied to the shear strength parameter of the material, cohesion and internal friction angle. From the recorded computation result, it can be seen that the total displacement grows higher with the increase of the SRF. This shows a rather diffusing relationship between two parameters. In the Shear Strength Reduction method, the Critical SRF represents the actual value of FoS. From the slope stability concept it is known that the higher the Fos value, the more stable the slope become. However from the displacement and SRF graph it clear that the greater the SRF, the larger the displacement generated. This can be justified by research by Griffitths et al (1999) that stated that the displacement recorded in SSR Finite Element is the displacement occurred prior to displacement. Therefore, higher SRF value means that it takes large amount of displacement before failure occur.

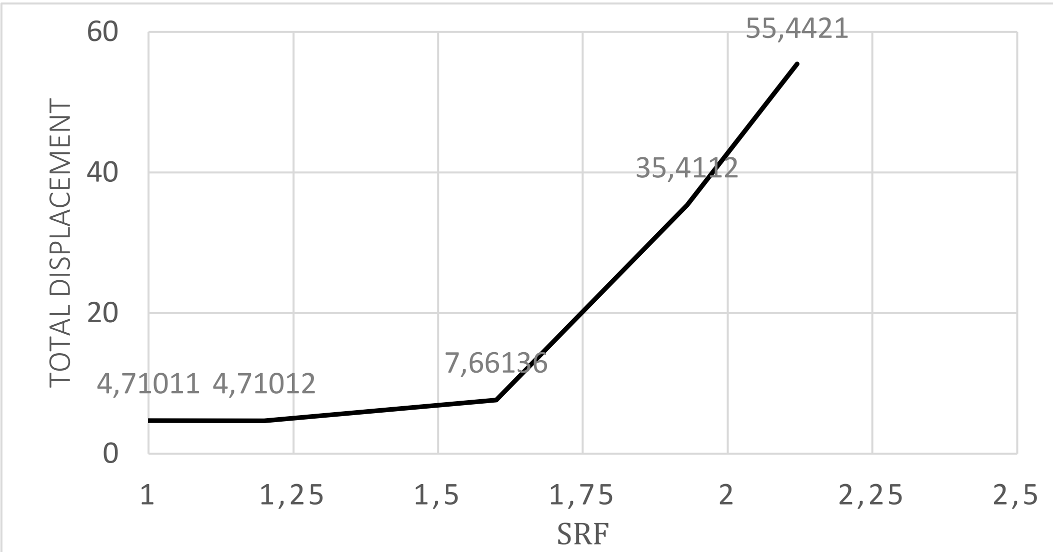

Figure 5 Relationship Between SRF and Total Displacement

From fig. it can be seen that the total displacement tends to decrease with the decrease of SRF. The total displacement decreases from 588,362 meters at SRF value of 9,5 with the tolerance of 1 until 7,66136 meters with 1,6 SRF and tolerance value of 1 x 10^{-4}. The displacement value stabilized at 4,71012 meters and decreases to 4,71011 meters at the tolerance value of 1 x 10-^{6}. This shows that 1 x 10^{-5} is the optimum value of tolerance as the displacement tends to stabilized at this value, with the SRF of 1.2, because further reduction give no significant change in the Total Displacement value.

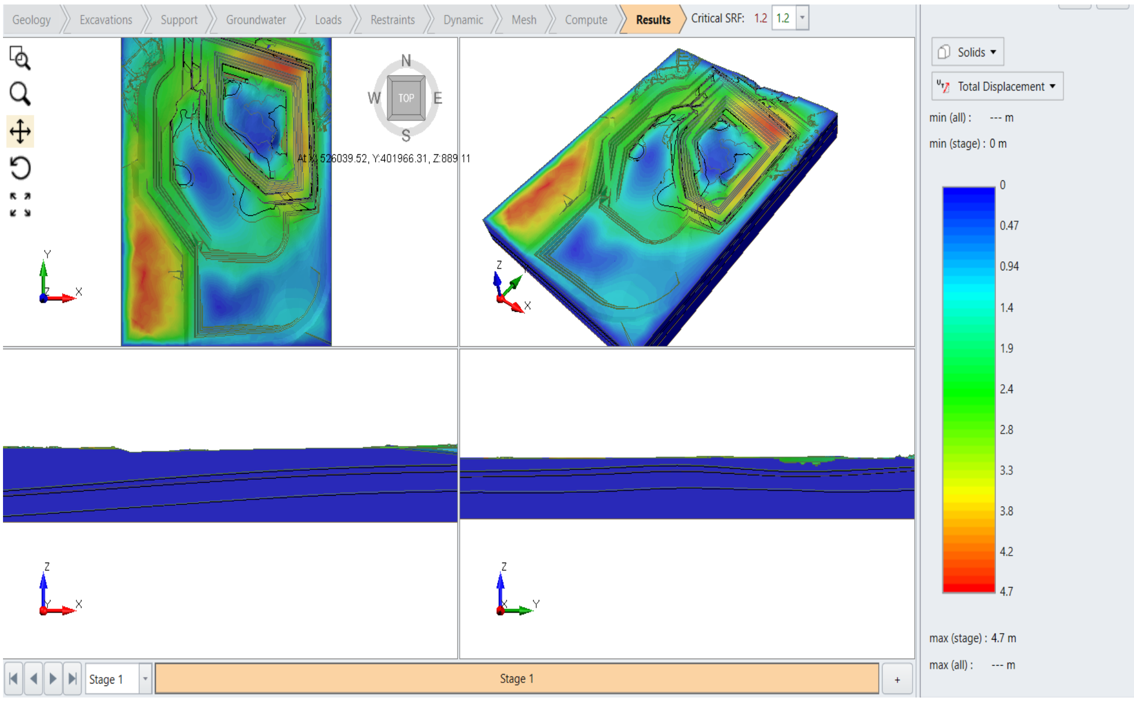

Figure 6 3D FEM Computation Result using Optimum Value of Tolerance

4. Conclusion

Tolerance value plays an integral part in the 3D SSR Finite Element Method. It marks the the stopping point of an iterations. The SRF value increases with increase of the tolerance value because the tolerance act as the minimum limit of the step size in the SSR analysis. The lower the tolerance, the lower SRF value needed to reach convergence (end of analysis). For the relationship between tolerance value and total displacement from the graphic it is clear that the displacement increases with the increase of tolerance value. In smaller value of tolerance, the material can only tolerate small amount of displacement before it collapses. Therefore, the slope fail with only small amount of displacement. Higher SRF value generates higher displacement as the material shear strength decreases and unable to withstand self-weighted force. From the SRF and displacement graphic it determined that 1×10^{-5} is the optimum value of tolerance with SRF of 1.2, as the displacement tends to stabilize at 4.71012 meters.

5. Credits

Authors would like to give special thanks to Muhammad Kemal Ghifari for the support and input in the form of counselling and discussions. The authors would also like to thank Trisakti University for their support of computer hardware and software that have made this research possible.

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