International Journal of GEOMATE, Nov., 2016, Vol. 11, Issue 27, pp. 2808-2814
Geotec., Const. Mat. & Env., ISSN: 2186-2982(Print), 2186-2990(Online), Japan

BACK-ANALYSIS OF HOEK-BROWN CRITERION: ROCK SLIDE CASE IN MANADO

Rini Kusumawardani[1], Togani Cahyadi Upomo[1] and Muhammad Faizal[1]

[1]Civil Engineering Department, Universitas Negeri Semarang, Indonesia

ABSTRACT: The discontinuity of geological structure on tuff layer of rock slopes in Manado triggered a phenomenon of rock slope instability. Mohr-Coulomb criterion which is commonly used as a method of analysis is not suitable to solve the slope stability problem because this criterion does not consider the condition of the geological structure as one of its factors. This paper analyzed the rock slope stability by accommodate the condition of the geological structure using Hoek-Brown criterion. Geological structure effect in Hoek-Brown criterion was realized in the form of GSI (Geological strength index). Poor geological structure will reduce GSI. In this paper, GSI of tuff has been determined by discontinuities of mapping and back analysis. The results from discontinuities mapping revealed that the rock structures were very blocky to blocky and surface conditions were very poor to poor. GSI value ranges between 20-30. From back analysis with shear strength reduction, GSI value was 20 and UCS value was 230 kN. The results are quite close with the field observation.

Keywords: Hoek-Brown Criterion, Slope Stability, Rock Slope, Joint Set, Finite Element

1. INTRODUCTION

Folds, discontinuity and faults were geology structure conditions that caused rock slope instability [7]. Complexity of geology structure is not accomodate in Mohr-Coulomb failure criterion. Based on experimental evidence and theoritical experience, Hoek-Brown made a failure criterion to accommodate the problems of geological structures in rock slope stability [5].

In recent years, there are some methods to analyze rock slope stability include stereographic projection, limit equilibrium method, finite element method, discrete element method, and lagrange differential method [6]. One of the popular techniques used Finite Element analysis in rock slope stability in order to determine the shear strength reduction (SSR). The concept of SSR systematically reduced the safety of the shear strength envelope of a material and computed the Finite Element models of the slope until reached a certain limit of deformations or solutions do not converge [2].

This paper will discuss about back analysis of rock slope stability in Manado, Indonesia, using shear strength reduction method and variate Geological Strength Index (GSI) and UCS (Uniaxial Compressive Strength) condition.

2. GENERELIZED HOEK-BROWN CRITERION

Since the geological structure in the field is too complex, it is not an easy task for field engineer to determine the cohesion and angle friction in a rock mass. Some factors should be considered such as the direction, spacing, and roughness of discontinuities plane which varies widely.

Hoek-Brown Criterion was introuduced by Hoek from research in brittle failure of intact rock and Brown from model studies of jointed rockmass behaviour [4]. This failure criterion is based on uniaxial compressive strength then reduced by joint condition in the rockmass.

Generelized Hoek-Brown equation is expressed as [4] :

$$\boldsymbol{\sigma_1 = \sigma_3 + \sigma_{ci}\left(m_b \frac{\sigma_3}{\sigma_{ci}} + s\right)^a} \qquad \text{.......... (1)}$$

With σ_{ci} is the uniaxial compressive strength of intact rock, m_b, s is material constants, and σ_3 and σ_1 are major and minor effective principle stresses at failure respectively. Therefore, equation of m_b expressed as:

$$\boldsymbol{m_b = m_i exp\left(\frac{GSI-100}{28-14D}\right)} \qquad \text{........... (2)}$$

Constants s and a are expressed by the following relationships:

$$\boldsymbol{s = exp\left(\frac{GSI-100}{9-3D}\right)} \qquad (3)$$

$$\boldsymbol{a = \frac{1}{2} + \frac{1}{6}\left(e^{-GSI}/_{15} - e^{-20}/_{3}\right)} \qquad (4)$$

GSI is the geological strength index and D is a disturbance factor and for equations σ and τ is described as follows,

$$\tau = (\sigma_1 - \sigma_3)\frac{\sqrt{1+am_b\left(m_b\frac{\sigma_3}{\sigma_{ci}}+s\right)^{a-1}}}{2+am_b\left(m_b\frac{\sigma_3}{\sigma_{ci}}+s\right)^{a-1}} \quad (5)$$

$$\sigma_n = \frac{1}{2}(\sigma_1 + \sigma_3) - \frac{1}{2}(\sigma_1 - \sigma_3)\frac{am_b\left(m_b\frac{\sigma_3}{\sigma_{ci}}+s\right)^{a-1}}{2+am_b\left(m_b\frac{\sigma_3}{\sigma_{ci}}+s\right)^{a-1}} \quad (6)$$

3. SHEAR STRENGTH REDUCTION (SSR) IN HOEK-BROWN MATERIALS

To solve the rock slope stability problem, this research applies the analysis of Shear Strength Reduction (SSR) in Hoek-Brown Criterion in which the following steps should be followed: [2]

(i) Reduce the shear strength envelope by F factor.

(ii) Find new strength model parameter that confirm to the lowered envelope.

(iii) Use of the new parameters in conventional Finite Elements (FE) elasto-plastic analysis.

In order to decrease the Generelizad Hoek-Brown shear strength envelope by the factor F, we simply divide by F [2].

$$\tau^{red} = \frac{\tau^{orig}}{F} = (\sigma_1 - \sigma_3)\frac{\sqrt{1+am_b\left(m_b\frac{\sigma_3}{\sigma_{ci}}+s\right)^{a-1}}}{2+am_b\left(m_b\frac{\sigma_3}{\sigma_{ci}}+s\right)^{a-1}}\cdot\frac{1}{F}$$

$$= (\sigma_1 - \sigma_3)\frac{\sqrt{1+am_b^{red}\left(m_b^{red}\frac{\sigma_3}{\sigma_{ci}^{red}}+s^{red}\right)^{a^{red}-1}}}{2+am_b^{red}\left(m_b^{red}\frac{\sigma_3}{\sigma_{ci}^{red}}+s^{red}\right)^{a^{red}-1}} \quad (7)$$

4. SITE DESCRIPTION

Morphology in study area generally consist of of sloping hills. The range of slope is 5 to 15%, with elevations generally in the range of 60 to 140 meters.

The study area is situated geographically between Latitude 1° 26.295' N and Longitude 124° 50.870' E. It is situated in Manado, North Sulawesi, Indonesia (See Fig.1). In the research location, there is a national highway which connects from city to sub-urban area. Geological formation in landslide location is named Tondano Tuff. This formation consist of coarse clastic volcanic rock that mainly tuff, andesite, lapilli and breccia.

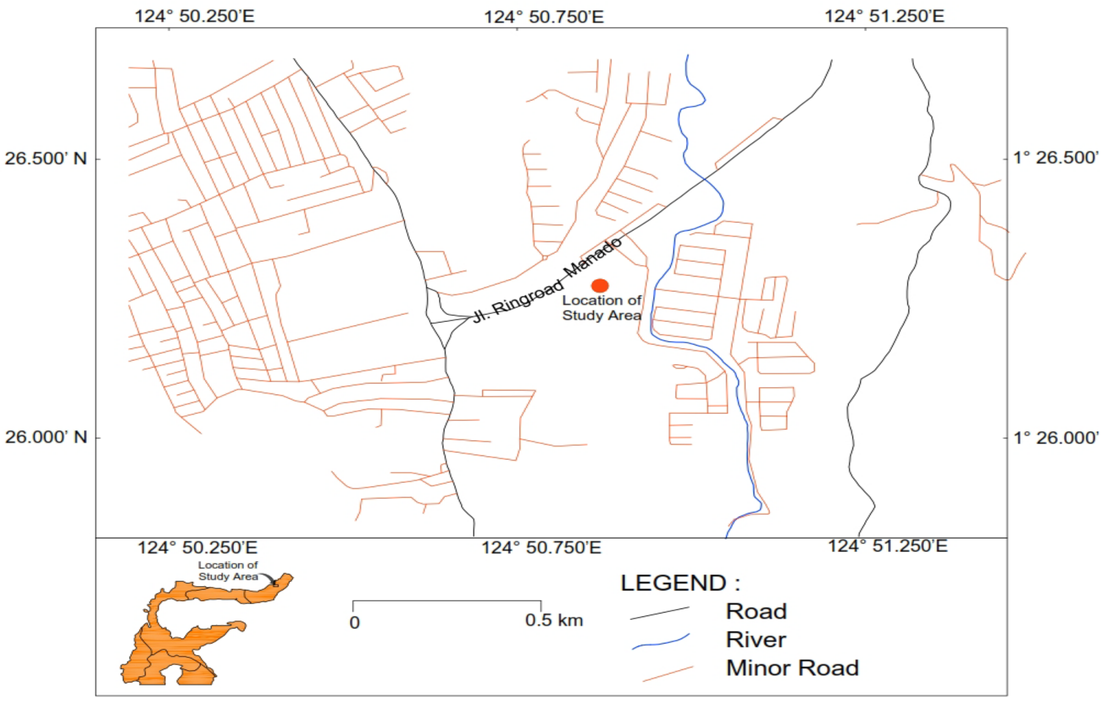


Fig. 1 Location of study area

In the field, the rock/soil layer consists of following types of rocks (see Fig. 2):

(i) Tuff with brown colour and moderately weathered, in the upper side of slope.

(ii) Breccia with dark brown colour and moderately weathered, below tuff layer.

(iii) Silty sand with brown colour and medium dense on tuff and breccia layer.

Discontinuity conditions of tuff are illustrated in Table 1 and Fig. 3. In Fig. 3, yellow line showing discontinuity conditions. Joint spacing approximately between 20 to 100 cm. In this condition, rock is very blocky to blocky. The condition of tuff surfaces was highly weathered. It is very poor to poor. According to GSI table, the value of GSI was 20 – 30 (See Table 2.).

Table 1 Discontinuity Condition in Rock Slide Area

No	Dips	Dips Direction
1.	68°	N60°E
2.	64°	N75°E
3.	46°	N170°E
4.	47°	N122°E
5.	82°	N230°E
6.	47°	N209°E
7.	21°	N155°E
8.	47°	N84°E
9.	74°	N283°E
10.	59°	N204°E
11.	14°	N110°E

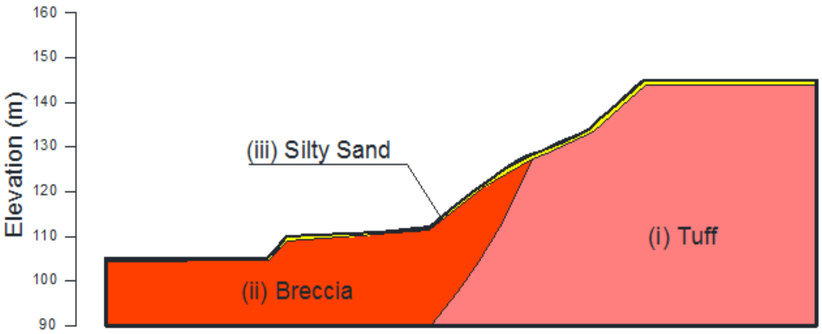
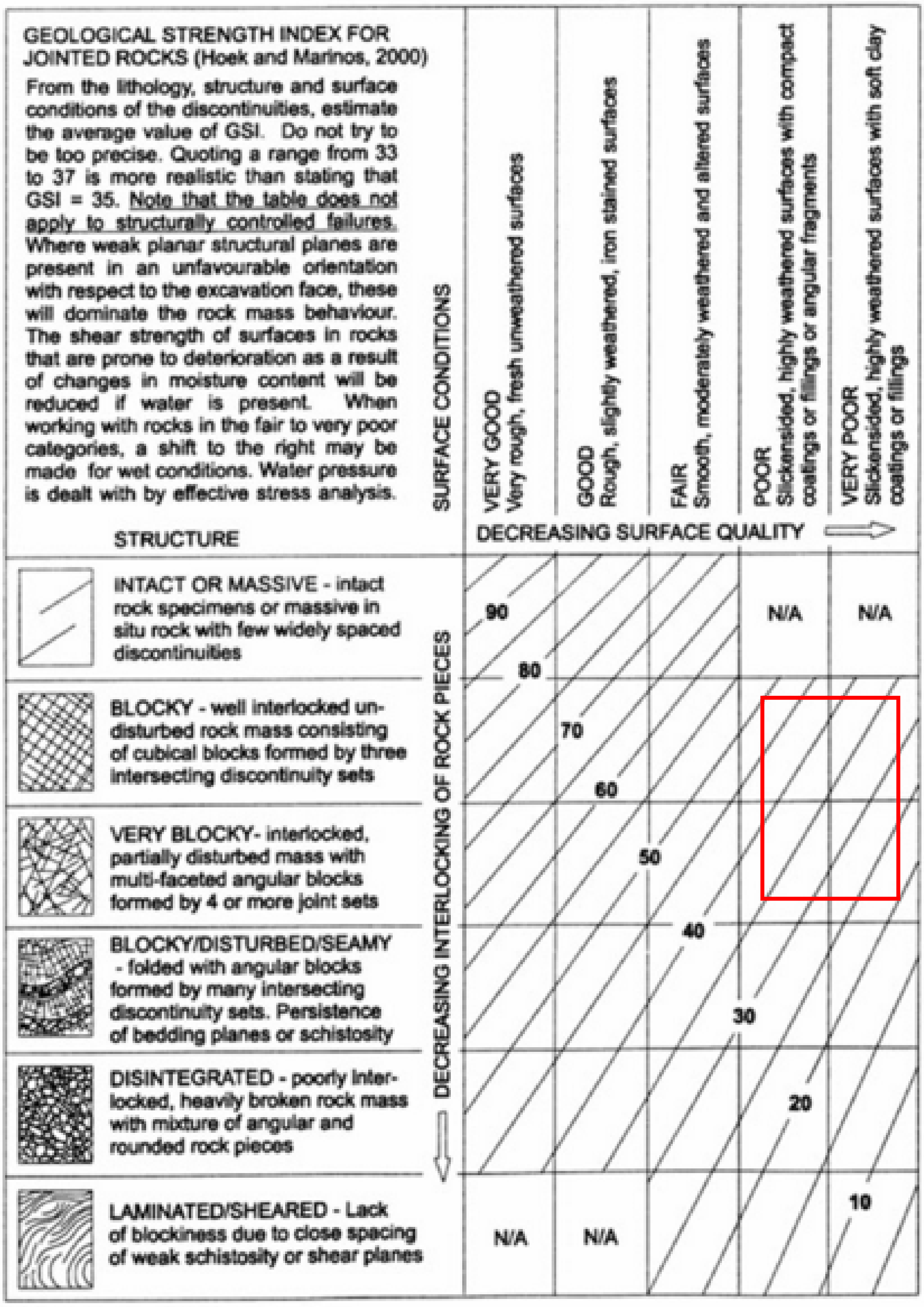


Fig. 2 Rock/Soil Layer Condition

Fig. 2 Discontinuity Condition in Rock Slide Area

Table 2 Geological Strength Index proposed by Hoek [3]



5. RESULTS AND DISCUSSION

5.1 Back Analysis

Back analysis of Hoek-Brown provides a more reliable shear strength than laboratory and in situ test. Back analysis could be utilized in two ways: first is by assuming a shear strength parameter and the second is by establishing a set of simultaneous equation which involves the information of two cross-sections [11]. This paper discuss back analysis by assuming UCS and GSI parameters of tuff layer using shear strength reduction in finite element method.

Finite element model was built in plane-strain elements. It has 2135 elements and 1169 nodes. The height of slope is 40 meters. Finite element model is illustrated in Fig. 4.

The values of UCS of Tuff layer used for the simulations were 200 kPa, 300 kPa, 400 kPa, 500 kPa and 600 kPa. Besides, values of GSI condition used are 60, 40, 30 and 10. Parameters of breccia and silty sand have been determined as shown in Table 3 and Table 4.

Calculation results are shown in Figure 5, in which revealed the value of UCS between 200 to 300 kPa and GSI between 20 to 60 give safety factor higher than 1. Otherwise, GSI 20 and value UCS between 200 to 300 revealed safety factor approximately one.

Table 3 Parameter of Silty Sand

Parameter	Value
Friction Angle	25^o
Cohesion	0.02 Mpa
Young's Modulus	20000 kPa
Poisson Ratio	0.3
Unit Weight	20 kN/m^3

Table 4 Parameter of Breccia

Parameter	Value
Compressive Strength	300 kPa
GSI	50
Intact Rock Constant (mi)	13
Young's Modulus	6143.7 Mpa
Poisson Ratio	0.3
Unit Weight	22 kN/m^3

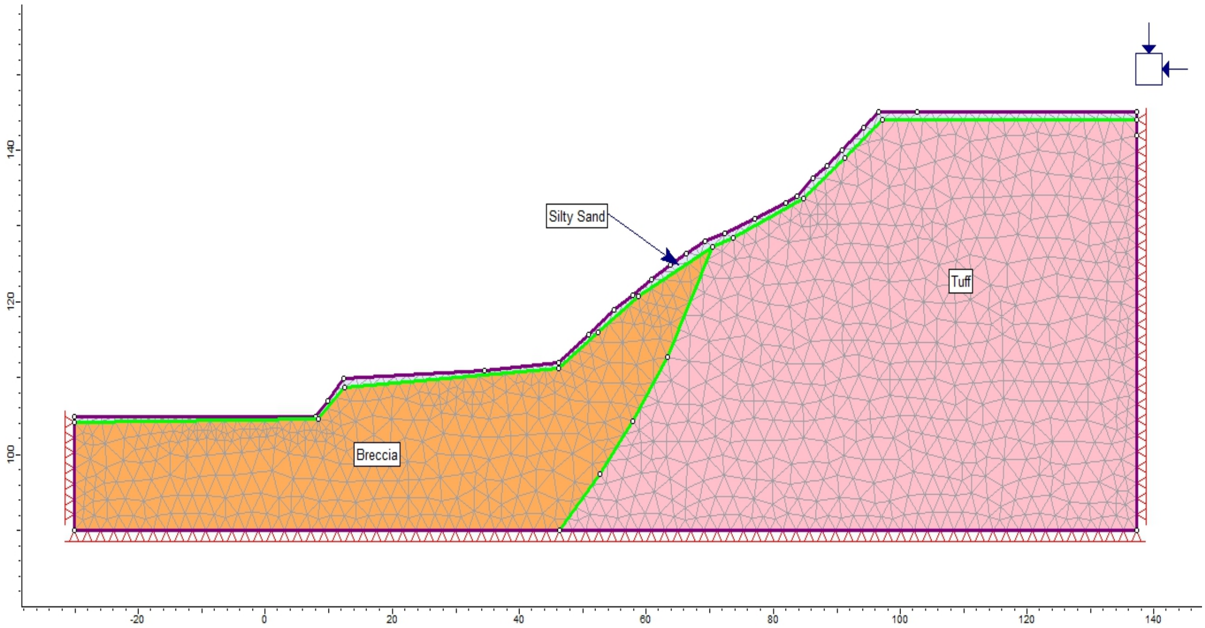


Fig. 4 Finite element model of rock slide area

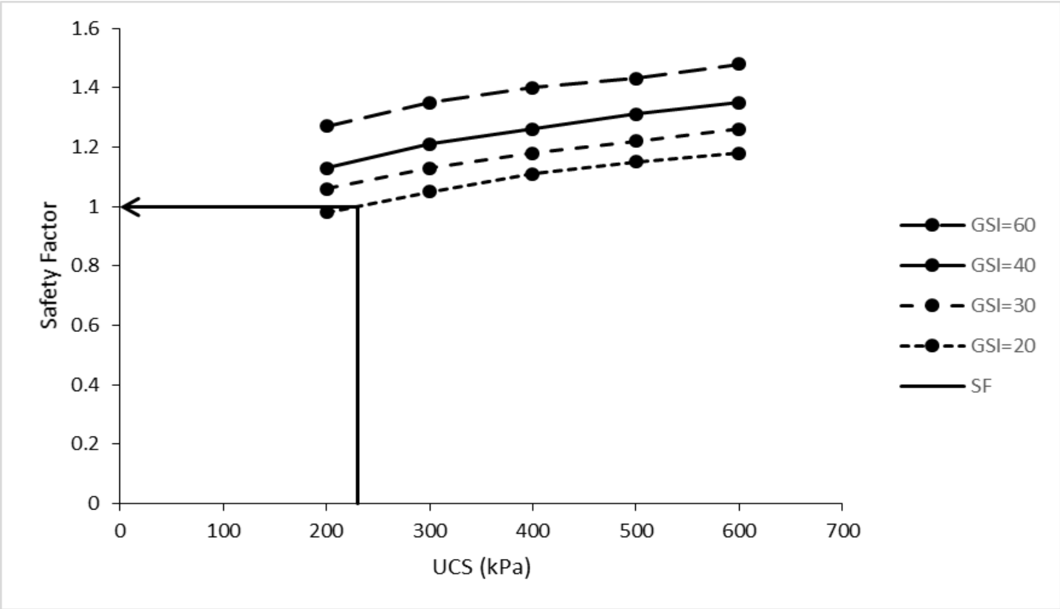


Figure 5: Result of UCS and GSI Simulation

Figure 5 shows that UCS and GSI provide significant effect in safety factor of rock slope stability. UCS depends on rock types and GSI depends on geology structure condition in the field. Therefore, if the slope conditions in the field have experienced sliding, the value of the safety factor is one. Based on Figure 5, in order to determine the value of UCS and GSI, with safety factor equal to 1, the UCS value was 230 kPa and the GSI value was 20. As the UCS and GSI values are determined, the result of Tuff parameters can be seen in Table 5.

Table 5 Parameter of Tuff

Parameter	Value
Compressive Strength	230 kPa
GSI	20
Intact Rock Constant (mi)	13
Young's Modulus	913.4 MPa
Poisson Ratio	0.3
Unit Weight	22 kN/m^3

Analysis of Finite Element by using parameters of tuff from back analysis are illustrated in Figure 6.

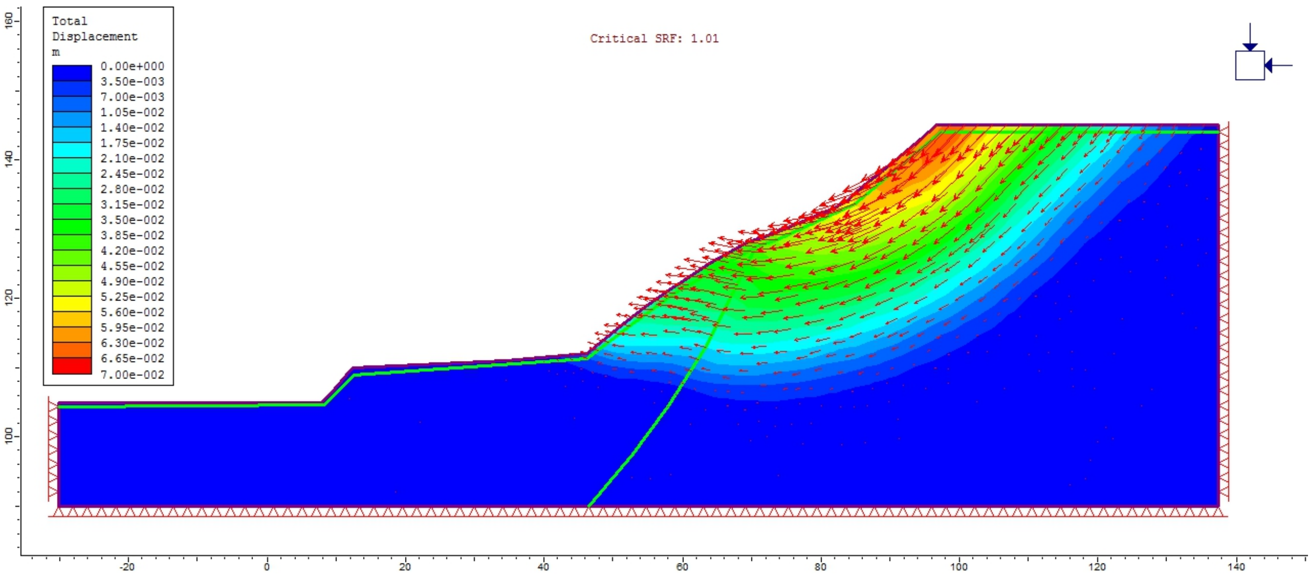


Fig. 6 Total Displacement of Finite Element Analysis

Fig. 6 depicted a critical safety factor of rock slope stability obtained equal to 1.01 with total displacement reached 0,7 cm at the top of slope. Failure of slope occurred at the tuff layer and for breccias layer could be denoted relatively stable.

6. CONCLUSION

(i) In analyzing the rock slope stability, the Hoek-Brown strength criterion is more realistic that Mohr-Coulomb criterion because the result is close to the condition in the field. The parameter of the GSI which analyses the geological condition of the rocks provides more reliable result, including the form of the fault, folds, and discontinuity.

(ii) Based on back analysis, when the safety factor equal to 1, the value of UCS is equal to 230 kPa and GSI is equal to 20.

7. REFERENCES

[1] Fossen, H., Structural Geology. Cambridge University Press, Cambridge, 2010.

[2] Hammah, R. E., Yacoub, T. E., and Corkum, B. C.,The Shear Strength Reduction Method for the Generalized Hoek-Brown Criterion. *The 40th U.S. Symposium on Rock Mechanics (USRMS): Rock Mechanics for Energy, Mineral and Infrastructure Development in the Northern Regions,* 2005.

[3] Hoek, E., Carter, T. G., and Diederichs, M. S. Quantification of the Geological Strength Index Chart. *47th US Rock Mechanics/Geomechanics Symposium*, 2013.

[4] Hoek, E., and Corkum, B., El criterio de rotura de Hoek-Brown – Edición 2002 Hoek-Brown failure criterion, 2002 Edition, (1), 1–8.

[5] Kumar, P. , Shear failure envelope of Hoek-Brown criterion for rockmass. *Tunnelling and Underground Space Technology*, *13*(4), 1998, pp. 453–458.

[6] Mohammed, M., Wan, L., and Wei, Z., Slope stability analysis of Southern slope of Chengmenshan copper mine, China. *International Journal of Mining Science and Technology*, *25*(2), 2015, pp 171–175.

[7] Stead, D. and Wolter, A., A critical review of rock slope failure mechanisms: The importance of structural geology. *Journal of Structural Geology*, 2015.

[8] Rocscience Inc., Phase2 v6.0 – a two-dimensional finite element analysis program, 2005

[9] Rocscience Inc., Slide v5.0 – a slope stability program based on limit-equilibrium analysis, 2003

[10] Wyllie, D.C., Mah, C.W., Rock Slope Engineering: Civil and Mining (4th Ed.).996 Spon Press, New York., 2004

[11] Zhang, K., Cao, P., and Bao, R., Rigorous back analysis of shear strength parameters of landslide slip. *Transactions of Nonferrous Metals Society of China*, *23*(5), 2013, pp. 1459–1464.

I International Journal of GEOMATE, Nov., 2016, Vol. 11, Issue 27, pp. 2808-2814.

MS No. 605731 received on Feb. 07, 2016 and reviewed under GEOMATE publication policies.

Pertinent discussion including authors' closure, if any, will be published in Nov. 2017 if the discussion is received by May 2017.
Corresponding Author: Rini Kusumawardani