Effect of pore water pressure on soil crack against safety factor of slope stability

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Abstract. The method used in this study is to simulate slopes that occur crack and get the influence of water saturation. The simulation is made with a computer application program, which is a program for calculating slope stability. The results of the analysis in this study found that the occurrence of cracks on the slope surface, the slope safety number will decrease when the crack is entered by water. Water entering the soil crack will cause pore water pressure which will then provide additional impetus to the slope landslide field. The greater the pore water pressure, the greater the decrease in security numbers. Besides that, the crack position from the edge of the slope has an effect on decreasing slope safety factor. A far the position of the crack from the edge of the slope increases the safety factor. The biggest decrease occurred in the position of 3 m crack from the edge of the slope. Crack positions greater than 3 m are the same. This happens because the slope failure field occurs at about 3 m from the edge of the slope.

1. Introduction

Slopes are part of the topography of the land formed due to differences in elevation from the two soil surfaces. The slope consists of the top of the slope, the foot of the slope and the base of the slope. Slope legs can be vertical or form a certain angle with a horizontal plane. The formation of slopes can be because naturally and also can be because it was made by humans for a certain technical purpose.

Natural slopes are often found in the highlands. The condition of natural slopes formed from the ground often experiences landslides. Slope slides occur because the driving force received by the slope is greater than the ability of the slope to hold it, thus forming a shear plane that has low stability. The factors that disturb the stability of the slopes include rainwater, vibrations that may originate from earthquakes or moving loads, construction loads that are built, cracks. Rainwater that enters the slope causes an impulse to the slope and also reduces soil strength. Landslides due to rainfall induction are a common problem in residual soil slopes from the tropics. It is widely known that slope failure is caused by rainfall infiltration [1]. If there are soil fractures on the slope, then this condition will further aggravate the stability of the slope. According to Chowdhury [2] the two main factors causing instability and slope erosion are high rainfall intensity and ground movement due to earthquakes.

Water conditions that seep into the slopes also cause a lot of slope landslides. This has been studied by [2, 3-6]. The influence of rainfall on the stability of the slope is more due to the absorption of rainwater which then causes excessive pore water pressure and also decreases the shear strength of the soil. Other influences have also been investigated such as the presence of cracks or fractures in the soil, proposed by [7, 8]. That the crack formed on the slope should be calculated in the calculation of the slope stability as the initial slope weakness.

The slope morphology slope was investigated by Gray [9]. The results of this analysis and observations show that concave slope profiles appear to be more stable and produce less sediment compared to uniform slopes or planar slopes. Tallon, O'Kane [10] restricted the entry of water into the slope by creating a layer on the slope that was applied to the mine slopes in the northwestern United States. While Li, Zhang [11] routinely monitor slopes, and observe information such as surface / underground movements, groundwater elevation, and location of rocks collected. Slope improvement is also done by pile pile into the slope until it penetrates the shear plane. Research conducted by Dhatrak and Bhagat [12] explains the results of several experimental studies conducted on lateral loads and tilt loads on long piles lying close to the slope. Slope instability will pose its own risk to human activities and even threaten human lives.

The level of risk according to Roy E. Hunt [13] is as follows: Low risk is an inconvenience that is easily corrected, does not directly endanger life or property, as a rock block of small size blocks a small portion of the road and is easily avoided and eliminated. Moderate risk if more severe disruptions occur, handled with some effort, but usually not directly endangering life or structure when they occur, such as slope debris entering one of the road lanes and causing partial closure for a short period of time until completion is removed. High risk: loss of all or part of an important road or structure, or complete closure of a road for some period of time but does not eliminate human life. Very high risk when threatening the life / human life in the event of a landslide, for example, the destruction of building structures / houses or trains when there is no time for warning.

Every year in the rainy season there are always landslides in the Indonesian Territory. In 2016 several slope landslides occurred in the Bali area. One of the worst and has not yet been handled is the slope slide in Petang Subdistrict, Badung Regency, Bali, that this slope slide has consumed all the road, causing transportation to be interrupted and must be diverted to other roads. The improvement of slope stability has also been studied by Arya [14] with the cement injection method so as to produce a higher slope safety rate. On the Denpasar Singaraja route there are also routine landslide cliffs which are very detrimental to transportation and also up to death. Economic losses and loss of lives have been caused by landslides. Efforts to overcome and prevent it have also been carried out and more methods are being sought to forecast slope stability more accurately.

Soil strength or soil shear strength is a major problem in geotechnics. All calculations of the stability of geotechnical structures are based on soil strength [15]. Also worth noting is the permeability of the soil when the land is entered by water. Because the entry of water into the soil pore will cause greater thrust and the strength of the soil will decrease. Thus it is necessary to know the pressure of the soil pore water on the soil crack against the slope stability security figures.

The problem raised in this study is how the influence of the magnitude of the soil pore pressure on the crack against the slope safety factor and how the influence of the crack position on the slope safety factor.

2. Method

In this study the research design will be used the experimental method. The research design used is to model the slope in a computer application program. This slope simulation will be made close to the slope geometry that has been landslide in Plaga Village, Petang District, Badung Regency, Bali Province. Physical properties and strength of land are sought in the area. Tests were carried out at the Soil Mechanics Laboratory of the Bali State Polytechnic Civil Engineering Department. In computer program simulations, cracks are made with variations in the location and variation in the amount of pore water pressure that enters the soil crack. So that the effect of pore water pressure on soil cracks on the safety of slope stability and the effect of crack position on the safety of slope stability are obtained.

The data collected for this study are primary data in the form of physical soil data, soil shear strength data, and soil topography data. In this study the tools that will be used are direct shear test equipment, soil property test equipment, computer program to calculate slope safety figures.

3. Results and discussions

3.1. Soil properties

Soil property testing is carried out to determine the physical properties of slope soil. This physical property is needed to determine slope stability and to know the physical condition of slopes in general. The physical properties tested were soil volume weight, soil water content and soil shear strength are cohesion and shear angle.

Tests are carried out by taking soil samples at a depth of 6 m and 33 m from the ground surface by drilling. The samples taken were then tested in the laboratory. In accordance with the test results obtained the unit weight on average is 1.665 gr / cm3 while the unit weight at a depth of 33 m is 1.674 gr / cm3. To determine the shear strength of the soil, the Direct Shear test is carried out. This test will get a C (cohesion) value and a value of □ or shear angle in the soil. Tests were carried out on samples from a depth of 6 m and from the drilling depth of 33 m. The test results are presented in Figure 1 for a depth of 6 m and Figure 2 for a depth of 33 m.

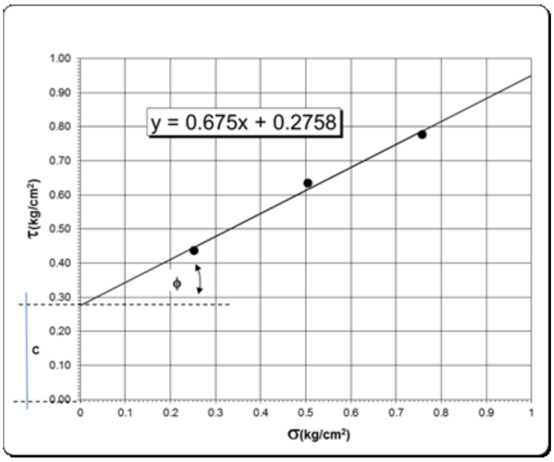

Figure 1. Direct shear chart of 6 m depth.

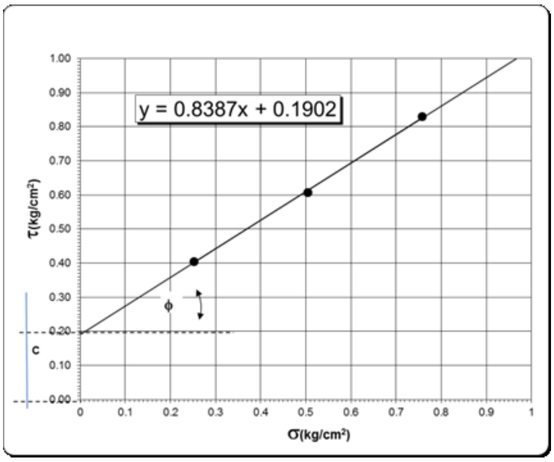

Figure 2. Direct shear chart of 33 m depth.

From Figure 1 it can be seen that the Direct Shear test chart equation is :

$$Y = 0{,}675\ x + 0{,}2758 \tag{1}$$

In the formula of soil shear strength from Mohr Coulumn are as follows:

$$\tau = 0{,}2758 + \ 0{,}675\ \sigma \tag{2}$$

Where :
Cohesion (C) = 0,2758 kg/cm^2
Internal Shear Angle (ϕ) = 34,02^o
From Figure 2 it can be seen that the Direct Shear test chart equation is :

$$Y = 0{,}8387\ x + 0{,}1902 \tag{3}$$

In the formula of soil shear strength from Mohr Coulumn are as follows:

$$\tau = 0{,}1902 + \ 0{,}8387\ \sigma \tag{4}$$

Where :
Cohesion (C) = 0,1902 kg/cm^2
Internal Shear Angle (ϕ) = 39,96^o

3.2. Effect of pore water pressure on slope stability

To get the effect of soil pore water pressure on slope stability, slope stability calculations were performed which did not occur pore water pressure and slope stability which received pore water pressure. Testing is done by calculating the "Slope Stability" slope of Geo Structural Analysis. The slope geometry analysed was get near to the geometric slope that landslide in 2016 in Antiga Village, Petang District, Badung Regency. The slope geometry is shown as Figure 4. After calculating the slope stability for the original conditions, the slope failure line is obtained as shown in Figure 3.

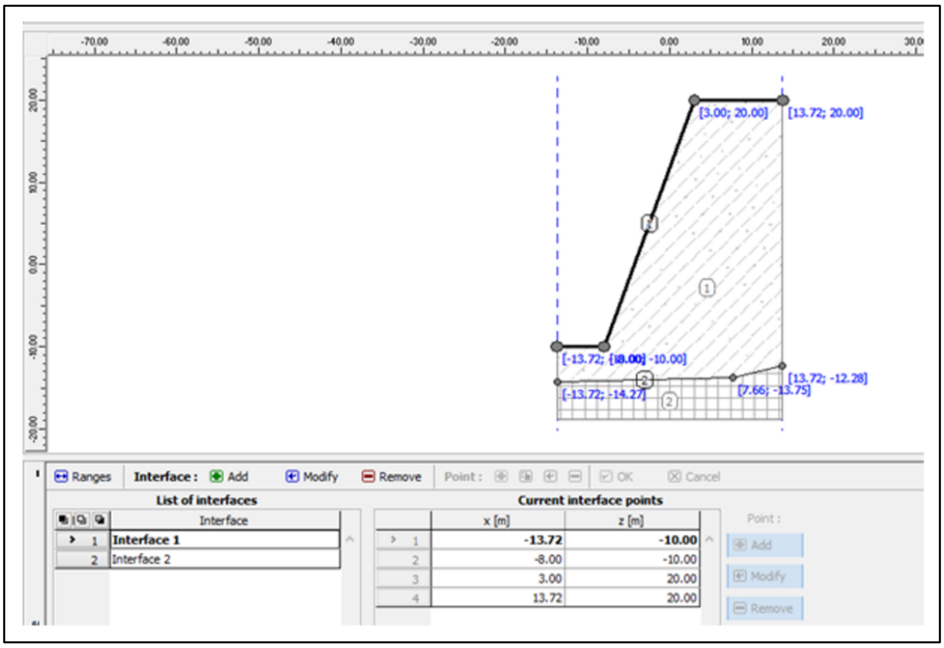

Figure 3. Slope geometry with a height of 30 m, slope angle 70°.

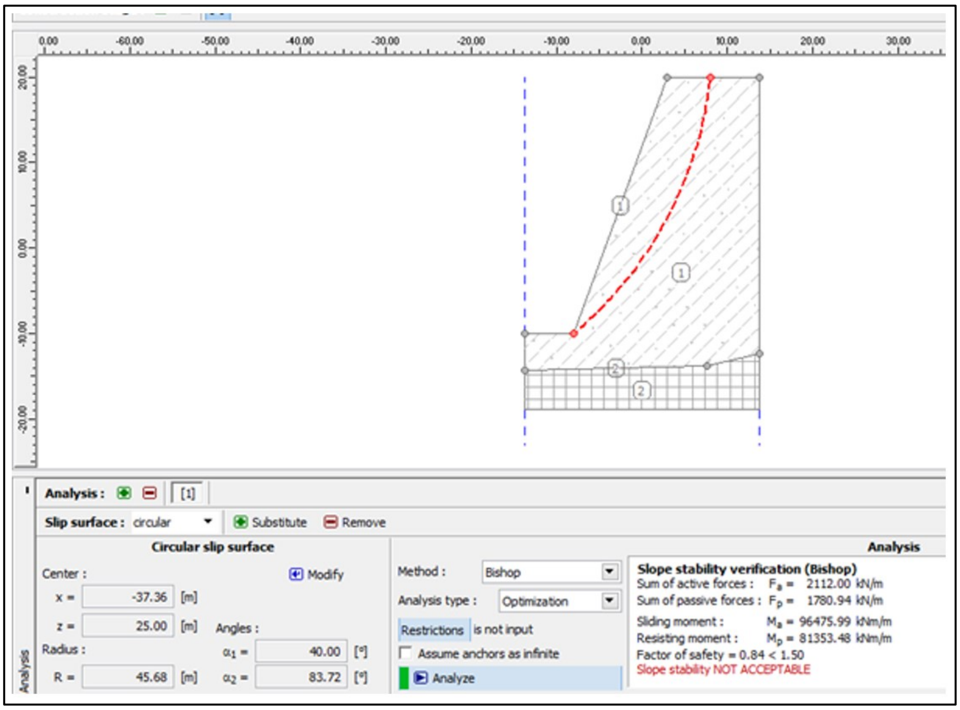

Figure 4. Slope failure line without the effect of pore water pressure.

After calculating the slope stability for the original conditions, the slope failure line is obtained as shown in Figure 4.

The safety factor (Fs) of the slope is 0.84 which is less than 1.0. This shows that the slope has collapsed because the Fs is less than 1.0.To obtain slope stability with safety Fs greater than 1.0, slope repairs are carried out. Improvements in this case are chosen by installing anchor at the foot of the slope.

After carrying out the anchor installation then slope stability was analyzed by anchor reinforcement. After obtaining a safe slope benchmark such as the analysis above, a simulation of cracks or fractures will occur on the upper side of the slope. After making a crack, the slope safety figures will be analyzed. This is done to see the effect of crack on slope safety factor (Fs) which shows slope stability. Next will be analyzed if the crack is filled with water when it rains or surface water that flows and enters the crack. Water entering the crack will cause pore water pressure on the crack. Pore water pressure will push the soil or parts of the slope so that the stability is predicted to decrease.

In slope stability has been shown for cracks. The safety slope number is Fs = 1.52. This Fs number is the same as Fs without crack. This shows that the occurrence of cracks on these slopes does not affect slope stability. This indicates that if the ground fracture does not fit in the landslide line, it will not reduce the slope security rate. This condition also applies when cracks occur in two locations, that the security number remains unchanged. This occurs in soil conditions where cracks are not entered by water.

The condition is then analyzed if the crack is entered by surface water, giving rise to a pore water pressure of 5 kPa. The pore water pressure shows the water level is 50 cm. So the crack analyzed is a crack with a depth of 50 cm and filled with water, so that the pore water pressure in the crack is 5 kPa. After analyzing Fs to 1.37. This Fs number decreases compared to the slope that occurs crack but is not entered by water, i.e. Fs 1.52.

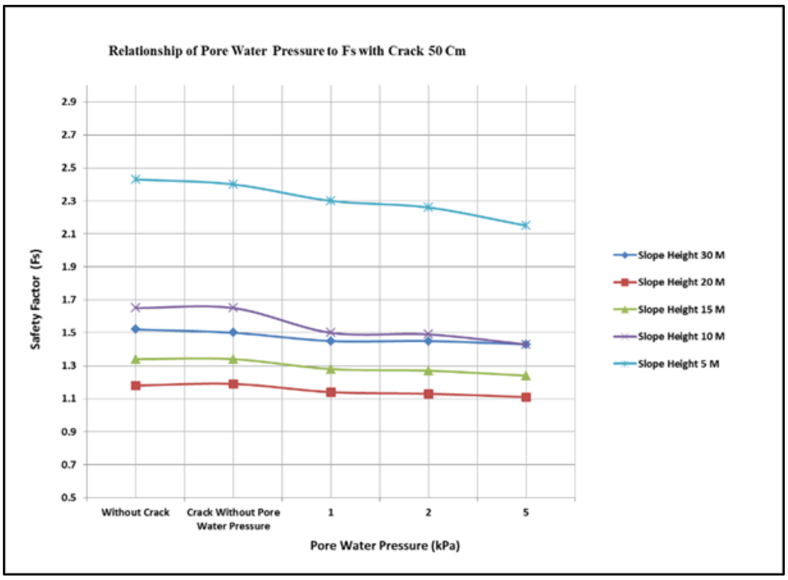

Figure 5. Relationship of pore water pressure to fs with crack 50 cm.

Further analysis of several conditions of pore water pressure to see the effect of pore water pressure on slope stability. The graph in Figure 6 shows the relationship between pore water pressure and safety factor Fs for different slope heights. Analysis of the slope height was varied, namely the slope height of 30 m, 20 m, 15 m, 10 m and 5 m. Each of these slopes was made as deep as 50 cm crack, then each type of slope was given the effect of varying pore water pressure of 1kPa, 2 kPa and 5 kPa. Each condition was analyzed for the safety slope Fs.

All slope types show that the presence of cracks on these slopes does not significantly affect slope safety figures. The safety slope Fs number will decrease when the soil crack is entered by water, resulting in pore water pressure on the soil. The greater the pore water pressure, the smaller the Fs. The percentage decrease in Fs is shown in Figure 6.

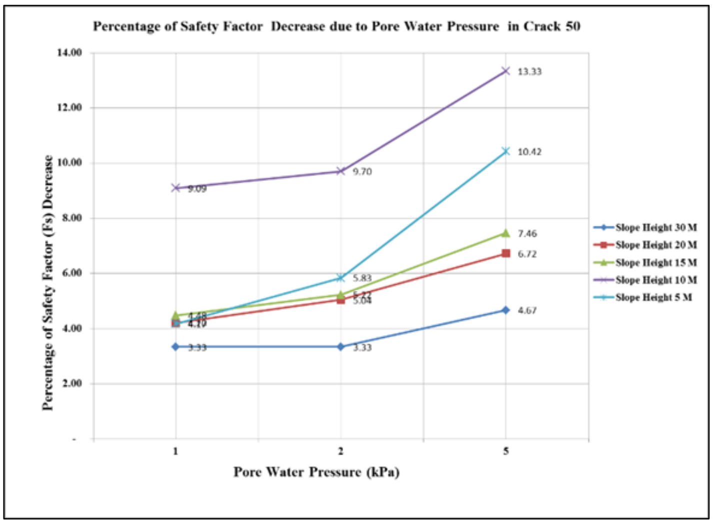

Figure 6. Percentage of decreasing safety factor due to pore water pressure.

In Figure 6 shows the percentage decrease in the safety factor of the slope (Fs) which is affected by pore water pressure. For slopes with a height of 20 m, 15 m and 5 m there is a decrease of about 4.20% if the cracks on the slopes get pore water pressure of 1 kPa or there is a puddle on the crack as high as 10 Cm. The biggest decrease occurred on slopes with a height of 10 m which is equal to 9.09% and the smallest on slopes with a height of 30 M at 3.3%.

All slope types show a decrease in the safety rate of Fs if the pore water pressure on the crack is getting bigger. The pore number pressure of 2 kPa indicates that there is a puddle of water at a crack as high as 20 cm and when the puddle reaches a height of 50 cm, the pore pressure of the soil becomes 5 kPa. The biggest effect occurs on the slope with a height of 10 M which gets pore water pressure of 5 kPa. The decline in Fs security rate was 13.33%.

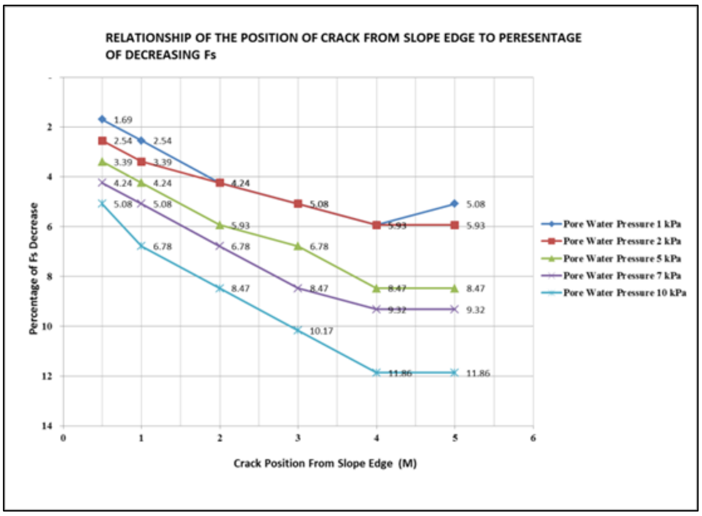

Figure 7. Chart of the effect of crack position on the 20 m slope against safety factor of slope.

3.3. Effect of Crack Position on Decreasing Security Numbers

To review the effect of the crack position on the slope on the slope safety figures, analysis of several crack positions was carried out on each slope type. The types of slopes analyzed were 20 m, 15 m and 10 m high slopes. The consideration is because this type of slope is a significant result of the effect of porous water pressure on slope stability.

Figure 8 shows a picture of the position of the crack and an analysis table of the influence of crack position on slope safety figures. The crack position is made on the slope surface with a distance of 0.5m, 1m, 2m, 3m, 4m and 5m from the edge of the slope. Crack depth of 100 cm. Then analyzed the influence of each crack if crack does not get pore water pressure and crust gets pore water pressure.

The graph of the percentage analysis of the influence of the crack position is presented in Figure 8. The graph shows that the crack position does not affect slope stability if the crack does not get water pressure or there is no water entering the crack. If crack is entered by water and pore water pressure occurs, there will be a decrease in Fs slope. The biggest reduction percentage occurs at 10 kPa pore water pressure, where this value is consistent with the above analysis where the greater the pore water pressure the slope stability decreases.

Crack position that is closer to the edge of the slope, the reduction percentage of Fs is smaller than that of a further crack position. This effect is constant at the position of the 4 m crack and even further. This is due to the position of the slope collapse plane at 3m from the edge of the slope.

The same thing also happened to the type of slope with a slope height of 15m and a slope height of 10m. Crack position does not affect the slope safety rate if the crack does not get pore pressure. But if there is pore pressure on the crack, the security number will decrease. The farther the position of the crack from the edge of the slope, the decrease in Fs will be greater, and the constant will decrease in position 3 m from the edge of the slope, see Figure 8 and Figure 9.

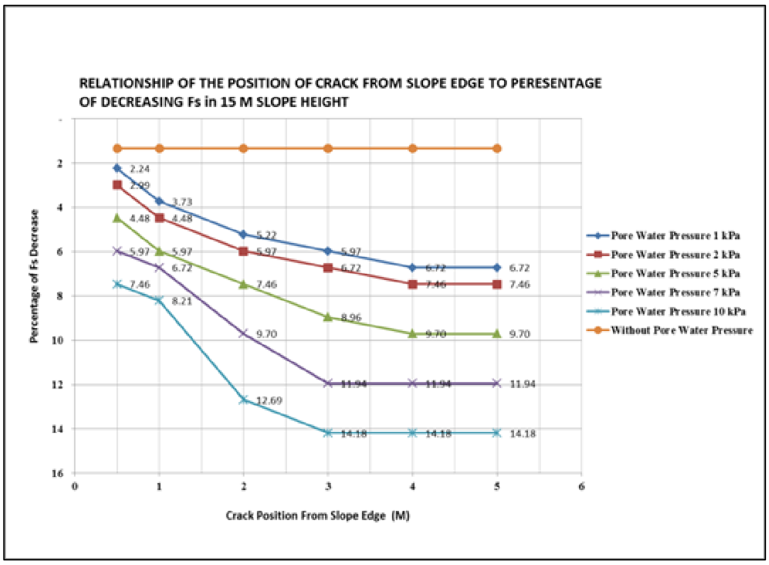

Figure 8. Chart of the effect of crack position on the 15 m slope against safety factor of slope.

With the above analysis, it can be seen that the crack position on the slope does not significantly affect the slope safety rate when the crack does not occur. This is because the crack does not reduce the soil strength that occurs in the landslide field. But if the crack is entered by water which causes pore water pressure, the security number will decrease. This is because the pressure of the pore water will cause additional pressure in the area of collapse. It is this pressure that gives excessive thrust to the segment of land that is going to landslide, so the security numbers are getting smaller.

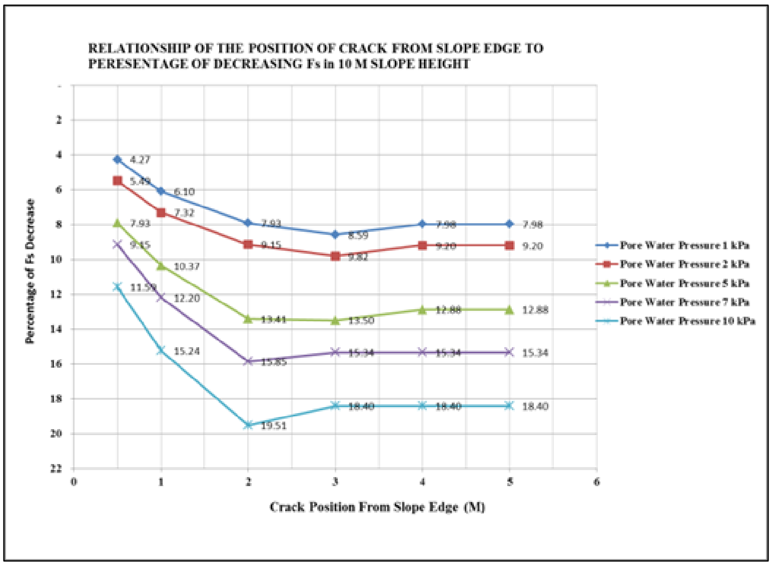

Figure 9. Chart of the effect of crack position on the 10 m slope against safety factor of slope.

The decrease in the safety number is even greater if the crack position is farther from the edge of the slope to a steady decrease in position about 3 m from the edge of the slope. This is because the position of the slope collapse field occurs at about 3 m from the edge of the slope. The more slope the crack occurs, the smaller the effect on the collapse plane.

4. Conclusions

With the occurrence of cracks on the surface of the slope, the safety rate of the slope will decrease when the crack is entered by water. Water entering the soil crack will cause pore water pressure which will then provide additional impetus to the slope landslide field. The greater the pore water pressure, the greater the decrease in security numbers.

The position of the crack from the edge of the slope affects the reduction of slope safety figures. This effect occurs when crack gets pore water pressure. The farther the position of the crack from the edge of the slope, the lower the security number. The biggest decrease occurred in the position of 3 m crack from the edge of the slope. Crack positions greater than 3 m are the same. This happens because the slope failure field occurs at about 3 m from the edge of the slope.

5. References

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