The effect of joint spacing on the stability of rock slopes reinforced with rock bolts

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ABSTRACT: In this paper, the effect of joint spacing on the stability of rock slopes reinforced with rock bolts was investigated. For this purpose, the rock slopes with different dips in jointed schist rocks were modeled using the Phase2 software and their stability were determined using the critical strength reduction factor (SRF) of slopes. In order to stabilizing slopes, the rock bolts with different angles were installed on the slopes. The results show that by increasing joint spacing, the strength reduction factor (SRF) has been increased and the maximum of SRF in each slope is obtained for the rock bolts perpendicular to the slopes. Furthermore, by increasing dip of slopes, the effect of joint spacing in the strength reduction factor (SRF) is irregular.

Keywords: Rock slopes; Rock bolts; Joint spacing; Strength Reduction Factor (SRF)

INTRODUCTION

The slope stability analysis has many applications in the design of rock slopes, roads and open pits structures. A number of methods have been suggested by researchers (Kirsten, 1982; Minty and Kearns, 1983; Caterpillar, 1988; Pettifer and Fookes, 1994) to evaluate the stability issues of slopes. These methods consider a different set of geotechnical parameters such as weathering, discontinuity spacing and groundwater. Joints are the most universal geologic structures as they are found in most every exposure of rock. They vary greatly in appearance, dimensions, spacing, and arrangement and occur in quite different tectonic environments. Joint spacing is the distance between individual joints within a joint set. The terms joint spacing and average joint spacing are often used in the description and assessments of rock masses.

Rock bolts have been used for many years for the support of underground excavations and rock cuts. Rock bolts often consist of plain steel rods with a mechanical or chemical anchor at one end and a face plate and nut at the other and they are always pre-tensioned after installation. For short term applications the bolts are commonly left ungrouted and for long term applications, the space between the bolt and the rock can be filled with cement or resin grout (Rocscience, 1999).

In the Strength Reduction approach, the soil or rock strength is dummy reduced, and so there is a need to redistribute the stresses. This can be done by the stress redistribution algorithm, and so this option can be indirectly used to do a strength reduction stability analysis.

In this Research in order to study the effect of joint spacing on the stability of rock slopes reinforced with rock bolts, the slopes with different dips composed of schist rocks were modeled.

Geomechanical parameters of schist rocks

In this study, the geomechanical parameters of the jointed schist were obtained using Roclab software (Hoek et al. 2002). These parameters are obtained based on The Hoek-Brown failure criterion and it is presented in Fig. 1.
Modeling of rock slopes

To study the effect of joint spacing on the stability of rock slopes reinforced with rock bolts, the slopes in different dips such as 30, 45, 60, and 75 were modeled by Phase2 software (Rocscience, 1999). In the models, the pattern of parallel deterministic joints was used in spacing of 1, 1.5, 2, 2.5 and 3 meters. Also, the joints all over the slopes have the same conditions in the spacing of joints, the roughness of joints’ surface, and the resistance of joints’ walls. Moreover, the length of rock bolts and the distance of their places were 7 meters and 5 meters respectively. In addition, the installation angles of rock bolts on the slopes differ from -60 to -180 degrees from horizontal. By run the made models, the critical strength reduction factor (SRF) of slopes was obtained (for example, as Figs. 2 to 5).

![Figure 1. The geomechanical parameters of schist rocks](image1)

![Figure 2. The slope of 60 degrees with parallel deterministic joints and spacing 1 meters reinforced with rock bolts that were installed at angle of -180 degrees (the critical SRF is equal to 1.89)](image2)
Figure 3. The slope of 60 degrees with parallel deterministic joints and spacing 1 meters reinforced with rock bolts that were installed at angle of -150 degrees (the critical SRF is equal to 1.90)

Figure 4. The slope of 60 degrees with parallel deterministic joints and spacing 1 meters reinforced with rock bolts that were installed at angle of -120 degrees (the critical SRF is equal to 1.89)
Figure 5. The slope of 60 degrees with parallel deterministic joints and spacing 1 meters reinforced with rock bolts that were installed at angle of -90 degrees (the critical SRF is equal to 1.88)

Similarly, the values of SRF for other slopes and other joint spacing (1.5, 2, 2.5 and 3 meters) are obtained and presented in Figs. 6 to 9.

Figure 6. The diagram shows the values of SRF for the slope with dip of 30 degrees and different joint spacing reinforced with rock bolts that were installed at different angles.
Figure 7. The diagram shows the values of SRF for the slope with dip of 45 degrees and different joint spacing reinforced with rock bolts that were installed at different angles.

Figure 8. The diagram shows the values of SRF for the slope with dip of 60 degrees and different joint spacing reinforced with rock bolts that were installed at different angles.
The diagram shows the values of SRF for the slope with dip of 75 degrees and different joint spacing reinforced with rock bolts that were installed at different angles.

The diagrams in Figs. 6 to 8 show that by increasing joint spacing, the strength reduction factor (SRF) is increased. This is for the fact that by increase in spacing of joints, the Geological Strength Index (GSI) will increase and the amount of mb in Hoek-Brown equation has an increase, so the shear strength envelope of slopes will rise and as a result, the strength reduction factor (SRF) will increase.

\[
m_b = m_i \exp \left( \frac{GSI - 100}{28 - 14D} \right)
\]

\[
\sigma_1' = \sigma_3' + \sigma_{ci}' \left( \frac{m_b \sigma_3'}{\sigma_{ci}'} + s \right)^a
\]

Moreover, the diagrams show that by increasing dip of slopes, the effect of joint spacing in decrease or increase of SRF is irregular and the maximum SRF in each slope is obtained for the rock bolts perpendicular to the slopes.

**CONCLUSION**

In this research that with aim to analysis the effect of joint spacing on the stability of rock slopes reinforced with rock bolts is done the following results are obtained:

By increasing joint spacing, the strength reduction factor (SRF) has been increased.

By increasing dip of slopes, the effect of joint spacing in the strength reduction factor (SRF) is irregular.

For all joint spacing, the maximum SRF is obtained for the rock bolts perpendicular to the slopes.

**REFERENCES**