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Bolt length requirement in underground openings

R.K. Goel[a,*], Anil Swarup[a], P.R. Sheorey[b]

[a]Central Mining Research Institute, Regional Centre, CBRI Campus, Roorkee 247 667, India
[b]22 Palm Road, Civil Lines, Nagpur 440 001, India

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Abstract

A parametric study has been carried out using the numerical analysis code FLAC^{3D} to obtain the influence of various shapes of underground openings on the maximum induced boundary stress. Five shapes—viz. circular, horseshoe, rectangular, elongated D-shape and elliptical—have been considered. For each shape, four tunnel depths and five horizontal in situ stress models have been taken for the study of induced boundary stresses.

The values of maximum and minimum induced boundary stresses in the roof and wall have been obtained from the analyses. This data has subsequently been used to develop correlations to estimate the normalized maximum and minimum boundary stresses, which have been subsequently compared with the strength of the rock mass obtained from the Sheorey's non-linear failure criterion for three rock masses represented by three values of Bieniawski's RMR and three values of crushing strength of intact rock material. The values of minimum factor of safety at the roof and the wall have been collected from all the plots. Using these data sets, different correlations have been developed to estimate the minimum factor of safety ($f_{\min}$) in the roof and wall.

Since the bolt length should be normalized with the opening size, some more computer models have been run with varying tunnel width of 5 and 20 m besides the earlier 10 m size to obtain the correlations for estimating the bolt length. The depth of factor of safety contour of 1.5 from the opening periphery has been picked up from all these models and the correlations have been developed for estimating the roof and wall bolt length for the five shapes of underground openings. The correlations for bolt length show that in addition to the shape of underground openings and in situ stress, the bolt length also varies with the rock mass type. These correlations have been verified for field cases of elongated D-shape openings.

Keywords: Underground opening; Numerical analysis; In situ stress; Minimum factor of safety; Bolt length

1. Introduction

Formation of an underground rock excavation leads to the redistribution of stresses whose magnitudes and directions depend upon the shape of the excavation and the pre-excavation in situ stress field. These redistributed or induced stresses have a definite zone of influence within which rock failure may commence, creating a zone of disturbed or failed rock, depending upon rock mass competence vis-à-vis the magnitudes of these stresses. If the rock mass is very competent and the stresses small, a disturbed zone may not be created and more or less elastic rock conditions may prevail.

The formation of the failed rock zone always goes progressively deeper into the rock mass, its onset being at the excavation boundary. It may therefore be useful to know the boundary stress values in order to make a quick guess, in the first instance, whether an excavation will remain generally stable [1].

In this work a parametric study was carried out using numerical analysis code FLAC^{3D} to study the following issues: (a) the variation of the maximum boundary stress for various shapes of large underground openings, and (b) the bolt length corresponding to the maximum stress value and to develop correlations for obtaining the bolt length.

*Corresponding author. Tel./fax: +91 1332 275998.
E-mail address: rkgoel15@gmail.com (R.K. Goel).

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2. Approach and input parameters

FLAC^{3D} numerical analysis code developed by ITASCA of USA has been used for the study [2]. Various tunnel models have been prepared for the numerical analysis with combinations of different influencing input parameter values. Various parameters considered for the study are described below.

2.1. Shapes of underground openings

Among various shapes of underground openings, circular and D-shape (or horseshoe) tunnels are the most popular in hydro-electric, railway and road projects, while rectangular tunnels are common in the mining sector. The large underground openings for power projects and for storage purposes are mostly of elongated D-shape. Large openings of elliptical shape are also being preferred for underground storage of oil, LPG and for other specialized purposes. Thus, a total of five shapes of underground opening were considered for the analysis as shown in Figs. 1(a)–(e) along with their sizes.

2.2. In situ stresses

Hoek and Brown [1] used more than 100 data from in situ stress measurements and proposed the following equation for the vertical in situ stress:

$$\sigma_v = 0.027H, \tag{1}$$

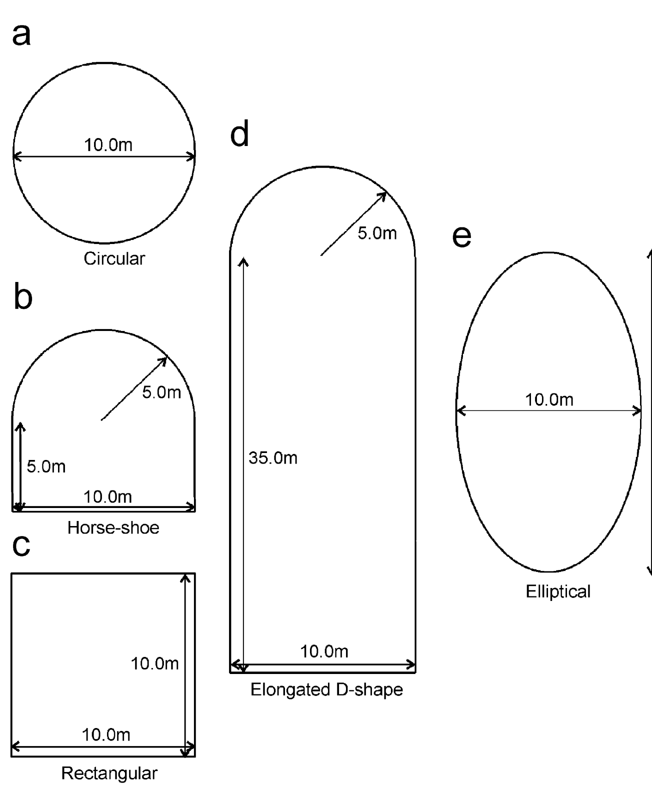

Fig. 1. Five different shapes of underground openings considered for analysis.

where σ_v is vertical in situ stress in MPa, and H is the depth in meters. They have also plotted the ratio of the average horizontal stress σ_h to vertical stress σ_v, also known as k, with depth, and obtained the following two equations of upper and lower bound curves:

$$k = \frac{\sigma_h}{\sigma_v} = \frac{100}{H} + 0.3, \tag{2}$$

$$k = \frac{\sigma_h}{\sigma_v} = \frac{1500}{H} + 0.5. \tag{3}$$

Putting the value of σ_v from Eq. (1), the above equations become

$$\sigma_h = 2.7 + 0.008H, \tag{4}$$

$$\sigma_h = 40 + 0.0135H. \tag{5}$$

Apart from the above, the results of stress measurements carried out in India by the National Geophysical Research Institute (NGRI), Hyderabad and the Central Mining Research Institute (CMRI), Dhanbad have also been studied.

Considering the above, and barring the very high range of Hoek and Brown (Eqs. (3) and (5)) a range of stress models were considered for input of the average horizontal stress (σ_h) in the present study as follows, where again the stresses are in MPa, and the depths in meters:

$$\sigma_h = 2.0 + 0.007H, \tag{6}$$

$$\sigma_h = 5.0 + 0.01H, \tag{7}$$

$$\sigma_h = 10.0 + 0.01H, \tag{8}$$

$$\sigma_h = 15.0 + 0.012H, \tag{9}$$

$$\sigma_h = 20.0 + 0.015H. \tag{10}$$

The same horizontal stress is used in both directions, i.e., perpendicular to the opening as well as along the opening.

2.3. Other input parameters

In addition to the shape of openings and five stress models (Eqs. (6)–(10)), values of other input parameters used for the study are as follows. For competent rock, we use depths of $H = 50, 150, 300$, and 500 m; rock mass rating (RMR) values of 50 and 75; and uniaxial compressive strengths of $\sigma_c = 50, 100$, and 150 MPa. For weak rock, we use depths of 50, 100, 150, and 200 m; RMR value of 35; and uniaxial compressive strengths of 50, 75, and 100 MPa. The values of depth of cover and uniaxial compressive strength have been taken different for competent and weak rocks. This is because, in the case of weak rocks, higher depth of cover may lead to elasto-plastic conditions, and the present analysis is limited to elastic conditions.