Optimization of the Distance between Twin Tunnels by Stress Analysis

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Abstract

In this research, the stress characterization around twin-tunnels passing through a hard rock mass mostly consisting of Charnockitic Gneiss, Biotite Gneiss and Garnet Granulitic Gneiss in Kaluganga Development Project was analyzed by Boundary Element Method numerical solutions. The distribution and magnitude of major and minor principal stress contours, mean stress, differential stress, total displacement, maximum shear strain, and strength factor contours around the tunnels were simulated using the "Examine 2D" software. Examine 2D is a plane strain boundary element programme for calculation of stresses and displacements around underground and surface excavations in rock. Modeling results show that the countour values of the strength factor around the tunnel is greater than 1 when the distance between tunnels is 4.2 m which is the actual designed distance between the twin tunnels. When the distance is less than 4.2 m, model results shows that the strength factor reaches 1 in 1.88 m, and the excavation becomes unstable.

Keywords: BEM analysis, Examine 2D, Kaluganga development project, Stress analysis, Strength factor

1. Introduction

In the process of an underground excavation it is very important to understand the rock mass behavior.

When an opening is excavated in rock, the stress field is locally disrupted and a new set of stresses are induced in the rock surrounding the opening. Knowledge of magnitude and direction of these insitu and induced stresses is an essential component of underground excavation design, since in many cases, the strength of rock is exceeded and resulting instability can have serious concequences on the behavior of the excavation [1]. Therefore, this research mainly focused on investigating the influence of geometry and in-situ stress variability on the stress changes around tunnel excavations using BEM analysis to optimize the distance between twin tunnels.

2. Study area

The Kalu Ganga Development Project is part of the Moragahakanda Development on the Amban Ganga, with water from Kalu Ganga being transferred into the planned Moragahakanda reservoir. The location of the reservoirs and their catchment area are shown in Figure 1. This study is focused on the twin-tunnels-LBO (Left Bank Irrigation Outlet) and TCO (Transfer Channel

Outlet) passing through a hard rock mass mostly consisting of Charnockitic Gneiss, Biotite Gneiss and Garnet Granulitic Gneiss in this Kaluganga Development Project.

Figure - 1 Location of the site [2]

3. Methodology

Rock specimens were prepared from the samples collected from the tunnel site. The strength properties were determined using Triaxial test, Uniaxial compressive strength test, Point load test and Brazilian test. Required geological information for BEM analysis was gathered from site documents. BEM analysis was performed using the Examine 2D software based on Hoek-Brown criteria. The analysis was performed firstly for individual tunnels and then for the twin tunnel to study the stress redistribution behavior due to adjacent tunnels. By moving the boundary of the tunnels the variation of the strength factor in the pillar region was studied.

3.1 Model geometry and input parameters for BEM analysis

Both TCO and LBO tunnels are of semicircular shape. LBO is 4.4 m in width and 1.8 m in height. LBO tunnel is 1.4 m in depth and 2.8 m width. The distance between the tunnels is 4.2 m (Figure 2).

Geological Strength Index (GSI), Uniaxial Copmressive Strength (UCS), Angle of friction (φ), Tensile strength and mi;material constant of intact rock were determined and used as input parameters (Table 1).

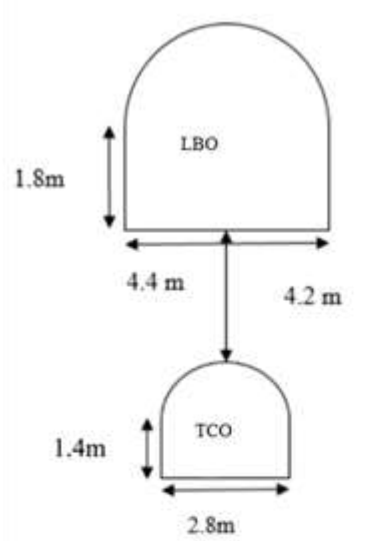

Figure 2 - Geometry of the twin tunnels

Table 1 - Parameters for feeding the software

Parameter	Value
GSI	75-80
Dip of joints	90°
Friction angle	25°-45°
UCS	45 MPa
Tensile strength	1.42 MPa
m*i*	33

3.2 The Boundary Element Method (BEM)

The BEM is a numerical technique for solving initial value problems based on an integral equation formation [3]. This name is given to this method due to its feature of boundary-only discretization and high accuracy in stress analysis.

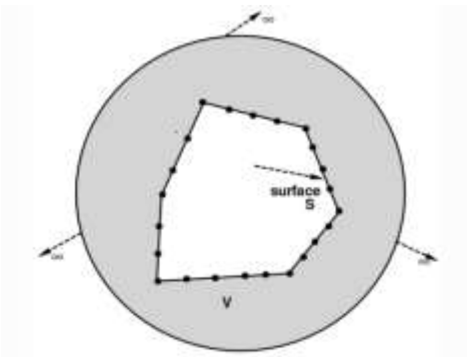

Figure 3 - Discretization the Boundary Element Method for 3D Unbounded Volume [4].

3.3 Rocscience Examine 2D

Examine 2D is a two-dimensional plane strain indirect boundary element program for the elastic stress analysis of underground excavation. The elastic boundary element analysis used in Examine2D dictates that the material being modeled is assumed to be: 1.Homogeneous.
2.Isotropic or transversely isotropic.
3.Linearly elastic.

3.4 Governing equations of BEM analysis

The modeling theme in the present study is based fundamentally on the governing of (1) principal stresses (σ_1 and σ_3), mean stress , differential stress (2) horizontal displacement, vertical displacement, and total displacement around the tunnel; (3) maximum shear strain and strength factor. The present BEM modeling is related to plane strain conditions. The major principal stress and the minor principal stresses are expressed by the equations (1) to (5).

τ_{xy}=shear stress

$$\sigma 1 = \frac{\sigma y + \sigma x}{2} + \sqrt{\left(\frac{\sigma y - \sigma x}{2}\right)^2 + \tau^2 xy} \text{........(1)}$$

$$\sigma 3 = \frac{\sigma y + \sigma x}{2} - \sqrt{\left(\frac{\sigma y - \sigma x}{2}\right)^2 + \tau^2 xy} \text{...... .(2)}$$

The mean stress(p) is given by the following equation.

$$p = \frac{(\sigma 1 + \sigma 2 + \sigma 3)}{3} \text{..............................(3)}$$

The differential stress(q) is given by the following equation.

$$q = \sigma 1 - \sigma 3 \text{.....................................(4)}$$

The strength factor is calculated by dividing the rock strength by the induced stress at every point in the model mesh.

$$\text{Strength factor} = \frac{\text{Rock Strength}}{\text{Induced stress}} \text{...........(5)}$$

If the strength factor ≤1, the excavation is unstable

If Strength factor >1, the excavation is stable.

4. Results and Discussion

The modeling results are presented in the following parameters.

- Distribution contours of major and minor principal stresses
- Distribution contours of mean stress
- Distribution contours of differential stress
- Distribution contours of horizontal displacement

- Distribution contours of vertical displacement
- Distribution contours of total displacement
- Distribution contours of strength factor

4.1 Distribution contours of mean stress, Differential stress , Total displacement and Strength factor of TCO tunnel

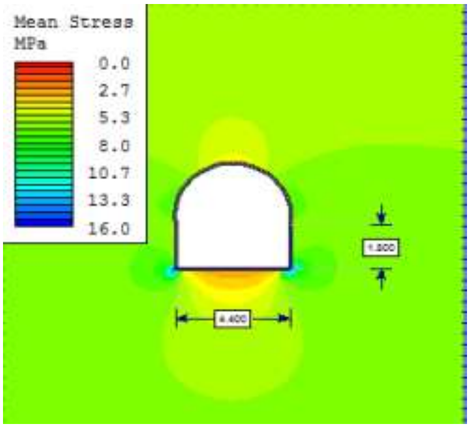

Figure 4(a)

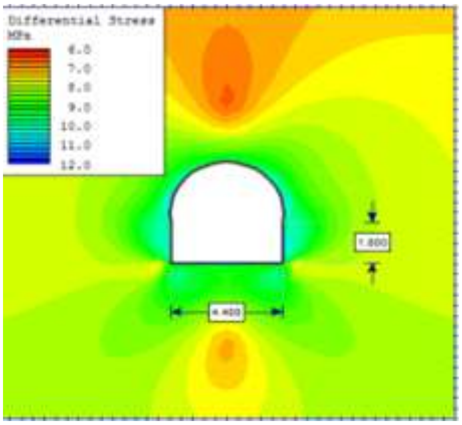

Figure 4(b)

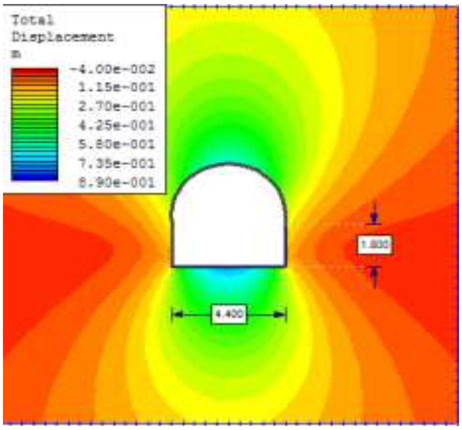

Figure 4(c)

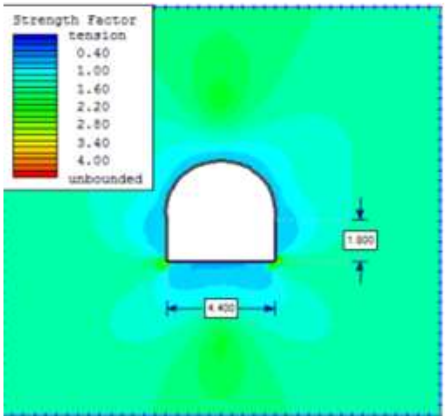

Figure 4(d)

Figure - 4 Modeling results of TCO tunnel (a) Distribution contours of mean stress. (b) Distribution contours of differential stress. (c) Distribution contours of total displacement. (d) Distribution contours of strength factor

In the TCO tunnel, mean stress value was about 3.5 MPa at the immediate roof and the value was 8 MPa toward the both rib sides. In the edges of the tunnel, the value was around 13 MPa. Middle of the floor the value reduces to 2.5 MPa.(Figure 4(a))

For the case of differential stress in the TCO tunnel, in the immediate roof, the value was 9 MPa and in the rib sides the differential stress was 10.5 MPa. In the immediate floor, the value was 9 MPa.(Figure 4(b))

The total displacement value of the immediate roof was 0.058 m and in the rib sides, it was 0.015 m (Figure 4(c)).

The most important factor that is considered here is the strength factor. Strength factor was symmetrical around the TCO tunnel except in the sharp edges in the floor. The value is 1 and in the shaft edges of the floor it is 2.8 (Figure 4(d)).

4.2 Distribution contours of mean stress, Differential stress , Total displacement and Strength factor of LBO Tunnel

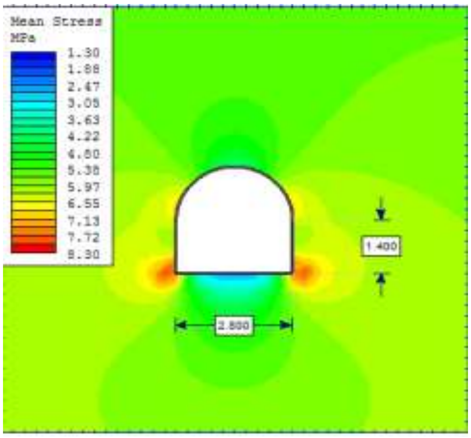

Figure 5(a)

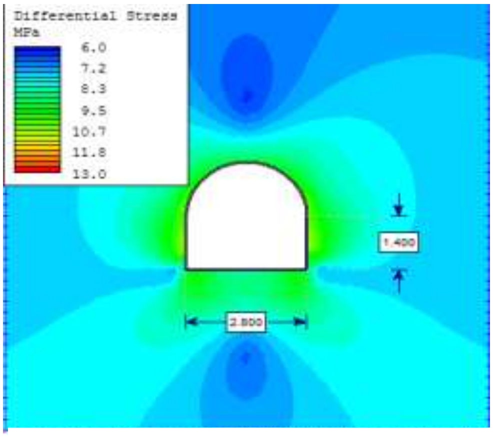

Figure 5(b)

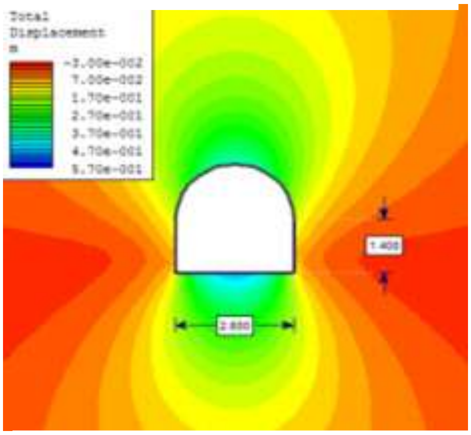

Figure 5(c)

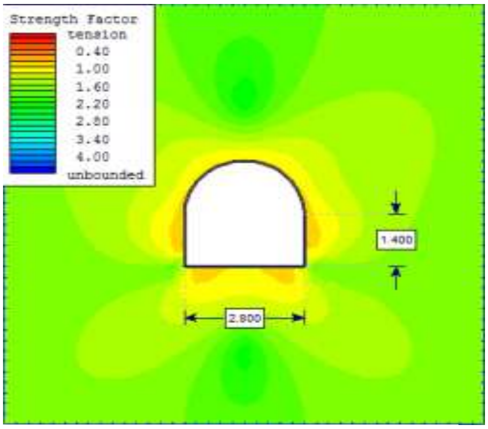

Figure 5(d)

Figure - 5 Modeling results for LBO tunnel (a) Distribution contours of mean stress. (b) Distribution contours of differential stress. (c) Distribution contours of total displacement. (d) Distribution contours of strength factor

4.3 Distribution contours of mean stress, Differential stress , Total displacement and Strength factor of TCO-LBO Twin tunnel

In the LBO tunnel, the mean stress value was 7 MPa at the immediate roof and, it was 6 MPa in left and right rib sides. In the edges of the floor, it increases up to 7.5MPa and middle of the floor it is 4 MPa (Figure 5 (a)).

The sharp corners at the junction between the floor and the tunnel sidewalls create high stress concentrations and also generate large bending moments in any lining installed in the tunnel. Failure of the floor generally initiates at these corners.

The differential stress in the LBO tunnel, in the immediate roof and the rib sides the value was 10 MPa. In the floor edges, it is 8 MPa and in the floor it is 10 MPa again. When it comes to the middle of the floor, the value decreases up to 9MPa. (Figure 5(b))
In the case of LBO tunnel, total displacement was 0.007 m in left and right rib sides. When it comes to the immediate floor, the value was 0.004 m and in the roof the value was 0.0037 m (approximately)(Figure 5(c)).
In LBO tunnel, the strength factor in both rib sides was around 2.5. In the immediate roof, it was in the range of 2 and 2.5. When it comes to the immediate floor value again resumed to 2.5 (Figure 5(d)). Around the LBO tunnel, the strength factor is greater than one. It indicates that the in-situ stress is greater than the induced stress around LBO tunnel if it stands along.

In the TCO tunnel, value of the mean stress in rib sides is 4 MPa. In the immediate floor, the value is 3 MPa and in the roof the value is around 4 MPa.In the LBO tunnel this value in rib sides is 4.95. Mean stress between the excavation is around 5 MPa. (Figure 6(a)).
In TCO tunnel, the differential stress is around 10 MPa in rib sides and 9.5 MPa in top of the Roof. In LBO tunnel, this value reaches to 10 MPa in rib sides. In the immediate floor, this value is 9 MPa and between the excavation it is 9.3 MPa.(Figure 6(b))
In the case of total displacement in the TCO tunnel, in the shaft edge the, value is - 0.001m and in the rib side, it is 0.3 m and top of the roof it is 0.58 m. In the floor, it is 0.4 m. In LBO tunnel, total displacement of rib sides is 0.135 m. On the top of the roof, the value is 0.15 m. In the floor, the total displacement is 0.5 m (Figure 6(c)).
The contours for the Strength Factor defined by the ratio of rock mass strength to the induced stress at each point is illustrated in Figure 6(d) and it shows that the strength factor parameter was greater than one in the designed distance, 4.2 m (Figure 6(d)).

When the gap between the twin tunnels was reduced, the model results showed that there was an occasion, the strength factor was less than 1 (In this moment, the distance between tunnels was 1.88 m.) (Figure. 7).
The excavation of a tunnel can cause failure of a certain thickness of the rock mass surrounding it, when the rock stress induced by the excavation is beyond the strength of the rock mass [2] or according to the model results, if strength factor < 1. In such situations, the rock failure area surrounding the tunnel can be termed as the loosening zone, which is measured and defined by the thickness of the zone.

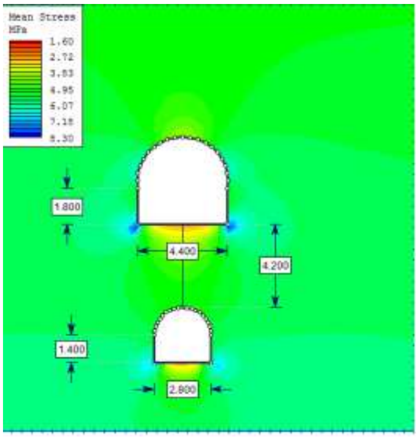

Figure 6(a)

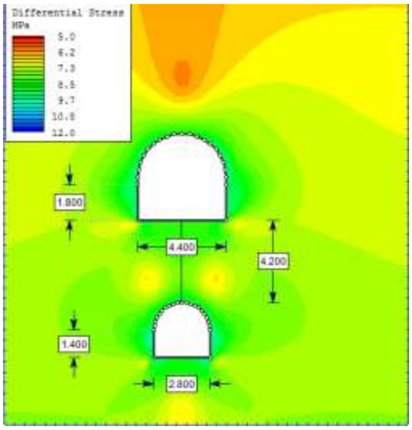

Figure 6(b)

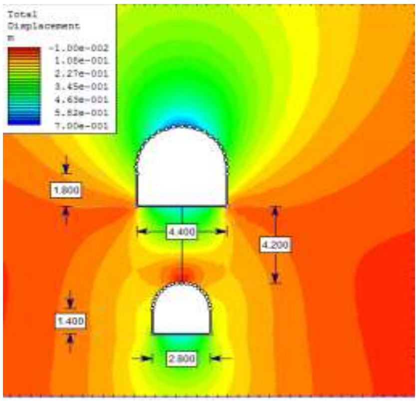

Figure 6(c)

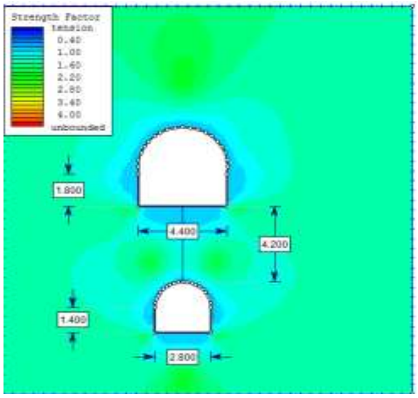

Figure 6(d)

Figure - 6 Modeling results for TCO-LBO Twin tunnel (a) Distribution contours of mean stress. (b) Distribution contours of differential stress. (c) Distribution contours of total displacement. (d) Distribution contours of strength factor

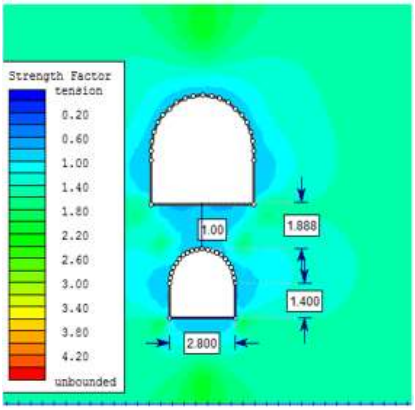

Figure - 7 Distribution contours of strength factor when the distance between twin tunnels reduced

When considering the strength factor of tunnels, they are in the safe condition when the distance is 4.2 m from each other. This can further be confimed by the findings of Hoek [1] According to Hoek, where the combination of rock mass strength and in situ stresses is likely to cause overstressing around the caverns and in the pillar, a good rule of thumb is that the distance between the two caverns should be approximately equal to the height of the larger cavern.

Hence, in this twin tunnel case study of Kalu Ganga Project, distance between the two tunnels is 4.2 m and more than the hight of the larger tunnel LBO (4 m).

5. Conclusions

The sharp corners at the junction between the floor and the tunnel sidewalls created high stress concentrations. Failure of the floor generally could initiate at these corners.

When the tunnels are in 4.2m distance, they are in a safe condition, according to the strength factor parameter. But, when the distance between the tunnels are reduced, the value of strength factor begins to reduce. When the distance is reduced further , strength factor reduces and the excavation becomes unstable.

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