Tunnelling and Underground Space Technology 37 (2013) 55–61

Contents lists available at SciVerse ScienceDirect

Tunnelling and Underground Space Technology

journal homepage: www.elsevier.com/locate/tust

Determination of support pressure for tunnels and caverns using block theory

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ARTICLE INFO

Article history:
Received 29 June 2011
Received in revised form 20 March 2013
Accepted 25 March 2013
Available online 25 April 2013

Keywords:
Key blocks
Factor of safety
Rock pressure
Block theory
Load cell
Rock bolt
Rib

ABSTRACT

The estimation of support requirements to stabilize underground structures is of prime importance for rational design of these structures. The characterizing parameters of rock mass may vary with depth. Determination of these parameters by drilled cores and Ground-Probing-Radar (GPR) is difficult and expensive due to anisotropy of rock mass. Laboratory testing is also expensive. Also the in situ conditions are difficult to simulate in the laboratory. The designer is thus resorting to empirical methods and analytical methods to determine these parameters. Often, the analytical techniques may mesmerize the designer to feel the problem and its solution on the screen of the computer. In this paper, an attempt has been made to develop algorithm based on Block Theory with geological information & mechanical properties of rock for determining the rock pressure. Limitations of this technique are number of joint sets not less than three and width of the opening up to 25 m. The algorithm determines all the wedges formed at a time by $3,4,5,6,\ldots,n$ joint planes with excavation plane responsible for manifestation of rock pressure at roof/wall. All the permutations and combinations for wedge formation can be considered in this respect. Rock pressure for design is determined for reinforcement of the underground openings. Spacing of rock bolts is found out as an additional feature. The alignment of the opening for optimal reinforcement can also be determined. Case history of Tehri Power House, India is taken up for analysis. The empirical correlations developed by Goel (1994) are used for comparative study. It was found that no appreciable rock pressure was developed at walls. Roof pressure is determined to be 140 kPa, which is almost same as observed. It is thus established that block theory may be applicable for design criterion up to depth of 500 m.

1. Introduction

In order to know the behavior or rock mass, in advance, all the theories are to be consulted. The analysis depends upon geology and rock material behavior of the specific site. Instability of excavations in rocks often initiates due to movement of unstable removable blocks, or key blocks. Block Theory proposed by Goodman and Shi (1985) can be used to analyze these unstable blocks for assessment of the stability of rock mass. Theses blocks can be identified by information of joint set orientations, the excavation shape and width of opening (Goodman, 1995). The authors present an algorithm for preliminary design of underground openings based on the concept of block theory. The main advantage of this algorithm is that it helps to fix up alignment of the opening with minimum reinforcement, in view of economy of supporting costs.

2. Objectives and assumptions

The main objective is to develop algorithm upon input information of three or more joint sets for determining the rock pressure and mechanical properties of rock. The proposed algorithm can be used prior to excavation to estimate the support pressure. As the excavation is progressed, the input parameters (geological) are reevaluated as face advances. Limitation of this technique is number of joint sets not less than three and width of the opening up to 25 m. Owing to limitations of the authors, software based upon this algorithm was developed up to wedges formed by 3–5 joint planes at a time. But, this algorithm may be helpful for consideration of all the wedges more than 5 joint planes at a time. It may be noted that all the units should be in SI system. Orientation of the co-ordinate system (Fig. 1) has been adopted as suggested by Goodman & Shi (1985).

3. Input parameters

The proposed algorithm is based upon fourteen steps. Input parameters are geological information such as (i) joint sets' nature

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http://dx.doi.org/10.1016/j.tust.2013.03.006

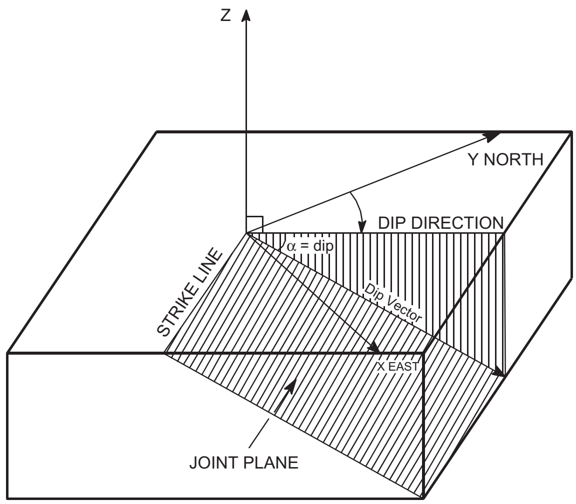

Fig. 1. Orientation of coordinate system.

(ii) alignment of the opening (iii) orientation of excavation plane (iv) width of the opening (v) water forces on joint planes (vi) friction angle, and (vii) cohesion of joint planes. All the wedges formed by $3,4,5,6,\ldots,n$ joints at a time can be analyzed by adopting all the combinations. The output parameters are (i) the weight and face areas of the wedge (ii) height of the wedge, which is useful for bolting (iii) rock pressure for reinforcement by bolting, or installing rib (iv) spacing of bolting/ rib. The additional feature of the algorithm is that the orientation of tunnel axis to obtain minimum reinforcement is determined. This algorithm may easily be translated into a computer programme to feel the design on computer's screen.

4. Methodology for computation

4.1. Step1: Assumptions

Assume the wedge is formed by n-joint planes with excavation plane at roof/wall, (α_1,β_1), $(\alpha_2,\beta_2),\ldots,(\alpha_n,\ \beta_n)$ be the dip and dip direction of joint planes respectively, $(\alpha_{n+1},\beta_{n+1})$ be dip and direction of roof/wall, $(\alpha_{n+2},\beta_{n+2})$ be dip and dip direction of tunnel axis and W_b be the width of the opening. Unit vectors $\bar{i}$, $\bar{j}$, $\bar{k}$ are considered along the along East, North and vertical directions (X,Y,Z) respectively as shown in Fig. 1.

4.2. Step2: Determination of unit outward normal vectors ($\bar{a}_k$) to the joint and excavation planes ($\bar{f}$) and tunnel axis ($\bar{g}$)

$$\bar{a}_k = (a_{kx}\bar{i} + a_{ky}\bar{j} + a_{kz}\bar{k})$$

where

$$\alpha_{kx} = \sin\alpha_k \cdot \sin\beta_k$$

$$\alpha_{ky} = \sin\alpha_k \cdot \cos\beta_k$$

$$\alpha_{kz} = \cos\alpha_k$$

$k = 1,2,3,4,\ldots,n$ (here 'k' is joint plane number)

$$\bar{f} = f_x\bar{i} + f_y\bar{j} + f_z\bar{k}$$

where

$$f_x = \sin\alpha_{n+1} \cdot \sin\beta_{n+1}$$

$$f_y = \sin\alpha_{n+1} \cdot \cos\beta_{n+1}$$

$$f_z = \cos\alpha_{n+1}$$

$$\bar{g} = g_x\bar{i} + g_y\bar{j} + g_z\bar{k}$$

where

$$g_x = \cos\alpha_{n+2} \cdot \sin\beta_{n+2}$$

$$g_y = \cos\alpha_{n+2} \cdot \cos\beta_{n+2}$$

$$g_z = -\sin\alpha_{n+2}$$

It is to be noted that tunnel axis is taken towards observer.

4.3. Step 3: Determination of edges of the wedge ($\bar{E}_k$)

$\bar{E}_1, \bar{E}_2, \bar{E}_3, \ldots\ldots\ldots\ldots\ldots \bar{E}_{n-1}, \bar{E}_n$ *aregivenby*

$$\bar{E}_k = (E_{kx}\bar{i} + E_{ky}\bar{j} + E_{kz}\bar{k})$$

where

$$E_{kx} = a_{ky}a_{(k+1)z} - a_{(k+1)y}a_{kz}$$

$$E_{ky} = a_{kz}a_{(k+1)x} - a_{(k+1)z}a_{kx}$$

$$E_{kz} = a_{kx}a_{(k+1)y} - a_{(k+1)x}a_{ky}$$

Here $k = 1,2,3,4,\ldots,(n-1)$

$$\bar{E}_n = (E_{nx}\bar{i} + E_{ny}\bar{j} + E_{nz}\bar{k})$$

where

$$E_{nx} = a_{ny}a_{1z} - a_{1y}a_{nz}$$

$$E_{ny} = a_{nz}a_{1x} - a_{1z}a_{nx}$$

$$E_{nz} = a_{nx}a_{1y} - a_{1x}a_{ny}$$

4.4. Step 4: Determination of a vector ($\bar{h}$) perpendicular to the vectors ($\bar{f}$) and ($\bar{g}$)

$$\bar{h} = \bar{f}x\bar{g}$$

$$\bar{h} = h_x\bar{i} + h_y\bar{j} + h_z\bar{k}$$

where

$$h_x = f_yg_z - g_yf_z$$

$$h_x = f_yg_z - g_yf_z$$

$$h_y = f_zg_x - g_zf_x$$

$$h_z = f_xg_y - g_xf_y$$

$$|\bar{h}| = \sqrt{h_x^2 + h_y^2 + h_z^2}$$

4.5. Step 5: Define

$$l_k = \bar{f} \cdot \bar{E}_k = (f_xE_{kx} + f_yE_{ky} + f_zE_{kz})$$

where $k = 1,2,3,\ldots,n.$

4.6. Step 6: Computation of height of wedge (ALT)

Define

$$P_k = \bar{E}_k \cdot \bar{h} = E_{kx}h_x + E_{ky}h_y + E_{kz}h_z$$

where $k = 1,2,3,\ldots,,n.$