Tunnelling and Underground Space Technology 26 (2011) 172–178

Contents lists available at ScienceDirect

Tunnelling and Underground Space Technology

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

Numerical modelling of in situ stress calculation using borehole slotter test

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ARTICLE INFO

Article history:
Received 3 March 2010
Received in revised form 6 July 2010
Accepted 25 July 2010
Available online 1 September 2010

Keywords:
Numerical modelling
In situ stress
Slotter test
Rock mechanics

ABSTRACT

Accurate determination of in situ stress magnitude and orientation is an essential element of the design process of all underground openings. A stress calculation method was proposed for the new stress measurement technique using the borehole slotter device. Two major objectives were the focus of this research work. The first goal was to simulate the slotter test process numerically and delve into the mechanisms involved in this test. A precise 3D numerical model of a typical slotter test condition was constructed using the FLAC3D code. The effects of variations in rock mass deformation modulus on the strain/stress relieve, and thus borehole slotter test results, were investigated numerically. The second objective of the work was to employ 3D modelling in the interpretation of slotter field tests conducted at Bakhtiari dam site. These tests were aimed at determining the stress magnitude and orientation to be used in the design of underground chambers and tunnels associated with Bakhtiari dam. The stress regimes measured in field were applied as boundary condition on the constructed 3D model and a backward analysis was conducted. For each case the actual strain field measured was compared against strain field calculated numerically. Accordingly, the boundary condition (stress magnitude and orientation) associated with the model results that provided the best fit to the measured data was determined as the governing stress regime. A good agreement was achieved between numerical and field test results. The obtained numerical results provided valuable insights in selecting the governing in situ stress condition from a set of recorded field data.

1. Introduction

Knowledge of in situ stress distribution within ground is an essential design component of underground openings and tunnels. The magnitude and orientation of in situ stress components significantly affect the stability of underground openings and may lead to severe stress concentrations and failures around the opening. With regard to the complex nature of earth geology, measurement of ground stresses has always been a difficult task. Various methods have been developed to measure the in situ stress regime within the ground. These methods can be broadly categorized into strain relief, hydro fracturing, borehole breakout, and seismic methods.

Borehole slotting (a strain relief method) is a relatively new stress measuring technique which is designed for quick operation in boreholes and for high density measurements at reasonable cost (Bock, 1993). The borehole slotter is an instrument which is used in HQ boreholes (96–104 mm diameter), and allows the calculation of 2D stress tensor in a plane normal to the borehole axis. This instrument enables the calculation of full in situ stress tensor using three boreholes without the need for mounting strain gauges on the borehole wall. The borehole slotter technique requires cutting of half moon shaped slots at different orientations parallel to the test hole axis using a small diamond impregnated blade and monitoring of strains which are relieved normal to the slot direction. The aim of developing this method was to avoid the high cost associated with other in situ measurement methods and also to increase the accuracy of field measurements.

The slotter technique has proven reliable in the field and has had certain commercial successes (Ljunggren et al., 2003). The objectives of this paper are to simulate the slotter test procedure numerically and demonstrate the effects of variations in rock mass modulus and ground stress conditions on the in situ stress measurement results.

2. Borehole slotter technique principles

The borehole slotter test is based on the principle of local stress relieve. In this test, a pneumatically driven diamond saw is used to create slots of up to 25 mm deep into the wall of a borehole of 96–101 mm diameter (INTERFELS Corporation, 1993). The diameter

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doi:10.1016/j.tust.2010.07.002

and thickness of cutting saw are 90 and 1 mm respectively. The intension of the test is to measure the circumferential stress relieve in the vicinity of the slot. It is intended to not disturb the in situ stress field by drilling large boreholes in the rock mass (see Fig. 1).

Before, during, and after slotting the circumferential strain is measured at the borehole wall in the vicinity of the slot. The tangential strain is measured by a specially developed recoverable strain sensor (Foruria, 1987; Bock and Foruria, 1984). The strain gauge is mounted at 15° from the slot location according to the INTERFELS test procedure recommendation.

3. Numerical simulation of borehole slotter test

The first objective of this study was to numerically simulate the borehole slotter test and look into the mechanisms involved in the test. Moreover, the effect of rock mass modulus on the test results was evaluated. The intension was to model the test procedure as precise as possible. Accordingly, a sophisticated 3D model of the test condition was constructed. The advanced 3D finite difference code FLAC3D was used for the modelling. This code is a product of ITASCA consulting Inc. (Itasca Consulting, 2002) and is equipped with sophisticated mesh generation, material behavior modelling, etc. capabilities.

3.1. Model construction and modelling strategy

The built-in programming capability of FLAC3D was used to generate a high resolution and accurate mesh. This enabled the modelling of slot arrangement and stress change/strain relieve happening in the borehole wall during the slot cutting process. Fig. 2 illustrates the 3D view of the constructed model of a typical slotter test hole and its surrounding rock mass. In this model three slots were simulated at the borehole mid-height and parallel to the borehole axis at 120° apart. Fig. 3 shows a close up plan view of the constructed numerical model of the test borehole and implemented slots. Strain measuring locations, as demonstrated in the test procedure, are also shown in Fig. 3.

In order to simulate the saw cutting process, the slot was modelled using the crescent shaped zones. The slot model was built such that the slot cutting process could be simulated in six consecutive stages. Therefore, the progressive cutting of slot and associated stress relieve in the slot vicinity were modelled fairly realistic. The advantage of modelling the slot sawing process is that the exact depth, in which stresses are completely relived, for a given condition, can be determined. This knowledge can help in the selection of appropriate instrument type and saw dimension. Fig. 4 illustrates a magnified view of the FLAC3D mesh constructed to simulate the slot cutting process.

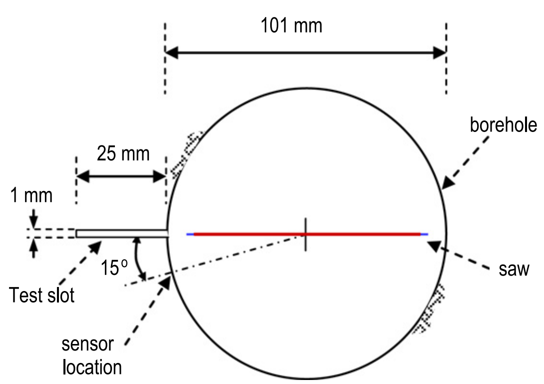

Fig. 1. Plan view of the slotter test set up (not to scale).

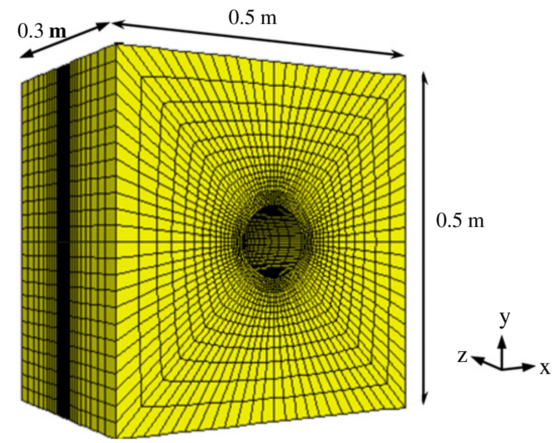

Fig. 2. FLAC3D model of the slotter test hole.

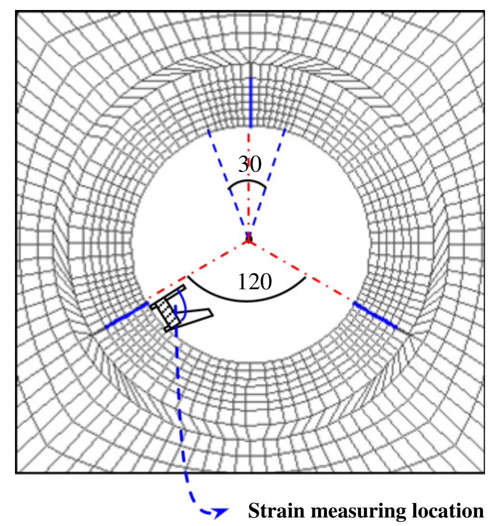

Fig. 3. A magnified plan view of the FLAC3D test hole and slot model.

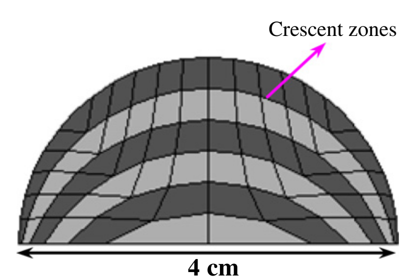

Fig. 4. A magnified view of the FLAC3D mesh at slot location.

With regard to the conditions and nature of borehole slotter test, the material (isotropic, homogeneous) behavior was assumed to be linear elastic. Selection of an elastic/isotropic model reduced the modelling complexities (input data) and eased the verification and judgment of numerical results. Therefore, it was assumed that the rock mass surrounding the slotter test location behaves in an elastic manner during the test. In order to simulate the process, the rock mass Poisson's ratio and modulus of elasticity were assumed to be 0.25 and 10 GPa, respectively. Another important boundary condition affecting the slotter test result is the ratio of horizontal to vertical in situ stress. According to Corthesy et al. (1999), in order to observe the stress relieve around the slot during