International Journal of Mining Science and Technology 24 (2014) 825–831

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

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

# Predictive analysis of stress regime and possible squeezing deformation for super-long water conveyance tunnels in Pakistan

Wang Chenghu *, Bao Linhai

*Key Laboratory of Crustal Dynamics, Institute of Crustal Dynamics, CEA, Beijing 100085, China*

ARTICLE INFO

*Article history:*
Received 10 February 2014
Received in revised form 17 April 2014
Accepted 5 June 2014
Available online 14 November 2014

*Keywords:*
Super-long water conveyance tunnel
In-situ stress state
Squeezing deformation
Prediction analysis
Kohala hydropower plant

ABSTRACT

The prediction of the stress field of deep-buried tunnels is a fundamental problem for scientists and engineers. In this study, the authors put forward a systematic solution for this problem. Databases from the World Stress Map and the Crustal Stress of China, and previous research findings can offer prediction of stress orientations in an engineering area. At the same time, the Andersonian theory can be used to analyze the possible stress orientation of a region. With limited in-situ stress measurements, the Hoek–Brown Criterion can be used to estimate the strength of rock mass in an area of interest by utilizing the geotechnical investigation data, and the modified Sheorey's model can subsequently be employed to predict the areas' stress profile, without stress data, by taking the existing in-situ stress measurements as input parameters. In this paper, a case study was used to demonstrate the application of this systematic solution. The planned Kohala hydropower plant is located on the western edge of Qinghai–Tibet Plateau. Three hydro-fracturing stress measurement campaigns indicated that the stress state of the area is $S_H > S_h > S_V$ or $S_H > S_V > S_h$. The measured orientation of $S_H$ is NEE (N70.3°–89°E), and the regional orientation of $S_H$ from WSM is NE, which implies that the stress orientation of shallow crust may be affected by landforms. The modified Sheorey model was utilized to predict the stress profile along the water sewage tunnel for the plant. Prediction results show that the maximum and minimum horizontal principal stresses of the points with the greatest burial depth were up to 56.70 and 40.14 MPa, respectively, and the stresses of areas with a burial depth of greater than 500 m were higher. Based on the predicted stress data, large deformations of the rock mass surrounding water conveyance tunnels were analyzed. Results showed that the large deformations will occur when the burial depth exceeds 300 m. When the burial depth is beyond 800 m, serious squeezing deformations will occur in the surrounding rock masses, thus requiring more attention in the design and construction. Based on the application efficiency in this case study, this prediction method proposed in this paper functions accurately.

## 1. Introduction

Accurate determination and analysis of in-situ stress fields is fundamental to the analysis and stability control of an underground project [1]. A planned hydropower plant (the Kohala hydropower plant) is located in the northeast of Pakistan and northwest of the Himalayan front fault. The collision between the Indian Plate and the Eurasian Plate, and the northward movement of the Indian Plate at the speed of 40–50 mm/a indicate a very complicated geological background in this area and cause many strong and violent earthquakes. In addition, the Himalayan front fault is regarded as the most active fault in this world [2–6]. The Kohala is a long water conveyance tunnel hydropower plant, located on the Jhelum River, a major tributary of the Indus River. The project includes a retaining dam, an underground sand basin, water conveyance tunnels, underground power generation houses, tail-water tunnels, and power transmission lines. The water conveyance tunnels are extremely long and deeply buried. Because of the complicated geological background and the complex hydropower project structures, it is essential to precisely know the areas' stress regimes and to evaluate the impact of the underground infrastructure on the stability of rock mass, particularly around the super-long water conveyance tunnels. However, the water conveyance tunnel is 17.5 km long, making it impossible to assign the number of boreholes along the water conveyance tunnel axes needed for in-situ stress measurement campaign to appropriately define the in-situ stress regime of the area. For these kinds of deeply-buried tunnels, only a few boreholes with easy transportation and good topographic conditions can be conducted

---

* Corresponding author. Tel.: +86 10 62846735.
*E-mail address:* huchengwang@163.com (C. Wang).

http://dx.doi.org/10.1016/j.ijmst.2014.10.015

to perform limited field tests providing some information about the geological conditions and in-situ stress regime. Under such a precondition, the in-situ stress regime of the undiscovered areas must be predicted based on the limited in-situ stress measurements and geological data. In this paper, we put forward a stress prediction method to predict the stress profile along the axis of the super-long, deeply-buried water conveyance tunnels, and analyze the possibility of squeezing deformations of the surrounding rock mass based on the predicted in-situ stress data.

## 2. Stress regime prediction of deeply-buried tunnels and its impact analysis

### 2.1. Theory for stress regime prediction

In-situ stress is a tensor, so the prediction of the stress regime for an engineering area includes the estimate and forecast of six independent parameters; the three principal stresses ($\sigma_1$, $\sigma_2$, and $\sigma_3$ or $S_H$, $S_h$, and $S_V$) and the three orientations of the stresses. Actually, it is impossible to determine or predict the in-situ stress regime accurately. Haimson emphasized this opinion on a number of occasions, and the fact that all stress measurement or estimate methods can only reveal the possible real in-situ stress state at best [7,8]. At the same time, Haimson suggested that the data based on other theories or from third parties should be used to validate the reliability of measurements. Therefore, before predictive analysis is conducted, the following assumptions should be made: (1) a major principal stress is the vertical stress, equal to the overburden weight; (2) the rock mass of an engineering area can be regarded as a continuous media and the stress regime in the geological unit should be relatively stable; (3) the heterogeneity and anisotropy of the rock mass and the discontinuities or inclusion objects in the geological unit have little effect on the whole in-situ stress regime and apply only locally within an engineering area. In other words, the three assumptions further restrict the application range of the methodology offered in this paper.

The prediction process of an in-situ stress regime can be subdivided into four steps. The first is to define stress directions and estimate the possible in-situ stress states (including normal faulting, reverse faulting and strike-slip faulting). The second step is to conduct field measurement campaigns, with a field investigation plan developed based on the outcomes of the previous step. The third step requires the prediction of an engineering area's in-situ stress regime using the modified theory model and/or the numerical model. The last step is to determine the stress regime accordingly. All the steps are indicated in Fig. 1.

In the first step, the stress patterns should be initially analyzed. At present, the collection and analysis of stress data have facilitated stress research, especially the World Stress Map (WSM) and the Database of Crustal Stress in China (DCSC). Through these two databases, a preliminary analysis of the stress pattern and the particular order in which the engineering area belongs to can be achieved and the stress direction can be similarly determined. At the same time, the collection of published references can help to understand the detail of the stress state of an area. In this stage, geological data based on geotechnical and seismogeological investigations can be used to deduce the stress regime directions with reference to the Anderson's theory [9,10]. Anderson's theory is fundamental to the above mentioned second assumption. That is to say, for a relatively isolated geological block, its stress state is to some extent stable, which is relevant to the spatial distribution of faults in the block and can be quantitatively described.

The second step is to conduct stress measurement campaigns, with the widely used hydrofracturing and overcoring methods. Amadei et al. wrote two classic books introducing the details of different stress measurement methods [1,7]. The measured stress data will be used to calculate the lateral pressure coefficient (ratio

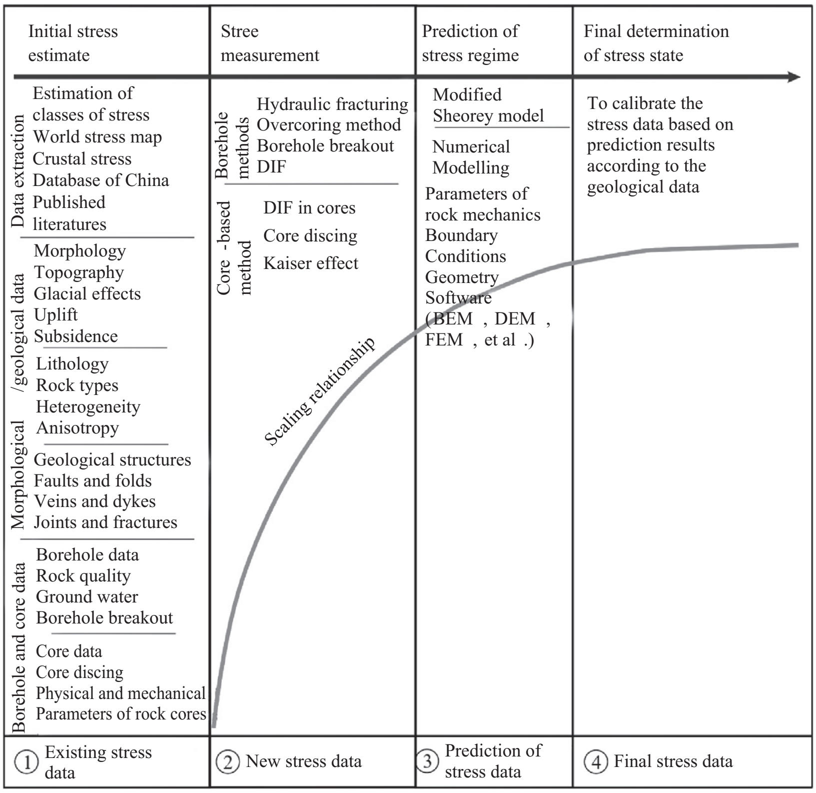

**Fig. 1.** Flow chart for the prediction of stress regime.