INFLUENCE OF GEOLOGICAL STRUCTURES ON IN-SITU STRESSES

by

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CERTIFICATE

This is to certify that the thesis entitled, **"INFLUENCE OF GEOLOGICAL STRUCTURES ON IN-SITU STRESSES"** being submitted by **Mr. Smarajit. Sengupta** to the Indian Institute of Technology, Delhi for the award of the degree of **DOCTOR OF PHILOSOPHY** is a record of the bonafide research work carried out by him. Mr. Sengupta has worked under my guidance for the submission of this thesis which to my knowledge has reached the requisite standard.

The thesis or any part thereof has not been submitted to any other university or institute for the award of any degree or diploma.

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ABSTRACT

The distribution of in-situ stresses in terms of magnitude and orientation effects the geometry, shape, dimensioning, excavation sequence and orientation of underground opening/structures. Some of the design solutions requiring in-situ stress measurements in the hydroelectric projects depend on the ability of the rock formation to support the excavation, the acceptable water pressure in the conduits and best orientation for the different components of the power house complex. In room and pillar mining, stresses in pillars affect the overall mine extraction ratio, the overall mine stability and layout. Borehole stability in petroleum industry is controlled by stress concentrations along the borehole walls. Knowledge of the in-situ stress field is also important for the fracturing of formations of oil and gas fields to enhance production.

The in-situ stress magnitude and orientation are found to be controlled by the major geological structures like folds, faults and intrusives. These structures bring about local heterogeneities in rocks, thus leading to refraction and/or rotation of stress trajectories. At many construction sites, observations on rotation of stress orientations were as high as 90° close to the geological structures. Due to the proximity of these perturbed stresses to the underground structures it is expected that these stresses will have a greater impact on the overall stability of the underground structures rather than the regional stresses. Thus stress perturbations due to local geological structures at the site of hydroelectric or mining projects must be clearly understood before stress values are taken as an input parameter for design of any

structure. The scope of the present study is based on the above observation. The different aspects of this study as proposed are as follows:

(i) To select sites with visible and demarcating geological structures like fault, fold, dyke, etc.

(ii) To conduct in-situ stress measurement in three to five boreholes at the proximity of these structures and to evaluate the in-situ stress conditions around these structures.

(iii) To evaluate the possible regional stress conditions nearest to the structures.

(iv) To establish a relation between regional stress, local perturbed stress and the geological structure with the help of simple numerical simulations.

(v) To establish the likely cause of the stress perturbation by the geological structures.

For the purpose of conducting the above study, two steps are followed.

In the first step, the perturbed local stresses are measured in the field by the hydrofracture method at the vicinity of the geological structures. The hydrofracture data is then compared with the data from borehole breakout, focal mechanism and deephole hydrofracture methods which are considered as of regional in nature for being distributed over a wider area and data generated are from greater depths. The comparison has given the degree of rotation of stress (stress perturbation) at the vicinity of geological structure. Ten cases from different Indian projects where hydrofracture tests are conducted, are considered for the study.

In the second step, a detailed parametric study has been conducted (a) to establish a relation between regional stress, local perturbed stress and the geological structure with the help of simple numerical simulations and (b) to establish the likely cause of the stress perturbation by the geological structures. The Universal Distinct Element Code (UDEC) a two -dimensional numerical programme based on the distinct element method (DEM) for continuum and discontinuum modelling has been used for simulation. UDEC has several built in material behaviour models, for both the intact blocks and the discontinuities, and permit the simulation of relevant discontinuous geologic or similar materials. The basic model is the Coulomb slip criterion, which assigns elastic stiffness, frictional, cohesive and tensile strengths and dilation characteristics to a joint.

For the determination of factors responsible for rotation of the stress direction by DEM the following assumptions are made.

i) Plane strain conditions applied in the model

ii) The intact rock blocks are assumed to behave as elastic/ plastic material (Mohr-Coulomb model)

iii) The discontinuity contact is treated as elastic perfectly plastic material (Coulomb slip model)

iv) Measured maximum compression direction and magnitude are assumed to be the perturbed stress direction and magnitude around the discontinuity.

v) Regional stress directions are assumed to be the boundary stress directions.

In the present analysis a 2-dimensional computational model consists of a block with an intersecting fault or dyke as the case may be is made. It is subjected to a bilateral tectonic stress field. The measurement zone has been taken inside the intact rock in the case of the' fault and inside the discontinuity in the case of the intrusive to keep the simulation close to field conditions. The configuration, the dimensions and the initial boundary condition for different cases are taken in accordance with the field conditions.

Different models are tried by varying the following parameters to identify the parameters responsible for change in the orientations of stresses near geological structures.

i) bulk moduli (K) of both intact rock and the discontinuity.

ii) shear moduli (G) of both intact rock and the discontinuity.

iii) cohesion (c) of intact rock,discontinuity and the discontinuity contact.

iv) friction angle (ϕ) of intact rock,discontinuity and the discontinuity contact.

v) normal stiffness (K_n) of the discontinuity contact.

vi) shear stiffness (K_s) of the discontinuity contact.

vii) angle (α) between the boundary stress direction and the strike of the discontinuity.

viii) ratio of boundary stress magnitudes (K_0).

The parametric study revealed that the rotation of stress is mainly influenced by the following parameters:

i) Influence of Moduli values (K and G)

With a change in the value of bulk modulus (K) and the shear modulus (G), for both country rock and the fault material, the in-situ stress orientation does not change significantly. The maximum rotation achieved is around 11°. No change in rotation (β) is noticed with different K and G ratios applied to the intact rock outside the fault and within the fault.

ii) Influence of angle of friction of the discontinuity contact (ϕ_c)

A higher rotation is achieved by lower friction angle of discontinuity contact. The magnitudes of friction angles of country rock and the fault material do not have much influence on the rotation of the stresses.

iii) Influence of boundary stress ratio (K_0)

A greater difference between maximum and minimum horizontal stresses gives a greater rotation of stresses.

iv) Influence of angle between the discontinuity plane and the maximum horizontal stress (α)

In the case of both fault and intrusive β is equal to 0° when α is equal to 0° and 90°. The maximum stress rotation (β) is achieved when α is 40° for fault and α is 10° for intrusive (Chapter V, Tables 6.15 and 6.16).

From the above the following conclusions are drawn:

i) Only three parameters viz angle of friction of the discontinuity contact (ϕ_c), boundary stress ratio (K_0) and angle (α) formed by the discontinuity plane with the maximum horizontal stress are having influence on stress rotation (β).

ii) External parameters like α and K_0 which do not depend on the material properties of either discontinuity or surrounding rock , are more responsible for stress rotation than internal parameters like c, ϕ, moduli (K,G), joint stiffness (K_n, K_s) which depend on the material properties.

v) Empirical Study

The following conclusions have been made from the study:

i) When a fault aligns parallel to the regional maximum horizontal stress, the rotation of stress (β) ranges between 0°to 41° with different regression types.

ii) When the fault is aligns perpendicular to the regional maximum horizontal stress, the stress rotation (β) ranges between 67° to 73°with different regression types.

It is observed in the field, different geological structures have rotated maximum horizontal stress direction from 24° to 87 with α ranges from 4°to 87°.

iii) The influence of fault on the stress rotation inside the surrounding rock is found to be 6 to 7 times the width of the fault.

iv) The influence of intrusive on the stress rotation inside the surrounding rock is found to be insignificant.

The conclusions drawn, from the parametric study by numerical method as compared to the results obtained from empirical method (for influence of α on β), are given below:

(i) The numerical method is best comparable with Power regression type of empirical method

(ii) The numerical method underestimates the degree of rotation of stress (β). The degree of underestimation increases with α value beyond 40°.

(iii) For all α values, the β obtained by empirical method is higher than those obtained by numerical method. The difference is nil at α=0°, and maximum at α=90°.

(iv) In the case of empirical method β increases with increase in α value and is maximum at α=90°. In the case of numerical method β increases with increase in α value and is maximum at α=40°. Beyond 40°, β value starts decreasing and becomes 0° at α= 80°.

The difference of β evaluated by empirical and numerical methods may be attributed to the isotropic conditions assumed for both country rock and geological structure in numerical analysis. This is in marked contrast to the actual field condition where rock as well as the geological structure is highly anisotropic. Gang et al., (1994) has shown that the rotation of stresses in an anisotropic material (where the moduli in X and Y directions are different) is very high. Nevertheless the numerical analyses have given scope to understand the role of various parameters responsible for stress rotation.

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