Abstract

Stability of underground working depends on geo-mechanical properties of rocks as well as geometrical and operational parameters of excavations. The primary objective is to optimize the loss of resource while ensuring the stability. The understanding of interaction dynamics between the parameters that control stability plays vital role in designing underground stopes and pillars. In this thesis, coupled FEM and fuzzy rules-based rock engineering system (RES) is proposed for the evaluation of rib and crown pillar stability in underground hard rock mines.

An extensive laboratory tests and field investigations have been carried out to determine the material properties of the ore body and waste rocks of a copper mine located in Madhya Pradesh, India. The estimated rock mass properties are applied for the analysis of finite element models of the underground excavations. A total of 243 elasto-plastic 3D numerical models are analyzed by varying attributes of five input (leading) variables namely rock mass strength, depth (insitu stress), height of excavation (stope inetrval), sequence of excavation with or without filling and crown pillar thickness. Average equivalent plastic strain ($\overline{EPS}$), an inverse of safety factor, over two consecutive pillars is the target output variable indicating the stability of the excavated zone (stope)-pillar system. The results of the finite element analysis in terms of average equivalent plastic strain are plotted on the stability graph which demarcates "stable", "transition" and "failure" zones. It is found that $\overline{EPS} \approx 0.06$ to 0.07 denotes the boundary between "stable" and "transition" zone and $\overline{EPS} \approx 0.09$ to 0.1 represents the boundary between "transition" and "caved" zone. Relationships between $\overline{EPS}$ and input variables are also determined using multivariate regression analysis considering the interaction terms. It is found that interaction between the variables cannot be ignored as far as stability of rib and crown pillar is concerned.

The study then focuses on the development of fuzzy rules-based RES and its implementation for evaluating underground pillar stability. Interaction matrix between the leading input variables are evaluated using fuzzy "IF-THEN" rules considering the results of finite element models. The "cause-effect" plot of the variables are also determined for 4 general geo-mining conditions and 6 specific conditions of the mine sites. It shows that rock mass strength and in situ stresses are the most dominant factors in determining rib pillar stability. Geometric factors like stope interval and crown pillar thickness have secondary effect on pillar stability. Filling of stopes would be necessary if rock mass condition of ore body is weak.

Vulnerability Index (VI) of rib pillars and a rib pillar stability index (RPSI) are formulated using cause and effect values. A relationship is determined between $\overline{EPS}$ and $RPSI$ and shows that it decreases exponentially with increasing $RPSI$ having R^2 of

0.78. A MATLAB code is developed to take the values of leading 5 input variables of a geo-mining condition and to provide RPSI and $\overline{EPS}$ based on the proposed fuzzy rules-based RES. The geo-mining condition may then be declared as "stable", "transition" or "failure" depending on the $\overline{EPS}$.

Keywords: Rib pillar stability, finite element method, equivalent plastic strain, regression analysis, fuzzy rules-based RES.