ABSTRACT

This study addresses the risk analysis of roof falls in Indian underground coal mines through various developed models. The roof fall hazards are the frequent problems in the underground coal mines, which are generally unpredictable due to the associated uncertainties arising out from the complex geological conditions and variability in mining parameters. In underground coal mining, roof strata control is the major problem, resulting into different severity of occupational injuries. During the period 1996-2001, in India, 253 coal miners lost their lives and 401 are seriously injured in 490 different roof fall accidents (DGMS). In India, 33.7% of the total fatal injuries in coal sectors are due to the roof fall (DGMS, 1996-2001). The consequences of roof fall ranges from minor injuries to fatalities. Apart from the loss of valuable lives, serious and reportable injuries to mine workers, downtime and equipment damage are also significantly contributing to the accident cost. Besides these, workers' medical treatment, compensation and man-days lost have the value addition to those of the overhead losses. This substantial loss forced the mine management to go for suitable methodology to control these hazards.

Quantitative risk analysis requires the hazard identification, its likelihood of occurrence, and the probable consequences. The parametric analysis of major contributing roof fall parameters for these roof fall accidents in the underground coal mines, especially having bord and pillar workings, requires sincere attention. The purpose of this research is to understand the probabilistic failure phenomenon to control the roof falls in the Indian underground coal mines by identifying the root causes of these accidents for their subsequent mitigation. Risk analysis has its merits in many industrial applications and can be applied to the mining field too. Probabilistic risk analysis like Monte Carlo method can be an effective tool to assess these risks and uncertainties.

The past roof fall data collected from five underground coal mines (named here as Mine A, Mine B, Mine C, Mine D and Mine E) include the date and time of roof fall

accidents and information related to those roof falls. The probability of roof fall is evaluated by modeling the number of roof fall accidents in a quarter of a year into Poisson distribution and the time between roof fall accidents to the exponential distribution. A cost model for the quantification of possible consequences is developed on the basis of loss to the employer and the risk profile is formulated. The risk profile formulated in the thesis shows the probability of exceedance plot in log-log paper. This curve identifies at a particular consequence, the maximum probability of exceeding that value. From the mean cost of consequences for a roof fall accident, Mine C shows the highest value, followed by Mine E. A decision analysis has been carried out for the case study mines on the basis of cost and benefit analysis for suitability of support improvement. The reliability study identified Mine C as the most reliable for roof fall accidents and Mine D, the least. Though, the reliability estimates show that the mines are more or less equally reliable for the roof falls, the other factors, sometimes come into the effect. The risk based on probability and consequences of the roof fall accidents identified that the average expected loss is the maximum in Mine C and minimum in Mine A. The specific results for the case study mines through logistic regression model for the severities of roof fall accidents are summarized as follows: i). Wider gallery width (≥ 4.2m) is 5.75 (95% CI is 1.80-18.38) times more prone to major accidents than narrower gallery width. This may be due to the reason that rock load is dependent on width of galleries and widened galleries experience less pillar safety factor, ii). Thick seams (>4.8m) are 0.13 (95% CI is 0.02 - 0.67) times more amenable to major roof fall accidents in comparison to less thick seams (≤ 4.8m), iii). Deep workings (>120m) are 7.39 (95% CI is 1.47 - 37.10) times more prone to major accident as compared to shallow depth category (≤120 m). The reason may be due to the concentrations of more in-situ stresses at deep workings. A solemn attention should be paid on the support design based on the depth of super incumbent strata restricting the gallery width to reduce the risks of roof fall.

The study of occurrences of roof falls (incidents) in Mine C, identified the number of roof falls and the time between roof falls fit well to the Poisson and exponential distribution respectively. Again, the probability of the support safety factor less than 1 is found to be 0.246 for Mine C. From the summary of the advanced sensitivity analysis by Monte Carlo simulation, the gallery width at 1% (3.74m) of the distribution provided the highest rank for the mean safety factor (1.74) followed by the RMR at 99% (47.51), which is 1.68. From the regression sensitivity, the RMR and anchorage strength of bolts shows positive effect on support safety factor, whereas the spacing between the bolts and gallery width shows negative effects on support safety factor. The scenario analysis for correlation, ranked gallery width as the first factor to be controlled for support safety factor, followed by rock mass rating.