Available online at www.sciencedirect.com
ScienceDirect
Safety Science 47 (2009) 88–96
SAFETY SCIENCE
www.elsevier.com/locate/ssci

Logistic regression model for prediction of roof fall risks in bord and pillar workings in coal mines: An approach

Sanjay Kumar Palei *, Samir Kumar Das

Department of Mining Engineering, Indian Institute of Technology, Kharagpur 721 302, India

Received 18 September 2007; received in revised form 18 December 2007; accepted 14 January 2008

Abstract

The roof fall hazards are the major problems in underground coal mines, which are generally unpredictable due to the associated uncertainties arising out of the complexity of geological conditions and variability in mining parameters. During the six year period, 1996–2001, 253 Indian coal miners lost their lives and 401 are seriously injured in 490 different roof fall accidents. In India, 32.7% of the total fatal injuries in coal sectors are due to roof fall in bord and pillar method of workings. This paper attempts to predict the severities of roof fall accidents based on some major contributing parameters using the binary logistic regression model. In total, 128 roof fall accidents for the last few years from five underground coal mines in India having bord and pillar method of working are analyzed for this study. The results revealed that wider gallery width is more prone to major and serious accidents than narrower gallery width. Thin seams are more amenable to major accidents in comparison to thick seams. Unsupported or partially supported roofs have higher risk for contributing major as well as serious accidents. Deep workings are more prone to major accidents as compared to shallow depth workings.

Keywords: Accident; Bord and pillar; Logistic regression; Risk; Roof fall

1. Introduction

Roof falls continue to be one of the greatest single hazards faced by underground coal miners. The hazardous nature of roof falls in underground coal mine operations can be illustrated from the national statistics of mine accidents. During the six year period, 1996–2001, in India, 253 coal miners lost their lives and 401 are seriously injured in 490 different roof fall accidents. 32.7% of the total fatal injuries in Indian coal sectors are due to roof fall in bord and pillar method of working; whereas only 1% of the total fatal injuries due to roof fall are occurring in longwall method of working (DGMS, 1996–2001). The roof fall accident rates are less in longwall faces, since they are very few in number, mostly mechanized covering the working faces with powered roof supports and galleries with the combination of roof bolting, props and bars, and also areas of exposure due to drivage of galleries are much smaller than the bord and pillar method of working (Das, 1984). In underground coal mining, bord and pillar is the method of working, mostly preferable for flat tabular deposits in thin seams, where bords or galleries are driven in the solid coal to form pillars in the development workings. 'Pillars' of coal are left behind to support the roof and prevent collapse. Additional support is provided through the use of roof bolts and props. In some cases, the pillars are removed partly or fully in a later operation known as bord and pillar depillaring.

The complexity of geological deposit and variability of mining parameters leads to the occurrences of unwanted roof falls. There are various studies on finding relationship between the roof falls and geological conditions, stress state and mine layout (Molinda et al., 2000; Das, 2000; Phillipson, 2003). Phillipson (2003) emphasized on geological mapping for ultimate benefit of understanding the

* Corresponding author. Present address: Department of Mining Engineering, Institute of Technology, Banaras Hindu University, Varanasi 221 005, Uttar Pradesh, India. Tel./fax: +91 542 2369442.
E-mail address: sanjay_palei@rediffmail.com (S.K. Palei).

0925-7535/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ssci.2008.01.002

geology and projecting the zones of adverse ground conditions for the prevention of fatality. The identification of many slickenside features as faults and shear zones, which are true structural geologic features, increases the importance of basic structural geologic mapping in coal mines. Interpreting slickenside formation in terms of structural geology can allow areas of poor ground conditions to be projected ahead of mining, so that additional support measures can be planned in advance. Das (2000) studied the behaviour of coal measure roof rocks during mining, considering the geology and physico-mechanical rock properties. Molinda et al. (2000) performed simple regression analysis with some significant geotechnical variables like overburden, bolt strength, bolt capacity, grout length, density, entry width, coal mine roof rating (CMRR) and intersection span for predicting the roof fall rate. The results showed that there is relationship existing between intersection span and entry width; CMRR and overburden; CMRR and bolt length. For stronger roofs (high CMRR), shorter bolts are required, and there is a positive correlation between CMRR and depth of cover. Depth of cover is one of the major factors for the ground falls, as it is an indirect representation of the horizontal stress (Dolinar et al., 2001; Molinda et al., 2000) affecting the roof geology and the pillar strength. In most of the countries, mine workings having depths less than, or equal to 120 m are regarded as shallow depth category and more than 120 m, as deep mines (Dolinar et al., 2001). In their study, for the guidelines of roof bolt design, though they found statistically, the effect of depth of cover was relatively weak with all other geotechnical variables remaining the same, stated deeper mines are more likely to have high roof fall rates. Besides depth of cover, another important factor is the width of gallery. The relationship of gallery width with factor of safety of pillars has been well established and the immediate roof rocks may be classified as weak, or strong (Das, 1994). The management of roof fall risks in underground coal mines is explained by Duzgun and Einstein (2004) with the probability of roof fall, and cost of consequences by relative cost criterion. They provided two alternative methods of “do nothing” and go for “support improvement” by the cost-benefit analysis in their decision framework. A comparative study is conducted for a group of five underground coal mines in India for the reliability of mine for roof fall accidents and estimation of roof fall risks by Monte Carlo method (Palei and Das, 2005). Their results revealed that the probability of roof fall of a mine did not identify the overall risk, because the other component of risk, i.e. the costs of consequences of such roof fall accidents also play an important role.

Accident ratio (i.e. reportable injury:serious injury:fatality) studies indicated that there are many more minor injuries experienced than serious injuries and that for the same serious injury there have been numerous property-damage accidents and there are a large number of near-miss cases too. Bhattacherjee (2000) identified that for a group of six Indian coal mines, the four year ratio of reportable injury to serious injury to fatality was 50:5:1. A special attention is paid in this paper on the assessment of the risk of roof fall accidents of different severity in the coal mines having bord and pillar method of workings. The major contributing parameters may be categorized into different groups, which are responsible for unwanted outcomes. The contributing parameters has been grouped into two classes namely (i) geo-mining variables, such as gallery width, mining height, depth of cover, seam thickness, roof support status, and immediate roof and (ii) location variables like roof fall location and the individual mine. A binary logistic regression model is used for this study.

2. Case study

2.1. Mine description

Five underground coal mines are considered for the purpose of study and data are collected from those mines. All the mines have bord and pillar method of workings. Out of the five mines, three are located in Eastern India (relevant data collected from these mines from 1991 to 2004) and two are in Southern India (relevant data collected from these mines from 1996 to 2004). Each mine operates six days a week and three shifts a day. The roof supporting is done by systematic support rules (SSR) as specified by the Directorate General of Mines Safety. The roof supports used are mainly props, wooden cogs, and steel cogs reinforced with roof bolting and stitching. The average overall output per man-shift (OMS) for the case study mines during those period are 0.92, 0.51, 0.57, 0.93 and 0.77 tonnes for Mines 1–5, respectively.

2.2. Data and analysis

Since very few fatal incidents (11 in total) occurred during the aforementioned study period in the specified mines, the fatal and serious accidents are merged into a single category namely major accident. The roof fall accidents involving one or more reportable injuries are encoded here as minor accidents. The dependent variable for this study is the degrees of roof fall accident, and is categorized as major, serious, and minor. The variable degree of accident is important as it measures the injury severity, which is also an indirect measure of the vulnerability, briefly the cost of an accident. A more severe injury involves higher cost of operation compared to a minor injury. This is due to payment of workers’ compensation, medical treatment, downtimes, machinery breakdown, reduced production rates, and social costs. The terms like major accident, serious accident and minor accident used in the logistic regression model may be defined as mentioned below:

Major accident: Major accident may be defined as the accident involving at least either a fatal injury, or at least one serious bodily injury, which increases the cost of consequence.