DEVELOPMENT OF A TIME-DEPENDENT CONSTITUTIVE MODEL AND AN EXPLICIT CAVING SIMULATION APPROACH FOR STABILITY EVALUATION OF DEPILLARING PANEL

Thesis submitted in partial fulfilment for the Award of Degree

Doctor of Philosophy

By

Prudhvi Raju Gadepaka

DEPARTMENT OF MINING ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY
(BANARAS HINDU UNIVERSITY)
VARANASI - 221005
(INDIA)

Roll No: 19151006

2024

Chapter 7

Conclusions and Future Work

7.1 Conclusions and Suggestions

The stability of the underground structures depends on the strength of the pillars and the stress on the pillars. Stresses on the pillars depend on the caving behaviour of the overlying strata during depillaring operations. A time-dependent constitutive model for coal-mass and a simplified caving simulation approach has been proposed. The proposed models are implemented by considering a case study of depillaring panels. The following conclusions are drawn from the study.

1. South African bord and pillar coal mines were chosen to implement the proposed time-dependent constitutive model. Back analysis techniques were considered to deduce the strength properties of the Witbank coalfield. The relevant strength parameters are: (a) crack initiation strength properties $m_c = 1.47$ and $s_c = 0.01$, (b) ultimate peak strength parameters $m_p = 1.55$ and $s_p = 0.073$, (c) residual parameters $m_r = 0.125$ and $s_r = 0.0000$, (d) softening parameter $\alpha = 200$ and (e) peak reduction parameter $\beta = 0.00065$.

2. A plot of average strain with time has been plotted for all the cases. A sharp increase in average axial strain was observed before the failure of the pillar.

3. The strength parameters were validated with stable cases in the same coalfield (Witbank). The simulation results of almost all the stable cases showed a constant average axial strain with negligible increment with time, indicating the pillar's stability (the coal pillar's strength is more than the stress acting on a pillar).

4. The simulation results, particularly from failed cases, concluded that the pillar's deterioration/yielding begins at the surface, progressing deeper into the core over time, ultimately forming an hourglass shape.

5. A pillar strength equation with age was proposed based on a statistical analysis of the results obtained from the simulation for South African coalfields, particularly for Witbank. The suggested pillar strength equation (notations are mentioned in section 4.5) is useful for analysing strength deterioration over time.

6. A logical approach was considered to extrapolate the strength parameters from South African coalfields to Indian coal field cases. The deduced strength parameters are; (a) crack initiation strength properties (*mc* and *sc*) 1.32 and 0.008, (b) ultimate peak strength properties (m_p and s_p) 1.39 and 0.059, (c) residual strength properties (m_r and s_r) 0.11 and 0.000008, (d) softening parameter α = 200 and (e) peak reduction parameter β = 0.000195.

7. The deduced strength parameters are validated by considering field Indian cases. A pillar strength equation with age was proposed for Indian coal fields by statistical analysis of the results obtained from the simulation.

8. The proposed constitutive model is suitable for estimating the life of the pillar. It will be highly beneficial for predicting post-failure disasters, such as subsidence. Accurate life predictions allow for implementing proactive measures, minimising the risk of pillar failures.

9. The simplified explicit caving simulation approach has been proposed. It resembles the natural caving behaviour. It is easier to implement in the simulation process than the other approaches.

10. A case study of a mine with three panels (A, B, and C) was considered to suggest a design criterion for the mechanised depillaring panel by numerical simulation and field observations. During depillaring on the rise side of panel B, some of the goaf edge pillars, including barrier pillars, had a FOS less than 1.3, leading to excessive side spalling of pillars. Based on the observations, the next panel C, was designed so that the FOS (goaf edge and barrier pillar) should be more than 1.5. The panel C was then investigated during the depillaring operations, and no major strata-related issues were observed. Based on this, it is concluded that the FOS of the barrier pillar and goaf edge pillar should be more than 1.5, preferably 2.

11. The field observations, including the area of the first major fall and the subsidence profile, were largely in agreement with the numerical simulation results.

7.2 Future scope of work

1. The present study did not conduct any laboratory tests to deduce the strength properties of Indian coal. Instead, logical analysis was considered to deduce the time-dependent Hoek-Brown strength properties; however, future work should aim to include laboratory experiments to validate and refine these deduced properties for improved reliability.

2. As the pillar strength equation is proposed based on numerical simulation techniques, there is a need for validation of this with laboratory or field-measured data.

3. Field measured stress on pillars during depillaring can be used for further validation of the proposed explicit caving simulation approach.

4. The present work simulates caving progression and stress redistribution on remaining pillars using FLAC^{3D} as a static model; future work should incorporate

dynamic analysis with appropriate loading and boundary conditions to capture the continuous and dynamic nature of these processes.