Chapter 5

CONCEPTUAL FLOOR FAILURE MODES INDUCED BY LATERAL STRESS AHEAD OF THE LONGWALL SUPPORTS

5.1 INTRODUCTION

Although floor failure at longwall faces has been associated with weak rock (Peng, 1984, Bieniawski, 1987), there have been many instances when floor buckling has occurred just ahead of the longwall supports, despite the floor being competent rock. Floor failure in strong bedded rock is associated with failure of weak bedding planes and strata movement towards the goaf opening. This chapter presents the concept of floor failure subject to high lateral stress based on numerical modelling and field observations, and outlines a practical approach for estimating the risks involved.

Buckling floor failure at the longwall face is associated with displacement of yielded coal towards the goaf. Roof and coal are laterally unconfined and are free to move towards the goaf, but floor movement is inhibited by pinning action of the longwall supports. If the coal-floor interface is weak, it will allow differential lateral movement between the coal and the floor, however, if the coal-floor interface is strong, the floor will partially restrict coal displacement towards the goaf, and large shear forces will exist close to the coal-floor boundary. If a weak bedding plane exists at a shallow depth below
the floor, the shear force may fail the bedding and large lateral stresses will develop in the upper floor that resist lateral displacement of coal towards the goaf. If the upper floor is relatively thin its strength may be exceeded, resulting in floor buckling or compression failure manifesting itself as floor heave ahead of the powered supports.

The main objective of this study is to present a conceptual model of floor failure influenced by insitu stress relief, vertical abutment, and expansion of the failed coal face. Both theoretical analysis and numerical modelling were used to provide the design tools needed to predict floor failure.

5.2 MECHANISM OF FLOOR FAILURE INDUCED BY LATERAL STRESS

Floor heave can be experienced under the following circumstances:

(a) Loading a weak and wet claystone floor,
(b) Loading broken floor, and
(c) Buckling or compression failure due to weakly bedded floor.

The load below the base of the powered support rarely exceeds the bearing capacity of the floor. While Terzaghi's equations for bearing capacity of soils
(Terzaghi, 1967) can be used to investigate stability of claystone or broken floors, floor buckling mechanism is discussed here.

It is common to see roof and floor buckling when excessive vertical loads fail undersized coal pillars adjacent to the roadway. This frequently occurs to longwall panels when small pillars are exposed to full vertical abutment loads. The failure mechanism that causes roof and floor buckle is shown in Figure 5.1. Floor buckling failure will occur if lateral stress exceeds floor strength, but to induce lateral stress, driving forces and opposing reactions must satisfy static equilibrium where the sum of all active forces and opposing reactions acting on the floor must equal zero.

A significant lateral stress relief towards the goaf is commonly experienced ahead of the longwall face (Matthews, 1992), but lateral strata movement above the floor (associated with the stress relief), induces large shear stresses within the floor (Aggson, 1978).
Figure 5.1 Excessive yield of coal ribs drive roof and floor to buckling failure

If a weak bedding plane exists at a shallow depth in the floor, slip along the bedding can occur and induce excessive lateral stress in the upper floor. Numerical modelling indicates that for low angles of friction this stress is larger than the reactions supplied by the 'pinning' action of powered supports. If the floor is strong it will move towards the goaf until the driving force and opposing reaction forces are equal in magnitude. If the driving force required to displace the bedding plane below the support base is excessive, the floor will buckle or fail in compression between the face line and support base.
Figure 5.2 Floor buckling due to excessive coal expansion above the weak bedding plane

Figure 5.3 Floor buckling failure in the diagrammatic form
This failure mechanism can often be seen underground and is shown in Figures 5.2 and 5.3.

Parameters influencing floor failure can be divided into:

(a) lateral stress generated by strata movement towards the goaf,
(b) reaction force opposing floor slip,
(c) effect of friction angle along the bedding on lateral stress in the floor,
(d) effect of bedding plane depth on floor stability, and
(e) strength of the floor strata.

These aspects are described in detail below.

5.2.1 Lateral Stress generated by Strata movement towards the Goaf

Lateral strata movement towards the goaf is complex, depending upon a large number of parameters which include vertical abutment stress, depth of coal failure, the magnitude of lateral stress relief, seam strength, seam thickness, and the location of weak bedding planes. The theoretical analyses of all parameters are not attempted here, however, a numerical model was constructed to investigate some of the variables.
5.2.2 Reaction Force Opposing the Slip within the Floor

Floor movement towards the goaf is opposed by shear resistance induced below the longwall supports combined with the weight of floor strata, conveyor, and goaf. The longwall supports provide a pinning action (normal force) to the sliding floor while the other factors provide additional resistance to floor slip. The maximum shear force $S_{\text{max}}$ resisting the sliding floor (Brady, 1985) can be expressed as:

$$S_{\text{max}} = (N + \gamma h A) \tan \phi + G \tag{5.1}$$

where:

$N = \text{Capacity of Longwall supports}$

$\phi = \text{Angle of friction along the bedding plane}$

$G = \text{goaf resistance}$

$\gamma h A = \text{self-weight exerted by the part of floor above the bedding plane}$

$A = \text{area of floor}$

To satisfy force equilibrium in the floor, lateral force induced by moving strata cannot be greater than the force due to shear resistance ($S_{\text{max}}$), to prevent slip.
5.2.3 Effect of Friction Angle on Displacement along the Bedding Plane in the Floor.

Coal expansion generates a lateral stress that drives the floor towards the goaf. Increased friction along the bedding plane allows some redistribution of lateral stress deeper into the floor whereas the increased angle of friction along the bedding plane would also minimise bedding failure ahead of the longwall face. When the floor is unloaded it will slip along the bedding plane until the forces generating lateral strata displacement are balanced by reaction forces generated along the bedding plane. Reaction forces are the result of the pinning action of the hydraulic supports. Increments in friction angles along the bedding plane would provide enhanced shear resistance against movement, and thereby increase the reaction force generated below the support base.

5.2.4 Effect of the Bedding Plane Depth on Floor Stability.

Forces generating lateral stress in the floor are independent of floor thickness above the weak bedding, but if forces acting on the floor are constant, lateral stress will depend on the cross-sectional area of the floor above the failed bedding plane. This lateral stress is inversely proportional to the cross-sectional area, therefore, thinner floors above the weak bedding plane will carry increased stress and are subject to a greater risk of buckling failure.
Two types of buckling can occur, the Euler's buckling failure or the three-hinge buckling failure (Afrouz, 1992). The Euler formula for column buckling can be used to estimate the floor buckling criterion. The theoretical buckling criterion for a long column is given by:

\[ P_{cr} = \frac{\pi^2 E I}{L^2} \]  

(5.2)

where:

\[ E = \text{Young's Modulus of Rock} \]

\[ I = \text{Second moment of area for the cross-section of floor} \]

\[ L = \text{Unconfined length of floor} \]

It is clear that the greater the floor thickness and the shorter the floor span, the greater is the resistance to buckling. In practice, the Euler formula overestimates the stress needed for buckling because it does not consider any imperfect geometry or uneven distribution of loading, non-homogeneous nature of floor strata, or any presence of confinement.

Three-hinge buckling failure develops when mining induced fractures in the floor and an uneven geometry of the dilating floor form detached blocks that are in contact at the corners, as shown in Figure 5.4. When the centroids of forces (hinges) acting at the corners of the blocks align, the floor becomes unstable. The geometry of thin floor beds indicates a greater potential for this type of failure.
5.2.5 Strength of Floor Strata

In general, the effective strength of laminated strata is reduced if horizontally loaded. The Euler equation indicates that buckling failure is dependent on the elasticity and geometry of the floor rather than its inherent strength, however, heavily laminated floors with weak bedding planes can develop a matrix of thin beams that can lead to a complex floor failure.
5.3 **NUMERICAL MODEL**

Strata behaviour about the longwall face was modelled using Fast Lagrangian Analysis of Continua (FLAC) to investigate the parameters contributing to floor failure. More details about FLAC modelling are discussed in the FLAC manual Version 3.2 (Itasca 1993). Failure of a weak bedding plane located 0.2m below floor level was modelled and stress concentrations in the floor studied for different depths of cover, seam thickness, and bedding plane strength properties. Two models were constructed to simulate longwall mining. The first model used large scale geometry (Figure 5.5) to obtain the boundary stresses required to incorporate into a smaller model that studied in more detail parameters contributing to lateral stress concentrations in the floor. Details of the near field model depicting the caving zone are illustrated in Figure 5.6, rock properties and other relevant parameters used in the model are given in Table 5.1.
Figure 5.5  FLAC MODEL - Overall element discretization of surrounding rock strata
Figure 5.6 FLAC MODEL – Portion of element mesh in the near vicinity of longwall face

Table 5.1 Rock Properties used in FLAC Model

<table>
<thead>
<tr>
<th>Strata Type</th>
<th>Bulk Modulus (GPa)</th>
<th>Shear Modulus (GPa)</th>
<th>Angle of Internal Friction</th>
<th>Cohesion (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof</td>
<td>5</td>
<td>3</td>
<td>30°</td>
<td>3</td>
</tr>
<tr>
<td>Coal</td>
<td>1</td>
<td>0.5</td>
<td>30°</td>
<td>1</td>
</tr>
<tr>
<td>Floor</td>
<td>5</td>
<td>3</td>
<td>30°</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bedding Plane</th>
<th>Normal Stiffness (GPa)/m</th>
<th>Shear Stiffness (GPa)/m</th>
<th>Cohesion (MPa)</th>
<th>Friction along Bedding Plane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interface</td>
<td>3</td>
<td>3</td>
<td>0 - 1</td>
<td>5 - 30</td>
</tr>
</tbody>
</table>
5.3.1 Results of Numerical Modelling

To identify the parameters that elevate lateral stress within the floor, a bedding plane was placed 0.2m below floor level and the floor was numerically fixed to prevent it from slipping towards the goaf. Lateral stress increase within the floor was studied as each parameter changed.

5.3.2 Shear Stress in the Floor generated by Strata Movement towards the Goaf

To enable shear stress to fully mobilise along the bedding plane, relatively high strength properties were assigned to the bedding. Shear stress in the floor near the toe of the face was computed and plotted against the depth of cover and seam thickness. Shear stress values in the floor at different depths of cover are given in Figure 5.7. Failure occurs when mobilised shear stress exceeds the critical shear strength of the bedding plane (based on linear Mohr-Coulomb criterion). The results indicate that floor failure is unlikely if the angle of bedding friction exceeds 30°. Decrease in the angle of friction allows bedding failure to propagate further ahead of the longwall face. For angles of friction of 10°, 20° and 30°, failure propagated approximately 2-3.5m, 1-2m, and 0.5m ahead of the face, respectively, depending on depth of cover.
Figure 5.7  FLAC MODEL – Vertical and shear stress in floor versus distance ahead of longwall face
5.3.3 Development of Lateral Stress in the Constrained Floor above the Bedding Plane

The 0.2m thick floor above the failed bedding plane was restricted at the toe of the longwall support to study how much maximum lateral stress can develop. Lateral stress magnitudes in the floor were studied with respect to depth of cover and the angle of friction $\phi$ along the bedding. The results summarised in Figure 5.8 indicate that lateral stress increases as the friction angle is reduced while it also increases in proportion to seam thickness and depth of cover. Negligible forces in the floor beam were present when the angle of friction along the bedding plane was increased more than 30°.

5.3.4 The Effect of Reaction Force onto Lateral Stress in the Floor.

Reaction forces resisting strata movement are generated by the pinning action of longwall supports, the weight of armoured conveyor, and the floor located in the goaf. If the lateral forces acting on the upper floor are larger than the reaction forces, the floor will slip towards the goaf, relieving any excess force. When the modelled floor above the bedding plane moved towards the goaf the lateral force acting on the floor decreased to approximately the theoretical value given by Equation (5.1).
Figure 5.8  FLAC MODEL – Lateral stress in floor induced by strata movement and powered supports versus bedding friction and seam thickness
Assuming the supports provide the major reaction opposing floor movement, maximum lateral stress in the floor can be computed using Equation (5.1). Theoretical reaction forces plotted against maximum lateral stress in the restricted floor indicated that maximum floor stress occurs when friction angles are between 15°-25°, but with increasing goaf resistance, maximum stress in the floor will grow in magnitude and occur at a lower friction angle.

5.4 TECHNIQUES TO ASSESS PARAMETERS ASSOCIATED WITH FLOOR FAILURE.

5.4.1 Determining the Shear Resistance along Weak Bedding Planes

To assess possible floor buckling, potential weak bedding planes need to be located and tested. If weak bedding planes are located at a shallow depth, coring of floor samples is required at approximately 30° to the bedding planes with laboratory triaxial tests conducted to determine shear resistance along the bedding planes (Indraratna, 1990).
5.4.2 Estimating Maximum Lateral Stress in the Floor

Once the angle of friction along the bedding plane is determined the reaction forces generated by the longwall supports can be calculated on the basis of linear Mohr-Coulomb theory. Additional reactions caused by the armoured conveyor, goaf load, and weight of floor strata, are difficult to estimate, but if the floor in the goaf is broken, these reactions may not be large enough to provide substantial resistance to moving strata. Assuming the supports alone provide the reactions opposing floor movement, maximum lateral stress can be computed using Equation (5.1).

5.4.3 Estimation of Floor Strength

The results of FLAC modelling indicate that the major influence on floor strength is due to the type of floor failure subject to lateral stress depends on floor thickness (above the failed bedding plane) and unconfined floor length. The unconfined length of exposed floor at the face is measured from the face to the toe of the longwall support. Although gravity provides some stability to the floor slab, this may not be large enough to prevent floor buckling. In this case Euler Equation (5.2) can be used to estimate buckling failure in the absence of confining stress, but floor distortion and mining induced fractures must be considered for a more realistic analysis.
5.4.4 Minimising Floor Failure.

Several actions can be adopted to minimise floor failure:

- Keep longwall supports as close to the face as possible to reduce free floor span,
- Keep the floor dry because water ingress weakens the floor, and
- Mount the pull-out jacks on the longwall hydraulic support bases to minimise base penetration into the fractured floor.

5.5 SUMMARY

The results of FLAC modelling indicate that the major influence on floor failure is the location of weak bedding plane, the angle of friction along the bedding plane, and the magnitude of generated reactions resisting floor movement. This study shows that maximum lateral stress in the floor develops when the friction angle along the bedding plane is between 15° and 25°. Friction angles higher than 30° will reduce the magnitudes of lateral stress induced by moving strata, and friction angles lower than 15° reduce reaction forces generated by the pinning action of longwall supports.

It is difficult to quantify all of the parameters contributing to floor failure because many types of strata may be encountered during longwall extraction.
Change in bedding plane properties, bedding depth and type of rock affect the face such that only localised floor failures occur. Persistent floor failures are usually associated with thin, clay, or mudstone floors of a low strength, where numerous weak bedding planes allow lateral floor displacements.

Success in estimating floor stability is dependant upon the quality and quantity of geotechnical investigations and analysis of floor stability prior to mining.

6.1 INTRODUCTION

This chapter presents an analytical model of floor failure at the longwall coal mining face based on a multiple sliding block concept. Longwall mining, stresses and displacements of strata over longwall face are high stress concentrations can exceed rock strength and lead to floor failure. Factors that can, under unfavourable conditions, lead to floor failure include natural and disruption of mining.

Underground observations of the rock floor below the longwall face indicates the soft beds of rock are usually responsible for floor failures. However, local geology and bedding planes are typically present in the sedimentary strata and rock failure fractures that actually occur in regular intervals during face advance give, the floor strata a typical blocky appearance.