Ultimate bearing capacity and settlement of coal pillar sub-strata

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Received August 18 1989

Summary

This paper develops a rational approach for design of coal pillars under weak floor strata conditions considering ultimate bearing capacity (UBC) as well as pillar settlement. An approximate solution is presented for estimation of UBC for a shallow foundation on a two-layered rock system with consideration of both cohesion (c) and ($\phi$) for both layers. Similarly, deformability underneath a full-size pillar is estimated from deformability calculated from plate loading tests. The effect of adjacent pillars on UBC and deformability of coal pillars in a panel is considered using foundation engineering analysis techniques. The design of pillars based on limiting settlements considers both differential settlements as well as mean settlement of pillar in a panel. An attempt is made to validate the proposed design approach based on field data and observations at an Illinois mine.

Keywords: Coal pillars; room and pillar mine; bearing capacity; clay floors; pillar design.

Introduction

Design of coal pillars under weak floor strata conditions in the United States is presently based on the ultimate bearing capacity (UBC) of weak floor strata without a consideration of pillar settlement. Foundation failure of coal pillars is, however, most likely to occur during pillar extraction in room-and-pillar mining or for chain pillars in longwall mining. In a partial extraction room-and-pillar mining system, pillar settlements on weak floor strata, with associated floor heave in mine openings or differential pillar settlements, may result in changed geometry of mine roadways, roof, coal pillar, and floor failures, and surface and subsurface movements. It is, therefore, important that pillar design techniques for weak floor strata conditions should consider bearing capacity as well as deformability of weak floor strata.

Current design techniques typically estimate UBC underneath full size pillars using Vesic (1970) analysis, which considers weak floor strata as a two-layer non-homogenous cohesive soil system with weak layer overlying the stiffer layer and angle of internal friction ($\phi$) for both layers equal to zero. The validity of this analysis technique has never been checked for shallow foundations on layered rock strata involving a weak layer/s overlying a competent
rock layer. Furthermore, the effect of adjacent pillars on estimated UBC of a single pillar has never been considered in the analysis.

Problem definition

Coal seams in Illinois are generally associated with weak floor strata whose thickness typically ranges 2–6 ft (0.6–1.8 m). These weak strata are underlain by relatively competent beds which may have an order of magnitude higher strength and lower deformability as compared to the weak floor strata. The development of coal pillars in a partial extraction mining system typically results in a checker-board system with entry widths varying 16–20 ft (4.8–6 m) and pillar sizes varying 40–70 ft (12–21 m). The coal seam is generally overlain by relatively stiff layers, varying in thickness from 2–6 ft (0.6–1.8 m) which cause significant interaction between roof, pillar, and floor strata where weak floor conditions exist.

The design problem requires calculation of stable opening widths, including intersections and size of coal pillars, to insure stability against foundation failure and/or limiting pillar settlements. Prior to mine development, data available for design include lithologic cross-sections from boreholes, and strength-deformation geotechnical data on drill cores obtained during exploration. After mine development, plate load tests may be conducted in entries to obtain ultimate bearing capacity and deformability of immediate floor strata and boreholes may be drilled in-mine to obtain variability of weak floor strata thickness and its properties. Furthermore, studies related to in-mine performance of opening and pillars may be conducted to alter the design as needed.

The following elements of design must be developed in order to design a stable mining system for weak floor strata conditions.

1. Estimation of UBC and deformability underneath a small plate (150–300 mm²) from engineering index properties and strength-deformation properties on rock cores of immediate floor strata.

2. Estimation of UBC and deformability underneath a full size pillar from UBC and deformability values determined from small scale plate loading tests or estimated in (1) above.

3. Influence of adjacent pillars on estimated UBC and deformability in (2) above.

4. Calculation of loads acting on pillars.

5. Interaction between roof, pillar, and floor strata.

6. Definition of failure criterion for immediate roof and floor strata, and coal pillar.

These design elements are developed and discussed in this paper. Finally, an approach for design of coal pillars for weak floor strata conditions is presented with an example.

Estimation of UBC and deformability of weak floor strata underneath a small plate

Over the past 5 years, the Department of Mining Engineering has conducted plate loading tests, borehole shear tests, and laboratory geotechnical studies on immediate floor strata at seven mines in Illinois (Chugh and Atri, 1988, Chugh et al., 1989).

Based on statistical analyses the authors have developed regression equations below to