DESIGN OF PROTECTIVE BARRIER PILLAR AGAINST LARGE WATER HEAD IN UNDERGROUND COAL MINES

Thesis submitted in partial fulfillment for the
Award of Degree

Doctor of Philosophy

by

ANKUSH GALAV

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

17151001 **2023**

9. Conclusion

A steady-state hydro-mechanically coupled numerical modelling approach has been developed to assess the performance of PWBP in underground coal mines. Design criteria were developed for determining the rational size of PWBP and evaluating the adequacy of existing barrier pillars utilizing the outcome of this study and the Seepage Rate Severity Classification based on the prevailing drainage practice in mines. It considered the effect of cover depth, rock strength, pillar width, permeability, water head, and different flow regimes on the induced volumetric strain and the rate of water seepage rate for evaluating the rational design requirements of the PWBP.

The following conclusions can be drawn from this work:

(i) The existing approach of pillar design suggested the most common pillar width of 25-30 m at a cover depth of 100 m and a pillar width of 50 m at a cover depth of 350 m. However, they are unable to comment on the hydraulic performance of pillars for different water heads and cover depths.

(ii) Higher rock mass strength provided only marginal support to the stability of the PWBP as the weakening caused by the water absorption reduced its effective strength drastically in the water-saturated condition. The pillar system produced the worst rate of water seepage rate among the possible flow regimes.

(iii) The flow charts shown in Figure 6.11 can be used for design of PWBP in new mines. The suggested approach for evaluating the adequacy of existing PWBPs is given in Figure 6.12. The design chart for critical, controlled, and rational pillar width for a cover depth of 100-350 m is shown in Figures 6.8 -6.10. The pillar dimension obtained for the soft rock condition can be adopted for a conservative design in newly explored geo-mining conditions.

(iv) The ZoPVS of 100 % marked critical width of PWBP, which is liable to cause its piping failure and an uncontrolled seepage rate to cause inundation of the mine.

(v) A pillar width of 8.8–12.4 m was the critical pillar size for its piping failure at the shallow cover depth of 100 m, while a pillar width of 21.9–30.8 m was critical at a moderate depth of 250 m and 24.2–34 m at the high cover depth of 350 m in the hard and the soft rock conditions.

(vi) The proposed seepage rate severity classification helped define the maximum permissible seepage rate of 315 $\times 10^{-3}$ m^3/s/km (5000 GPM/km) to avoid inundation in a mine. This formed the design limit for controlled seepage rate through the PWBP.

(vii) The adoption of a 60 m wide pillar as per the prevailing regulatory provision is resulting in avoidable loss of coal at a shallow cover depth of 100 m, but it is unable to contain the water seepage rate within the permissible limit for water head of more than 75 % at 250 m cover depth and 50 % at 350 m depth. The water head needed regulation to 43-60 % to fulfil the requirement of controlled water seepage rate.

(viii) The minimum pillar width for avoiding piping failure varies from 8.8-24.2 m at the cover depth of 100-350 m.

(ix) A pillar width of 32.4 m is sufficient for containing the flow within the permissible limit at 100 m cover depth. However, it significantly increases to 92.8-134.6 m at the higher cover depth of 250-350 m. In these conditions, the required pillar width was reduced to 43-63 m for the regulated water head of 50 % of cover depth.

(x) The estimated rational pillar width varied from 19.6-53.4 m for the hard rock conditions and 27.7-75 m for soft rock conditions at the cover depth of 100-350 m. The desired water head for controlled seepage rate through these rational pillar widths varies from 64-152.4 m for hard rock and 86.8-205.7 m for soft rock conditions for this range of cover depth.

(xi) The following table provides the estimates of critical pillar width (A), desired pillar width for controlled seepage rate (B), and rational pillar width (C), along with the corresponding water head for a cover depth of 100-350 m.

Cover Depth, m	Critical width, m	Desired width, m	Rational width, m	Desired water head, m
	(A)	(B)	(C)	
100	12.4	32.4	27.7	86.8
150	20.8	52	46	134.2
200	26.9	72.3	59.2	166.9
250	30.8	92.8	67.8	188
300	33.1	113.5	72.5	199.5
350	34	134.6	75	205.7

(xii) The model validation studies conducted for PWBPs at Satgram Incline indicated that a 60 m wide barrier at 84.5 m depth has ZoPVs of 15 % and a total seepage rate of 118×10^{-3} m^3/s/km (1866 GPM/km). These numerical modelling based results were very close to the empirically obtained estimates of 15.28 % and flow rate of 130×10^{-3} m^3/s/km (2063 GPM/km). The severity of seepage rate at the water head corresponding to 100 % of the cover depth was classified as 'Moderate'. The controlled seepage rate width for the maximum permissible water seepage rate of 315×10^{-3} m^3/s/km (5000 GPM/km) was 22.8 m. The PWBP was overdesigned by 287 % w.r.t. the rational width of 15.5 m but it required controlling the water head to 59.5 m.

(xiii) The 30 m wide PWBP constructed in seam V in Lower Kenda mine against the waterlogged Haripur mine at a cover depth of 134.5 m was producing more than the permissible seepage rate owing to unregulated water head in the abandoned mine working, causing its periodical flooding and frequent mine closure. The modelling results showed ZoPVS of 33.61 %, while the total seepage rate was 315×10^{-3} m^3/s//km (5000 GPM/km). These results corroborated well with the estimated ZoPVS of 37.86 % and the total seepage rate through the pillar system of 338×10^{-3} m^3/s/km (5370 GPM/km). The 'high severity' of seepage rate, as depicted by the Classification criteria, substantiated the seasonal flooding in the mine. The critical, controlled seepage rate, and rational pillar widths were 9.8, 32.4, and 21.8 m, respectively, for this mine.

(xiv) Adoption of rational pillar width at Lower Kenda mine would require control of the maximum water head to 94 m. The mine needed to enhance its installed pumping capacity by about 38×10^{-3} m^3/s (600 GPM) to avoid the mine flooding during the monsoon period. These modelling-based results matched well with the field observations in terms of the severity of seepage rate and visual observations in the mine.

(xv) The research-based guideline can be helpful in the rational design of new barrier pillars and validate the adequacy of existing barriers against a known water head under a given geo-mining condition. It will enable the mines to deal with the impending risk and save mineral resources due to the enhanced reliability of design and safety to an acceptable standard.

10. Limitations and Scope for Future Work

(a) The scope of this work was limited to mines having a cover depth of 100-350m. The work can be extended for deeper mines.

(b) The findings of this work need to be validated based on laboratory and field-based instrumentation characterizing strain-dependent permeability of rock at different stress conditions.

(c) This study has focused on hydro-mechanical coupling only. One may explore including the chemical aspect for a complete understanding of the complex phenomenon that may prevail under such conditions.

(d) The present work has considered a continuum model for evaluating equivalent properties for jointed rock mass. An improved study will require a discontinuum modelling-based study.

(e) In-depth study of induced permeability and flow vector should be carried out for different conditions.