Room-and-Pillar design practices of Illinois coal (no 5) seam

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Abstract

Economic development as well as realization of the basic human needs is becoming increasingly dependent on the availability of modern energy availability. Fossil fuel based energy still remains the major source for sustaining and improving standard of life, though there are strong strides made by other sources as hydro, nuclear, gas, oil, etc. One estimate put the proven coal reserve in the state of Illinois to be at least 30 billion tones, another puts it 80 billion tones. Coal production from the mines in Illinois contributed about 61.7 million tons in 1990. In mines, pillars are left to perform a variety of functions which influence their size and disposition. Room and pillar method of coal mining constitute the major mechanism of coal extraction in most parts of the world. Wilson's approach divides the pillar into two zones and approximate rules were prescribed for stresses in the two zones. Partial extraction of coal through room-and-pillar mining mechanism plays a major role in Springfield coal seam (No. 5) in Illinois, USA too. The coal beds are typically flat tabular deposits. Until mid 1980s coal mining layouts were designed based on experience and procedures developed primarily for Appalachian region. In this paper an analysis of pillar design practices adopted in five mines operating in the Illinois coal seam has been made. There were no comprehensive design procedures available for mines in Illinois Springfield (No. 5) coal seam. So a detailed investigation was carried out to evaluate the failed and stable pillar data to assess the appropriate safety factor(s) for design as well as to analyse the applicability of the Wilson's approach in the No. 5 coal seam. Pertinent data were collected from permit application and field visits. The paper presents the geology of Illinois coal seam, a discussion on different pillar design equations available, analyses of the safety factors of both stable and unstable pillars, etc. A common design equation had also been developed for the mines operating in these two seams.

1. Introduction:

Illinois is a major coal producer region of US and its coal beds are typically flat tabular deposits. Until mid 1980s, coal mining layouts were designed based on experience and procedures developed primarily for Appalachian region. There exists many design equations and procedures on the basis of coal strength described in detail elsewhere (Mishra, 1992). Typically each approach proposes safety factors. Generally floor strength was not considered in pillar design. An investigation was undertaken to analyse the design practices followed in Springfield (No 5) coal seam. Specifically the investigation focused on three main aspects as:

(i) To evaluate the validity of the design procedure in use,
(ii) To determine the desirable safety factors for the design under different geo-mining conditions, and
(iii) To evaluate the applicability of the Wilson's approach

2. Approach:

Pertinent data related to geology, hydrology, pre-mining state of stress, mining conditions, design practices, observed instabilities, surface subsidence movements, etc. were collected for each mine. There were five mines under investigation. Mine development applications were also reviewed to collect relevant data on design procedures and operating safety factors for opening spans, coal pillars and floor pillars. Analysis of data included description statistics of operating and mining factors.

3. Data Analysis:

Data from mine permit applications were used to calculate pillar safety factors. These calculated safety factors were compared with those reported. The pillar safety factors were determined from observed values. Different mines used different formulae for the pillar design calculations. So to compare on the same basis, pillar safety factors for all mines were calculated on the basis of all pillar design formulae. These were then correlated with mining depth and percent extraction separately for main, sub-main, entries and rooms.

4. Geology:

Mine stability is greatly affected by the presence or absence of certain lithological units, their thickness and occurrences of geologic structures. Figures 1 and 2 represent the generalized columns of roof and floor sequences of the coal seam under consideration.

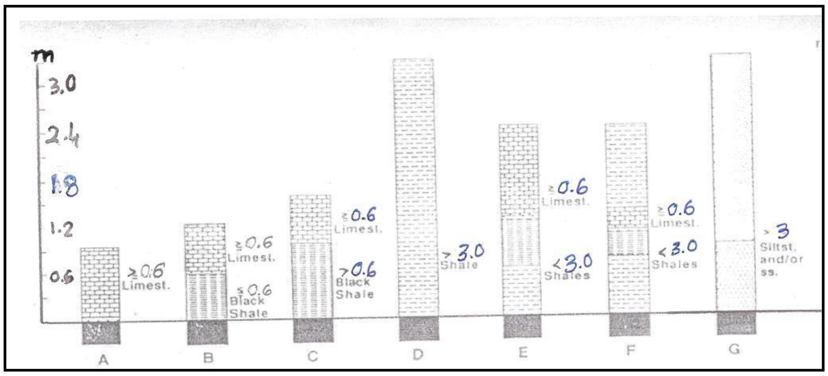

Figure 1 The roof sequence

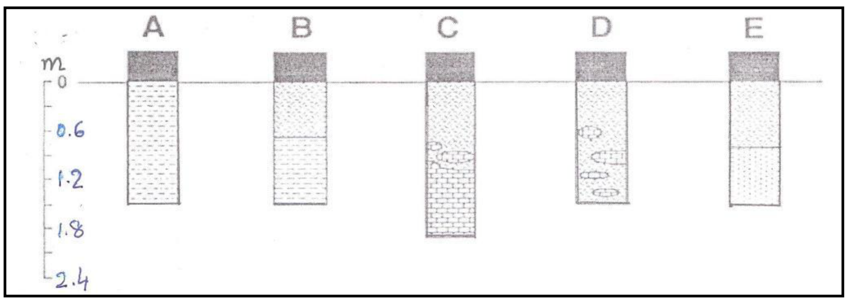

Figure 2 The floor sequence

5. Mining Practices:

All mines were working with room-and-pillar method. A typical mining layout is shown in Fig. 3. The average entry width in panels and rooms was 5.5 m while that for the mains and sub-mains were 4.57 to 5.5 m. Important operating design parameters for the mines are given in Table 1 and 2.

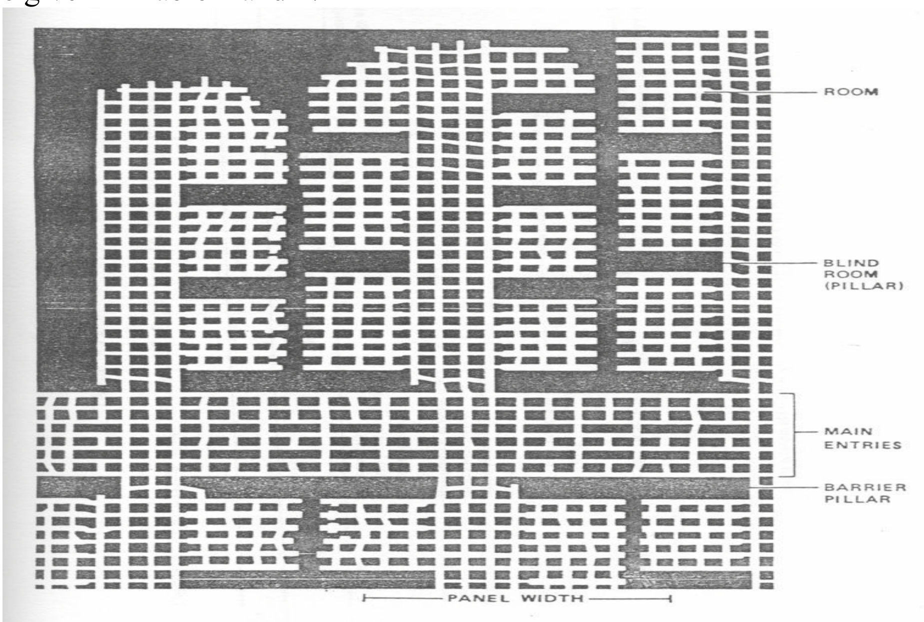

Figure 3 A typical room-and-pillar layout (Mishra, 1992)

Table 1
Important Operating Design Parameters for Mains and Sub-mains in mines

MAINS					SUB MAINS		
Mine No.	No of Entries	Width (m)	Barrier Pillar(m)	Remarks	No of entries	Width (m)	Barrier Pillar(m)
1	8-14	268.224	30.48	Mains consists of a barrier pillar of 30.48-38.10 m in between pillars	8	219.456	30.48-60.96
2	8-10	182.88	60.96	Mains consist of two sets of entries with barrier pillars of 30.48-38.10m between them	6	152.4	30.48-45.72
3	7-10	-	60.96-121.92	Mains have two sets of entries each having 7-10 entries			
4	5	208.483	60.96	Pillar spacing 9.144-12.192m (C -C)	8	195.072	
7	6-7	297.18-393.192		Mains consist of 60 X 70 (C-C)			
N.A. = Not Available							

Table 2
Important Operating Design Parameters for Panels and Rooms in mines

Mine No.	Panel Length (m)	Panel width (m)	Sub- Panel Made (Barrier pillar width(m))	No of entries for panel development	No of entries for room development	No of X-Cuts for room development
1	585.216-938.784	597.408	Yes(60.96)	7	8	8
2	603.504	246.888	-	6	5-7	5-7
3	-	-	60.96-121.92	5-6	6-8	6-8
4	426.72-1402.08	146.304	Yes(121.92)	4-7	8	8
7	1426.464	251.764	-	6	7-8	7-8

6. Design Practices:

The opening widths for mains and sub-mains were typically less than or equal to the opening span size in rooms and panels. However, for widths of 152.5 m or more the entry size was 4.9 to 5.5 m. Two mines used 4.9m entry width and the others had 5.5 m size. Square shaped pillar were frequently used except in a few locations where rectangular pillars were in vogue. All coal mines designed their pillar sizes based on strength of coal using tributary method for average load distribution. Empirical formulas as Bieniawski, Holland, Holland-Gaddy and Obert-Duval were used for such calculations.

7. Pillar Safety Factor Analysis (PSF):

Pillar safety factor analyses were initially conducted separately for mine permit application and mine observed data. As those data were almost identical, both the data sets were combined for analyses. All the analyses reflect here the approaches suggested by Holland and Wilson. Average values of influencing parameters, such as stress, mining depth and coal strength were used in this investigation. The calculated values reflected the followings:

A. Partial extraction ratio vary between 24% and 70 %
B. The pillar sizes in rooms were between 6.1m and 18.2 m and appear to be independent of mining depth up to 122 m. Similar pattern was also observed for the pillar sizes in panels, mains and sub mains, although dimensions varied between 6.1 m and 31.7 m.
C. The strength constant for the coal seam as determined by Gaddy's equation ranged from 3735 to 6145 and was independent of mining depth.
D. The calculated PSF values by Holland equation varied between 1.5 & 11.2 for a low extraction ratio (30-40%) and from 1.2 to 4.1 for high extraction ratio (65-70 %, Fig. 5). The PSF values appeared to be decreasing linearly with an increase in extraction ratio for all the pillar design approaches including that by Wilson (Fig. 5). The PSF values also tend to increase exponentially for mining depths less than 152.5 m.

E. Typically for mining depth less than 152.5 m, the pillar design was governed by a consideration of the strength of weak floor strata only rather than the strength of coal (Fig. 6). For depths more than 152.5 m, PSF values were higher than the values based on floor strength by a factor of 1.5 to 2.0.
F. The observed values were also true for the PSF values calculated from Holland-Gaddy, Obert-Duvall, Bieniawski and Wilson formulae.

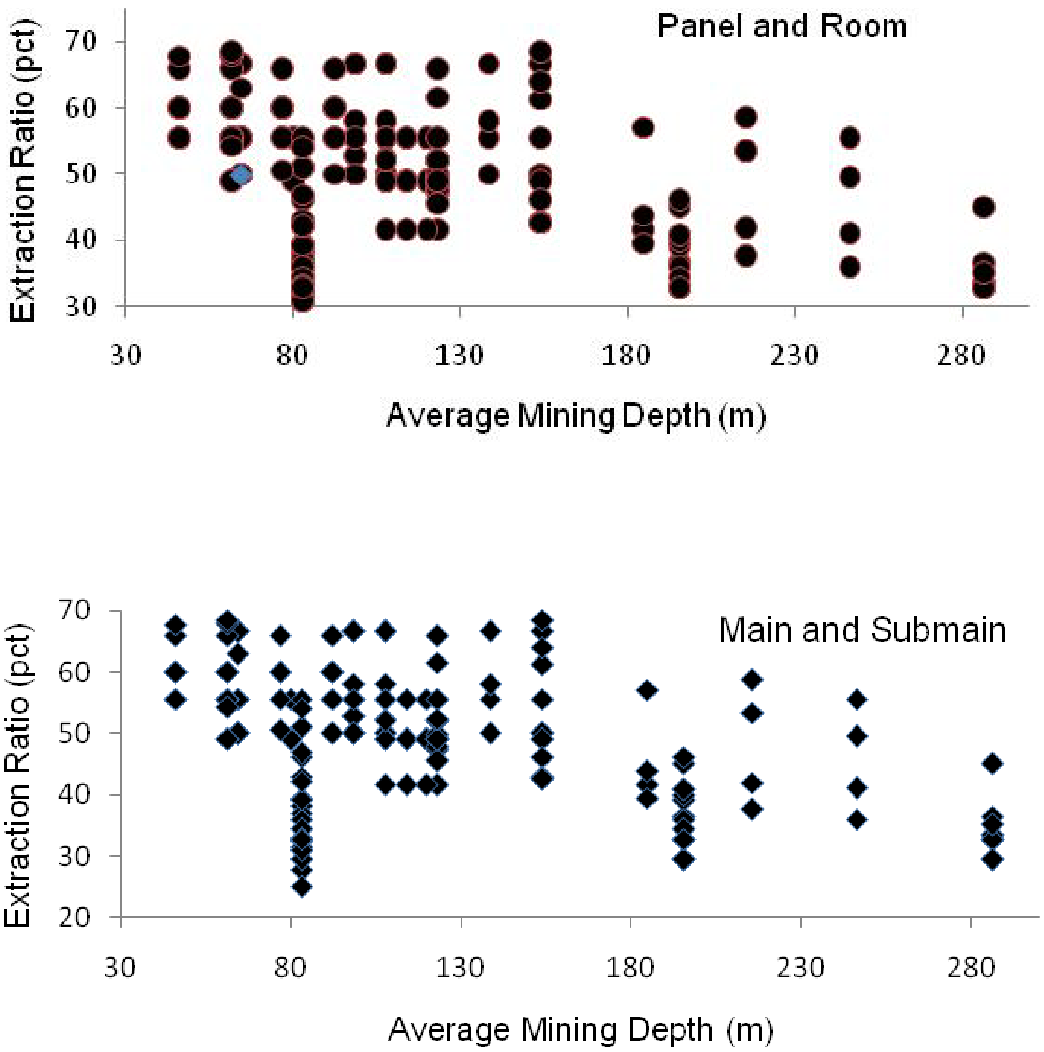

Figure 4 Variation of Extraction Ratio with depth for different working sections

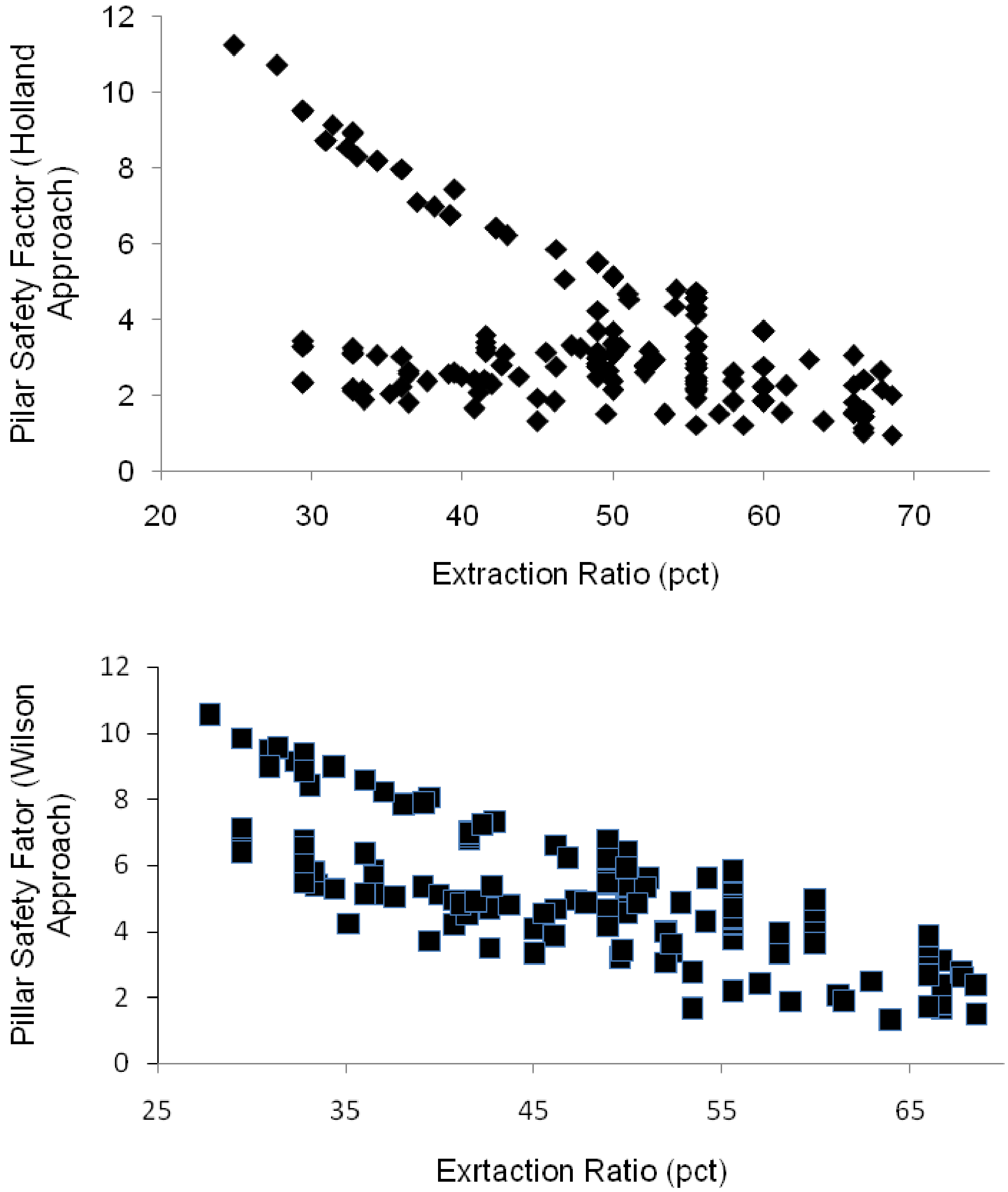

Figure 5 Variation of Pillar Safety Factor with Extraction Ratios

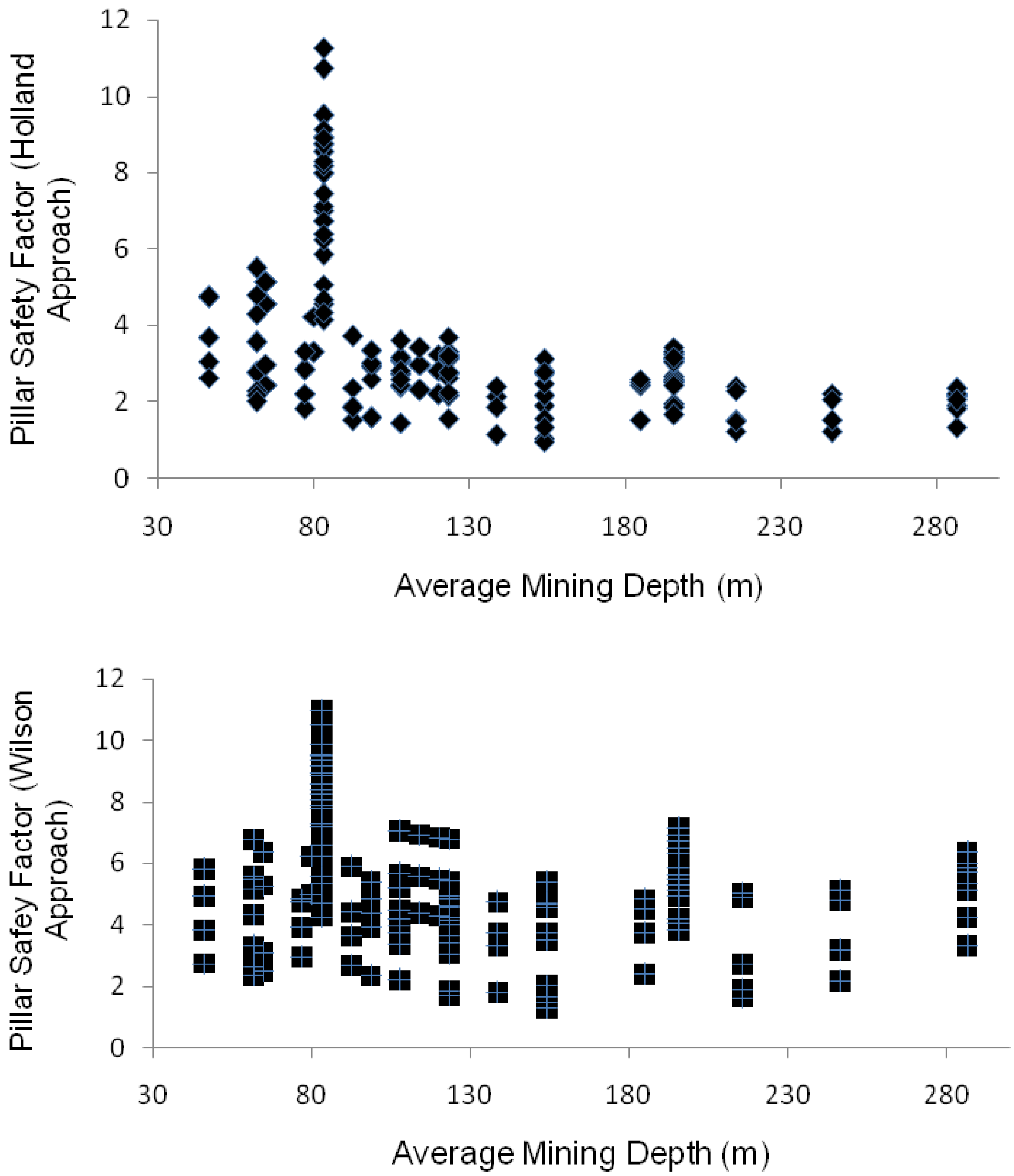

Figure 6 Variation of Pillar Safety factor with Mining Depth

Table 4
Determined Safety Factors for coal pillars in Mines

Parameters	Mine(1)	Mine(2)	Mine(3)	Mine(4)	Mine(7)
Depth (m)	64 – 152.4	61 - 122	193.55 - 283.46	45.72 – 91.44	122
Pillar Shape	Square	Rectangle	Square	Rectangle	Square
Mains and Submains					
Pillar Length (m)	10.72 – 14.11	22.8	24.68 – 25	11.58	15.24
Pillar Width (m)	10.72 – 14.11	13.71	24.68 – 25	11.58	12.2
Mining Height(m)	1.52 – 2	1.28	2.08	1.37	1.67
Entry Width (m)	4.81 – 5.8	7.62	5.48 - 6	5.48	6.1
Extraction Ratio (%)	49 - 52	51.7	32 - 34	50.4	52
Width to Height Ratio	7.35	17.8	11.8 – 11.9	8.64	7.27
Safety Factor					
Obert - Duvall	2.35	4.94	3.02 – 3.1	3	3.3
Bieniawski	3.21	7.3	4.3 – 4.4	4.2	4.6
Holland	2.69	4.4	3 – 3.1	3.29	3.5
Holland - Gaddy	1.82	3.7	2 – 2.1	2.78	2.61
Wilson	3.39	5.5	5.3 – 5.4	4.8	3.6
Panels and Rooms					
Pillar Length (m)	8.83 – 9.14	10.97 -13.41	24.38	6.4 – 7.92	9.44 – 14.32
Pillar Width (m)	8.83 – 9.14	10.97 -13.41	24.38	6.4 – 7.92	9.44 – 14.63
Mining Height(m)	1.64 – 1.92	1.28	2.07	1.37	1.67
Entry Width (m)	5.79 – 6.1	4.87 – 6.4	6	4.87 – 5.48	5.79
Extraction Ratio (%)	63 - 64	52 - 54	35.2	67 - 68	48 – 61
Width to Height Ratio	4.6 – 5.6	8.5 – 10.4	1.7	4.6 – 5.6	5.6 – 8.7
Safety Factor					
Obert - Duvall	1.1 – 2.4	2.3 – 4.6	2.02	1.7 – 2.2	1.9 – 3.4
Bieniawski	1.4 – 3.1	3.3 – 6.5	2.91	2.2 – 2.8	2.5 – 4.7
Holland	1.3 – 2.9	2.6 – 4.8	2.05	2.2 – 3.7	2.2 – 3.7
Holland - Gaddy	0.9 - 2	2.1 - 4	1.36	1.6 – 2.1	1.6 – 2.7
Wilson	1.3 – 2.5	3.9 – 5.5	4.25	2.3 – 2.7	1.8 – 4.1

G. Multiple linear regression analyses were carried out to develop a functional relationship between pillar safety factor (PSF), pillar width to working height (W/H) ratio, extraction ratio (e) and average mining depth (D). The results are as shown below. The best relationship is obtained for Wilson approach where the coefficient of determination (R^2) values was about 90 %. It can be used with confidence without knowledge of coal strength and triaxial stress factor. The high values of R^2 indicate that coal strength and triaxial stress factor for the seam is relatively constant.

Approach	Best fit Equation	R^2	No. of observation	Source of Data
Holland	12.551−0.137e−0.008D+0.142W/H	0.85	25	Observed
Wilson	11.186−0.131e−0.006D+0.212W/H	0.94	25	Observed
Holland	13.190−0.147e−0.008D+0.086W/H	0.84	180	Permit
Wilson	13.012−0.145e−0.005D+0.161W/H	0.98	180	Permit
Holland	12.585−0.139e−0.007D+0.112W/H	0.84	205	Combined
Wilson	12.902−0.144e−0.005D+0.161W/H	0.94	205	Combined

H. The pillar safety factor decreased linearly for mining depth of less than 137.2 m. But beyond 137.2 m the pillar safety factor values increased as the width of the inner core increased owing to larger coal pillar sizes.

References:

1. Mishra, M.K. (1992): An analysis of the design practices for partial Extraction Room-and-Pillar Mining in Springfield Coal Seam", Unpublished M.S. thesis, SIU, Cabondale, IL, US