Chapter

Support System Design for Deep Coal Mining by Numerical Modeling and a Case Study

Shankar Vikram, Dheeraj Kumar and Duvvuri Satya Subrahmanyam

Abstract

Importance of numerical modeling in mine design gained pace after modern way of approach took birth through many variants. Methods such as Continuum and Discontinuum emerge as most effective in resolving certain issues. Cases such as heterogeneity, prevailing boundary conditions in continuum case and presence of discontinuities in other have provided solutions for many causes. A suitable support system is designed for deep virgin coal mining blocks of Godavari Valley Coalfield in India. This analysis is carried out using numerical modeling technique. The results show that the stresses at an angle to the level galleries are adverse. The level gallery/dip-raise may be oriented at 20^0 to 40^0 to reduce roof problems.

Keywords: underground mining, Bord and pillar mining, finite element method, horizontal stress, rock mass classification

1. Introduction

Underground excavation results to stress redistribution and large-scale movement of the roof strata. Therefore, the study on stress is critically important to develop techniques for efficient coal mining [1–6].

In Pench mining area at Thesgora mines where intrusive of basalt flows and faults found, it has been witnessed that high horizontal stress affects the stability of development galleries. After reorientation of dip galleries closer to the principal stress in horizontal direction, no bed dilation was observed in the roof strata of the dip galleries, with improvement in working conditions [7].

This chapter aims to summarize the stress redistribution analyses, which were conducted by the numerical simulation method and design temporary supports based on the horizontal stresses estimated by numerical and empirical methods. The tension-weakening model was adapted for the numerical analysis of rock mass.

2. Details of the work site

The study area, Mandamarri shaft block sector-B is in the northern part of Bellampalli coal belt and it lies in dip side of block. Sullavai formation is the basement rock. The block is covered by barren measure and lower kamthi formation. The trend of the coal seams established from the sub-surface data shows the strike as

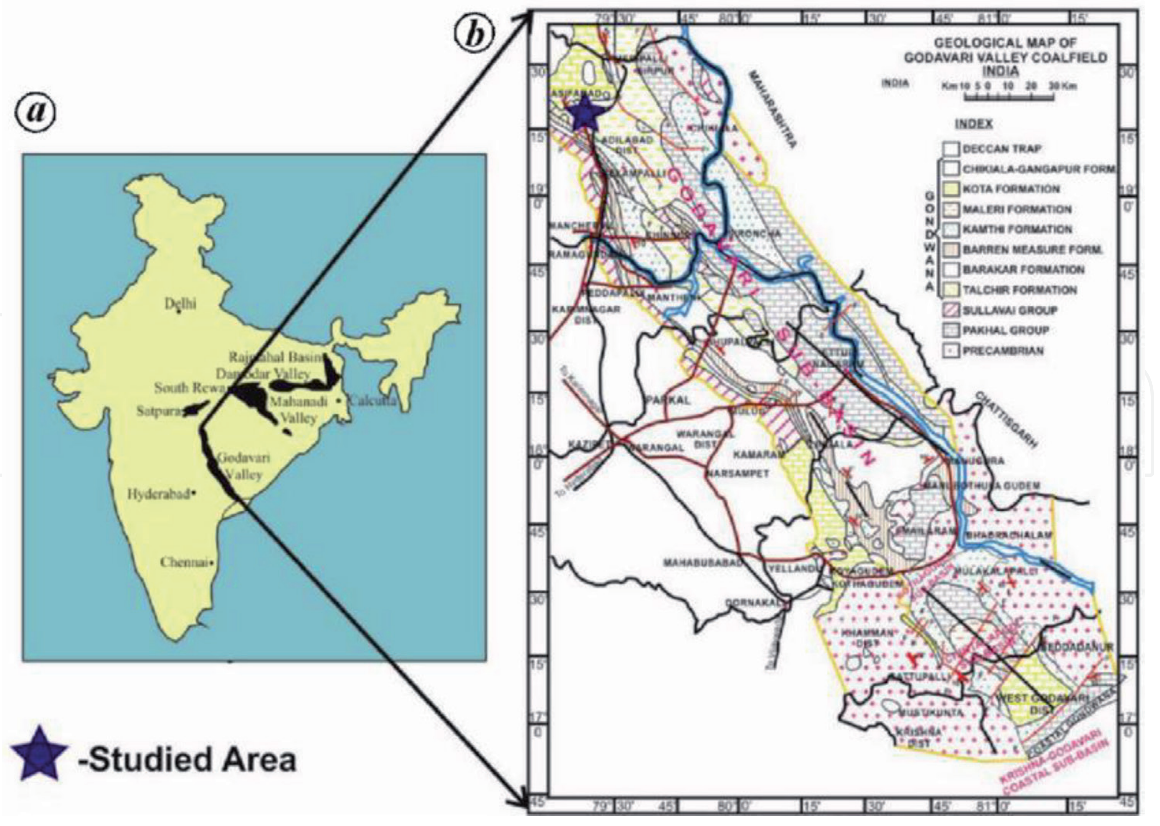

Figure 1.
Location of the investigation area.

North-West to South-East with North-Easterky dipping (**Figure 1**). Coal seam gradient varies from 1 in 3.6 to 1 in 4.3. Three faults have been deciphered sub-surface data.

The Pranahita–Godavari valley coalfield defines a north–northwest–south–southeast trending basin on a Precambrian platform. It is located within the 350 km course of the Pranahita and the Godavari rivers. Bellampalli coal belt comprises of 8 coal seams spread across 38.62 sq.km of 92.54MT.

3. Methodology and calculation sequences

The unfavorable orientation of the mine roadways with respect to high horizontal stress is suspected to be the cause of the roof falls. It is also observed that these roof falls do not occur throughout the mines at the same level though there is no change in the orientations of these roadways. The reason for such observation may be (1) due to favorable orientation of the roadways with respect to the maximum horizontal stress direction, or (2) reorientation of the horizontal stress due to the influence of discontinuities like major faults [8, 9].

Numerical simulation is a powerful technique for studies on rock mechanics and engineering, but its accuracy and reliability lie on the used simulation approach, constitutive model, material properties etc. The finite element method is a numerical solution, divided into non-overlapping regions connected to each other through points called nodes. The behavior of each element satisfying equilibrium conditions, compatibility, material constitutive behavior and boundary conditions is described, and the elements are assembled.

With the numerical simulation method, many studies were conducted on the stress redistribution induced by mining and other factors, among which the inherent perfect elastoplastic and strain-softening models using Mohr–Coulomb failure criterion are most used. However, both constitutive models embedded in FLAC3D (**Table 1**) [10–12].

Case	S_H	Deformation	S_s	S_d
i. (S_H) parallel to level gallery	18.00	12.52	6.00	1.75
ii. (S_H) is 40^0 to level gallery	18.00	12.53	6.50	1.75
iii. (S_H) is perpendicular (85^0)	20.00	12.88	7.50	2.00

Table 1.
Observations at the level gallery /dip-raise.

The safety factor (SF) for supports is estimated by the Eq. (3).

$$P_r \text{ in } t/m^2 = \gamma BF\left[1.7 - 0.037RMR + 0.0002\left(RMR^2\right)\right] \quad (1)$$

$$ASL = nA/Wa \quad (2)$$

$$SF = ASL/P_r \quad (3)$$

4. Model description and simulation

The parameters for boundary conditions were based on *in-situ* stress measurement conducted at study area, and the properties of the rock masses were based on the laboratory tests. To simulate the *In-situ* stress state, a 8.83 MPa load was vertically applied to the top boundary; according to the in situ stress measurement. A horizontal load of 6.22 MPa was applied perpendicular to the direction of strike of coal seam. Along the direction of strike, a horizontal load of 12.44 MPa was

Principal stresses	Results
Vertical Stress (S_v) in MPa (Calculated with an overburden of 517.55 m and density of rock = 2400 kg/m^3	12.17
S_H	12.44 ± 0.16
S_h	6.22 + 0.08
S_H orientation	40^0
$K = S_H/S_v$	1.22

Table 2.
Principal stress tensors as evaluated for the study area.

Properties	Coal	Non-Coal
Density (Kg/m^3)	1510	2290
Bulk Modulus K (GPa)	2.12	9.66
Shear Modulus G (GPa)	0.99	4.46
Cohesion C (MPa)	2.0	2.30
The angle of Friction φ (Degree)	20	34
Tensile strength (MPa)	1.0	0.25

Table 3.
Different input parameters considered for the simulation.

considered. The i*n-situ* stresses, which were taken into account in the model, are given in **Table 2**. The rock mass properties for the simulation were estimated from the intact rock properties, as summarized in **Table 3**.

5. Analyses and discussion

Study conducted in Australian coal mines has established a relation between roof failure in the roadways and the angle between the roadway axis and the maximum horizontal stress direction. From this a favorable direction of dip and level galleries with respect to major horizontal principal stress direction can be achieved. In Bord and Pillar mining method the dip drives and level galleries are driven perpendicular to each other. In a set of direction of maximum horizontal stress, either one of these or both may be oriented unfavorably with the orientation of the maximum horizontal stress [13–18]. The same has been taken into reference in this study.

A detailed investigation is carried out by numerical modeling to establish the most favorable direction of the dip drives/level galleries vis a vis direction of maximum principal horizontal stress from the stability point of view & design suitable support system.

As a result of numerical analyzing, redistribution of major principal stress (S_H) are given in **Figure 2** for three separate cases. The maximum stress at the roof is observed for case 3 (when Maximum Horizontal Stress is at 85^0 to orientation of level gallery/dip raises). The minimum principal stress at the roof is observed for case 1 (when Maximum Horizontal Stress is parallel to orientation of level gallery/dip raises) (**Table 4**).

The results of numerical analyses for roof convergence are shown in **Figure 3** for three cases. The maximum deformation at the roof is observed for case 3 (when Maximum Horizontal Stress is at 85^0 to orientation of level gallery/dip raises). The minimum deformation at the roof is observed for case 1 (when Maximum Horizontal Stress is parallel to orientation of level gallery/dip raises). The maximum deformation value and its location is introduced in **Table 4** with those of other cases.

In **Figure 4**, the results of numerical analyses on redistribution of shear stresses are given for all cases. The analyses indicate that the case 3 is also critical when considered shear stresses at 85^0 (**Table 4**).

The results of numerical analyzing on shear displacements under loading conditions are shown in **Figure 5**. Maximum shear displacement value and its location is given in **Table 4** with those of other cases.

In the context of this study, numerical simulations have been performed for estimating the major horizontal principal stress, roof displacement, shear stress,

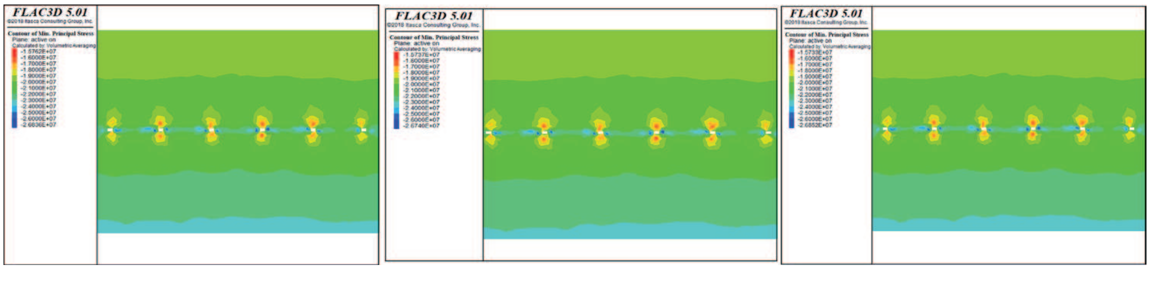

Figure 2.
Distribution of major principle stress: (a) case 1- maximum horizontal stress, which is parallel to orientation of level gallery/dip raises, (b) case 2- max. Horizontal l stress is perpendicular to orientation of level gallery / dip rises, and (c) case 3- max. Horizontal stress, which is 40^o *to orientation of level gallery/dip rises.*

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Layer	Rock type	Density (t/cum)	Layer thickness		Structural features		Weatherability%		Strength (MPa)		GW (ml/min)		RMR Value	Classification	
			cm	Rating	Index	Rating	Value	Rating	Value	Rating	Value	Rating		Class	Description
1	MGSST	2.18	30	24	5	20	82	8	0.85	0	10	8	49	III	FAIR
2	MTCGSST	2.2	52	27			91	11	11.9	4			57		
3	FTMGSST	2.23	49	27			88	10	13.3	4			56		
4	CTVCGSST	2.2	69	30			89	10	12.1	4			58		

Table 4.
Weighted RMR evaluated for the strata.

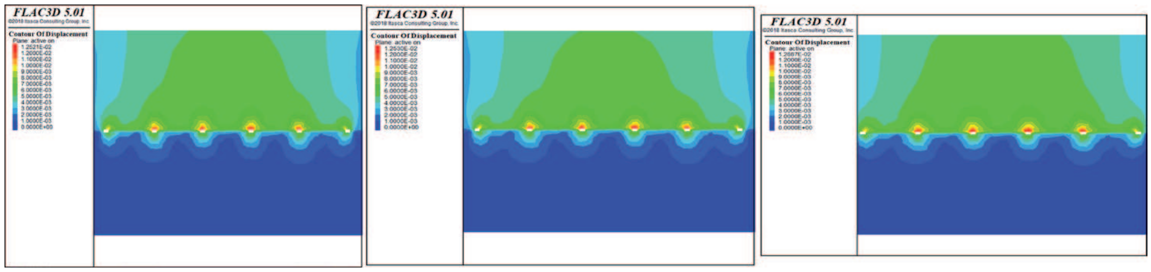

Figure 3.
Distribution of displacement: (a) case 1- maximum horizontal stress, which is parallel to orientation of level gallery/dip raises, (b) case 2- max. Horizontal l stress is perpendicular to orientation of level gallery/dip rises, and (c) case 3- max. Horizontal stress, which is 40^{o} to orientation of level gallery/dip rises.

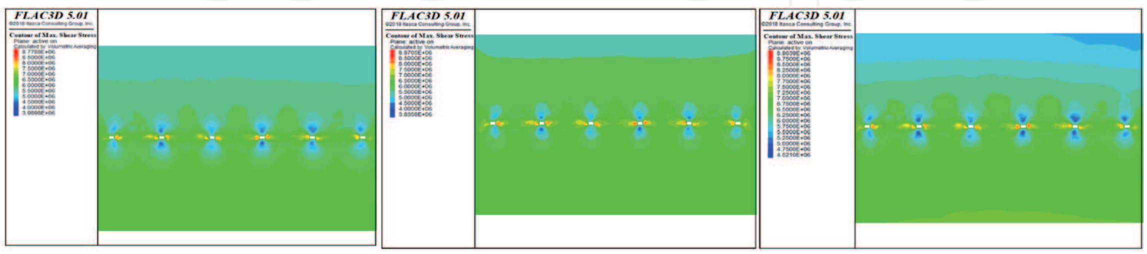

Figure 4.
Distribution of shear stress: (a) case 1- maximum horizontal stress, which is parallel to orientation of level gallery/dip raises, (b) case 2- max. Horizontal l stress is perpendicular to orientation of level gallery/dip rises, and (c) case 3- max. Horizontal stress, which is 40^{o} to orientation of level gallery/dip rises.

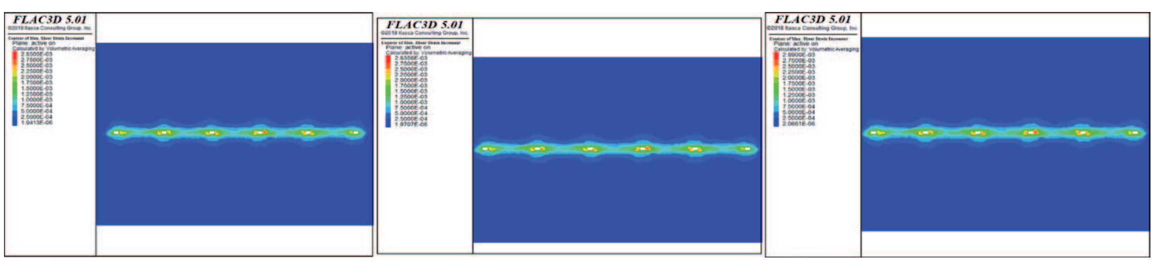

Figure 5.
Distribution of shear displacement: (a) case 1- maximum horizontal stress, which is parallel to orientation of level gallery/dip raises, (b) case 2- max. Horizontal l stress is perpendicular to orientation of level gallery/dip rises, and (c) case 3- max. Horizontal stress, which is 40^{0} to orientation of level gallery/dip rises.

and shear displacement on different mine geometries. The changes for each item have been showed in **Figure 6** on the basis of gallery orientation. The analyses indicate that the level gallery/dip-raise should be oriented at 20^{0} to 40^{0} to reduce roof problems. As based on the analyses, the authors recommended a temporary support system consisting of bolts for cool mine roof (**Table 5**). The recommend support system is illustrated in **Figure 7**.

6. Conclusion

Support design for an underground opening can only be assessed in conjunction with rock types and structural features. The strength of the rock depends on primarily the in-situ and mining induced stresses. In a common design, analysis begins with evaluation of the strength of the structural features and the forces acting during the mining processes [19].

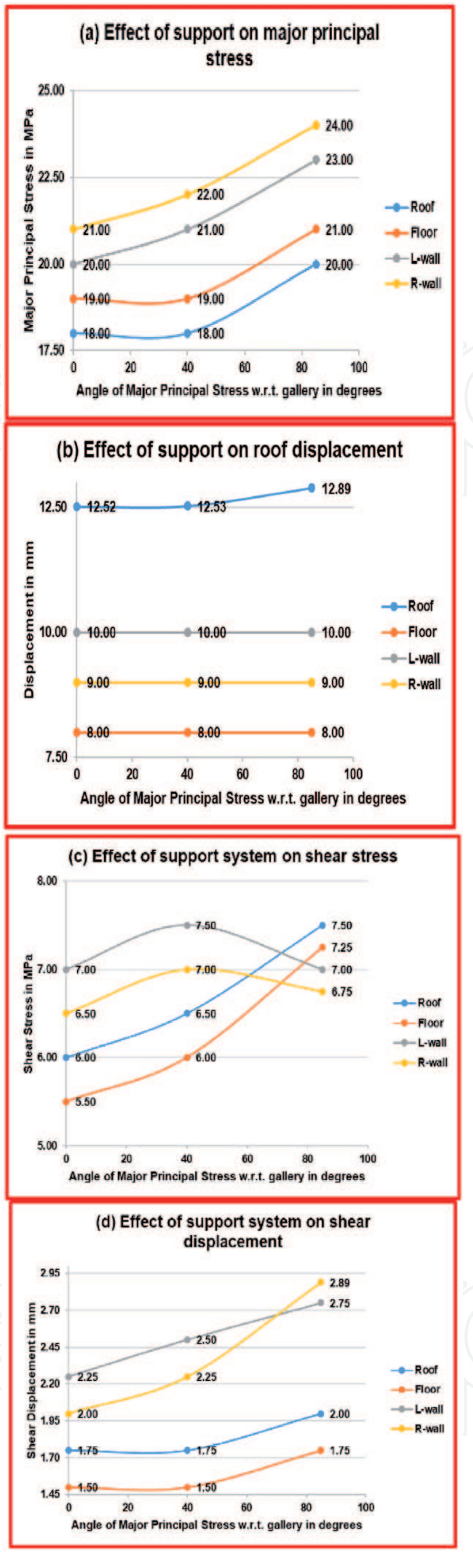

Figure 6.
Changes on the related item as based on orientation: (a) major horizontal principal stress, (b) roof displacement, (c) shear stress and (d) shear displacement.

An underground opening, analysis of the stress distribution is conducted through numerical modeling for different mine geometries. For typical studies, there are certain input parameters, which has to be assessed in field conditions I.e., in-situ measurements with geotechnical studies for the mining blocks. The numerical analyses indicate that the level gallery/dip-raise should be oriented at 20^0 to 40^0 to reduce roof problems.

Recommended Support Details
• Roof Bolts 1.8 M Length 22 mm diameter
• Spacing 1.0 M across and along with galleries
• Bolt density 7750 kg/m3, Young's modulus 2e11 N/m, Tensile strength 1.65e5 N/m.

Table 5.
Support recommendation for coal mine block.

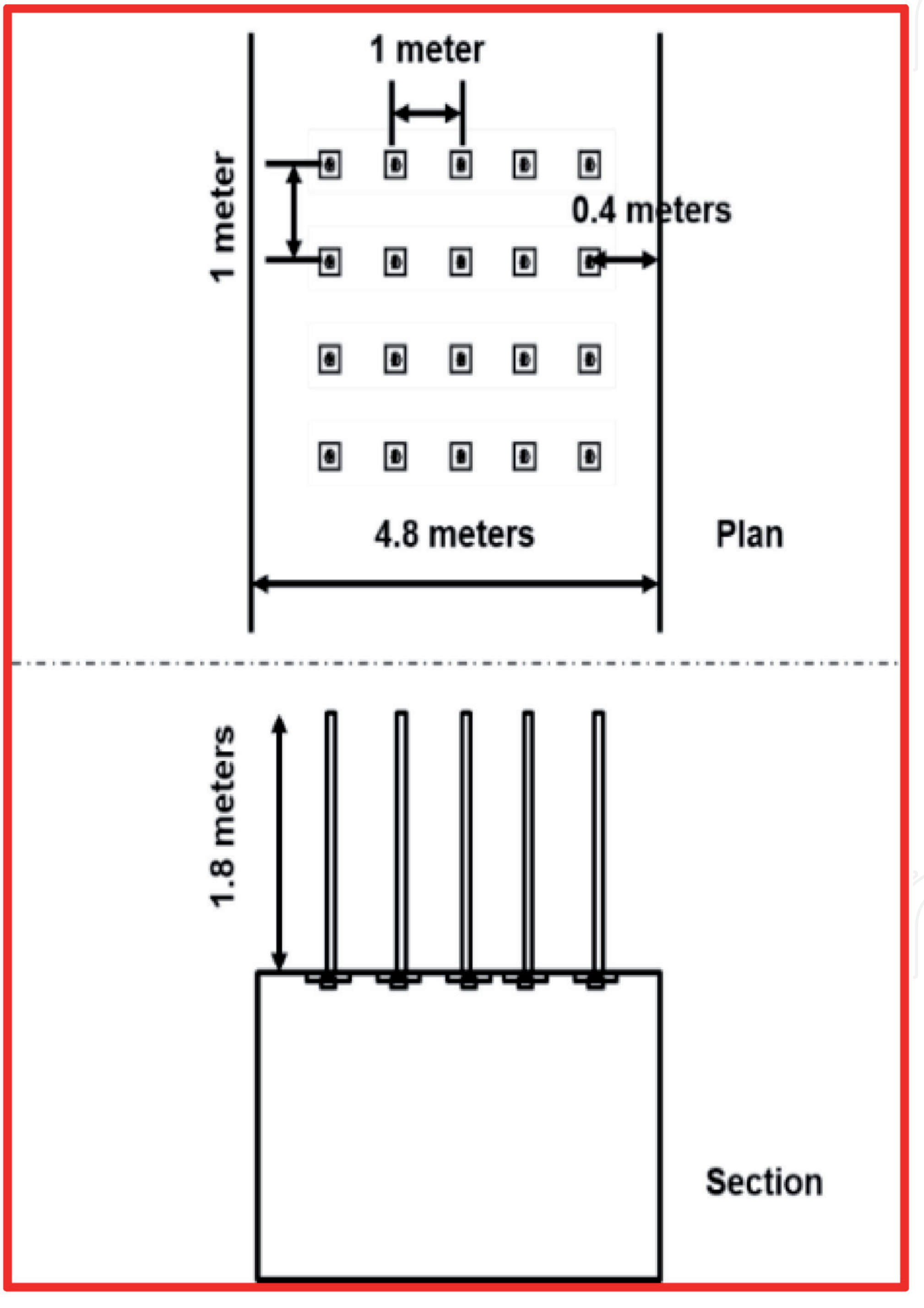

Figure 7.
Support system recommended for roof stability as based on the analyses throughout this study.

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