

STABILITY ANALYSIS OF ENTRIES IN A DEEP COAL MINE USING FINITE ELEMENT METHOD

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ABSTRACT

Strain-softening behavior of rock and coal layers around a coal mine opening was simulated using a quasi-elastic approach, which accounts for residual strength after failure. This simulation was achieved in such a way that material values were modified after each run, according to stress distribution, until the simulation reached an

equilibrium condition. MSC / NASTRAN Finite Element Method program was used for the simulation. The effect of a yield pillar system was analyzed in comparison with a regular pillar system. The results agreed with the field measurement in terms of stress distribution and floor heave.

INTRODUCTION

In view of the increasing need for the U.S. coal industry to enhance productivity and improve coal recovery, the longwall mining technique has recently been adopted because of its large extracting capability of underground coal deposits. This method of extraction, when used for deep underground mines, requires the development of three or four entries running parallel to the longwall panel. This study treats only the four-entry system.

The stability of developed entries in terms of floor and roof movements is greatly affected by the size of supporting pillars. The conventional system of pillars, consisting of three equally sized pillars, has created problems such as floor heave and a high state of

stress in the region adjacent to the longwall panel. The relatively recent development of a yield pillar system has shown an improvement over the conventional system in that it allows the pillar closest to the panel to yield, thus minimizing floor heave and allowing the high stresses to transfer to a relatively larger pillar situated further away from the longwall panel.

The object of this paper is to use a computer simulation technique to make an analytical comparison of the stress distribution in the pillars and of the floor movements relating to both situations.

STATE OF STRESS IN COAL PILLARS

The study area is an underground coal mine in the Black Warrior Basin in Alabama

where the depth of the coal seam is approximately 2000 feet. This mine uses two pillar systems in its longwall sections. The first one is the conventional system, called the regular pillar system. When subjected to high stresses, a yield zone is distributed around the edge of each pillar, followed by a peak stress zone. As the longwall face advances, the yield zone increases, with the peak stresses transferring toward the inner core of the pillar. This being the case, high stresses will be maintained in the region near the longwall panel, with floor heave developing in the entries adjacent to the panel.

The second system is called the yield pillar

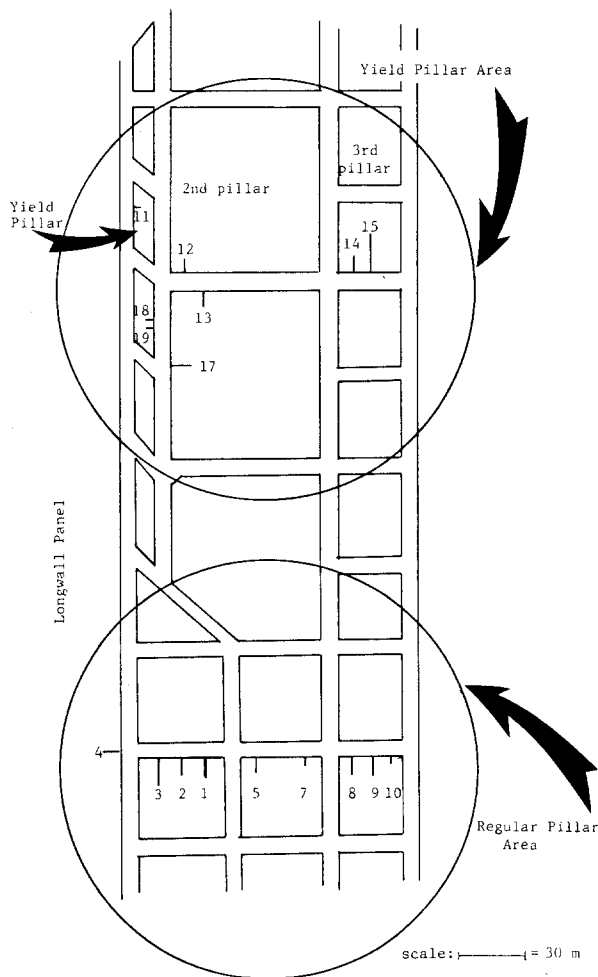


Fig. 1. Regular pillar and Yield Pillar Areas and gage locations.

system, in which the three pillars vary in size, in such a way that the stresses close to the panel will be transferred away toward the large pillar in the middle. This is achieved by yielding the first pillar adjacent to the panel.

Pillar stress was monitored, although accurate stress measurements follow a rather laborious and time-consuming procedure. Vibrating-wire stress meters had to be installed in the pillars at critical locations. The stress meters were placed at various depths varying from 3 to 9 meters, and were read at regular intervals of time. The regular and yield pillar, together with the gage locations in the study area, are shown in Fig. 1.

FINITE ELEMENT METHOD

In simulating both cases, a finite element program, MSC/NASTRAN, developed by NASA, was utilized. This package program is flexible enough to handle problems relating to statics, dynamics, heat transfer and many others. Because of the large number of elements needed to form the mesh, two programs were developed: one for generating two-dimensional grid points, the other to generate quadrilateral elements. Both programs are compatible with the MSC/NASTRAN input format. Figures 2 and 3 show the yield-pillar and the regular-pillar area models respectively.

In order to simulate the actual conditions existing in the area, extensive testing had to be conducted to determine the physical properties for each layer of rock and coal. Tables 1-4 give the necessary material properties input data. The regular-pillar model consisted of 877 plate elements with 1,038 nodes, while the yield-pillar model was formed by combining 984 elements and 1,158 nodes. Constraints for both models were placed along two edges of the models. Gravitational and horizontal loading have been imposed on the other two surfaces.

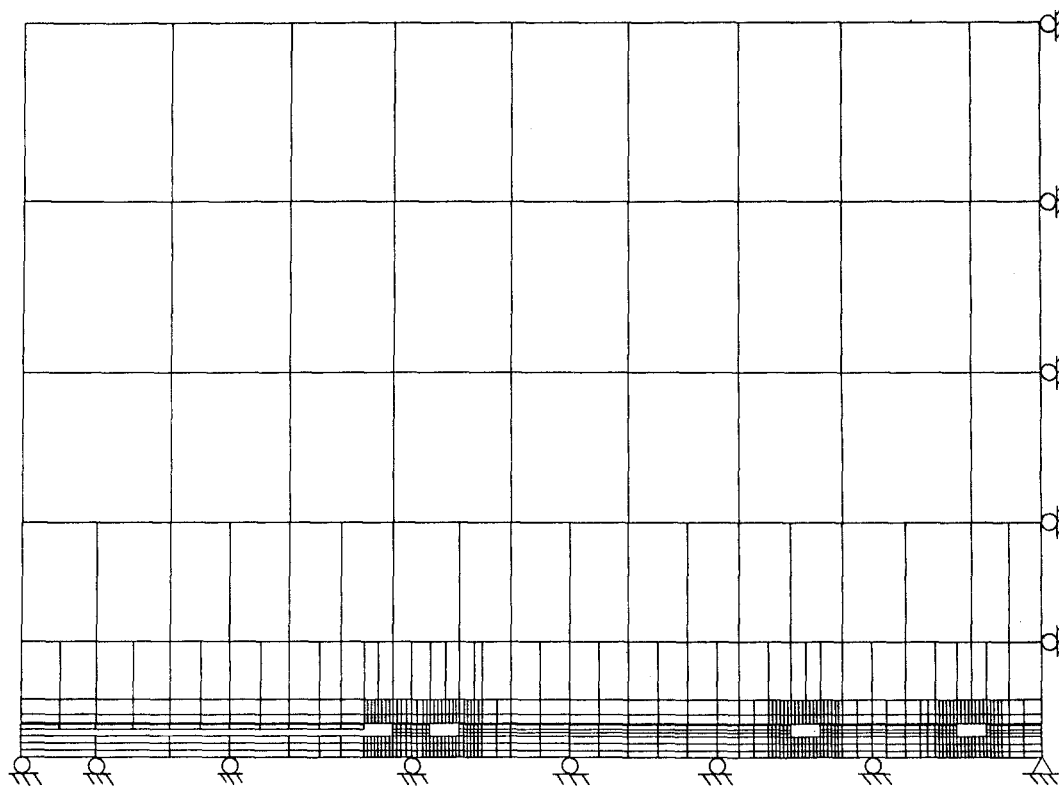


Fig. 2. Yield pillar model.



Fig. 3. Regular pillar model.

TABLE 1

Physical Properties of Rock Samples (Average Values)

Specimen	Direction	Strength (MPa)	Modulus of Elasticity (MPa)	Poisson's Ratio (ν)
roof	horizontal	61.24	24,483	0.38
	vertical	82.69	23,310	0.31
middleman	horizontal	34.64	31,724	0.43
	vertical	38.28	46,552	0.14
floor	horizontal	40.00	NA	NA
	vertical	NA	NA	NA

TABLE 2

Hardness test results (from 6 specimens for each direction, 10 tests on each specimen)

Specimen	Direction	Average Shore Hardness number
middleman	vertical	16.1
	horizontal	16.2
roof	vertical	24.2
	horizontal	27.6

The major variable affecting the iterative procedure is the modulus of elasticity because it represents the relative stiffness of the layers in question. This procedure has been previously discussed [1], adapted from previous theoretical work [2,3]. Assuming plain strain conditions and linearly elastic behavior, when

TABLE 3

Average tensile strength (Brazilian)

Specimen	Direction	Tensile strength (MPa)
roof	vertical	9.72
	horizontal	8.65
middleman	vertical	5.10
	horizontal	4.57
floor	vertical	5.81
	horizontal	NA

an element exceeds the Mohr-Coulomb criteria for failure, the difference between the calculated and the admissible residual stress is redistributed to other elements. This redistribution can be based on the stiffness of the system and its relation to the stiffness of the

TABLE 4

Triaxial test results on rock layers

Specimen type	Confining pressure (MPa)	Maximum vertical stress (MPa)	Angle of internal friction (ϕ)	Cohesion (MPa)
roof:	horizontal	3.45	106.35	—
		6.90	105.72	
middleman:	vertical	3.45	59.10	40.8
		6.90	61.86	
		10.35	58.83	
middleman:	horizontal	3.45	70.97	56.8
		6.90	61.59	
		10.35	74.48	
floor:	horizontal	3.45	52.35	38.9
		6.90	65.17	
		10.35	109.93	
floor:	vertical	3.45	100.35	35.0
		6.90	150.35	
		10.35	117.79	
				21.38

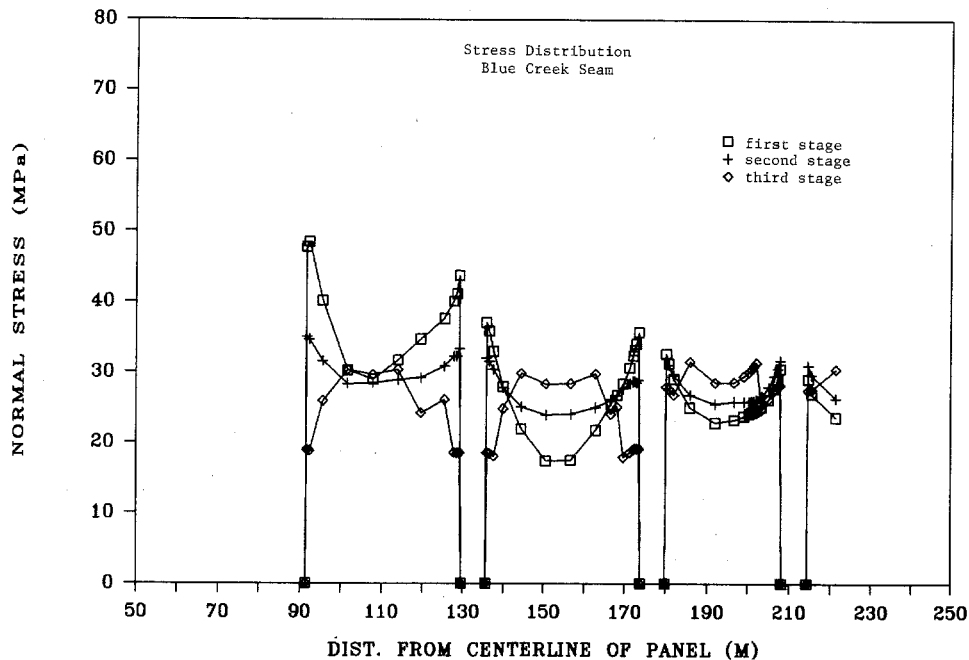


Fig. 5. Stress distribution for the Regular Pillar Area.

REGULAR PILLAR SYSTEM

Stress distribution for the initial run of the finite element program, as shown in Fig. 5,

shows high peak stresses valued at approximate 48.28 MPa at the edges, and at 27.59 MPa in the middle of the pillar. Because of the difficulty in getting readings in the mine

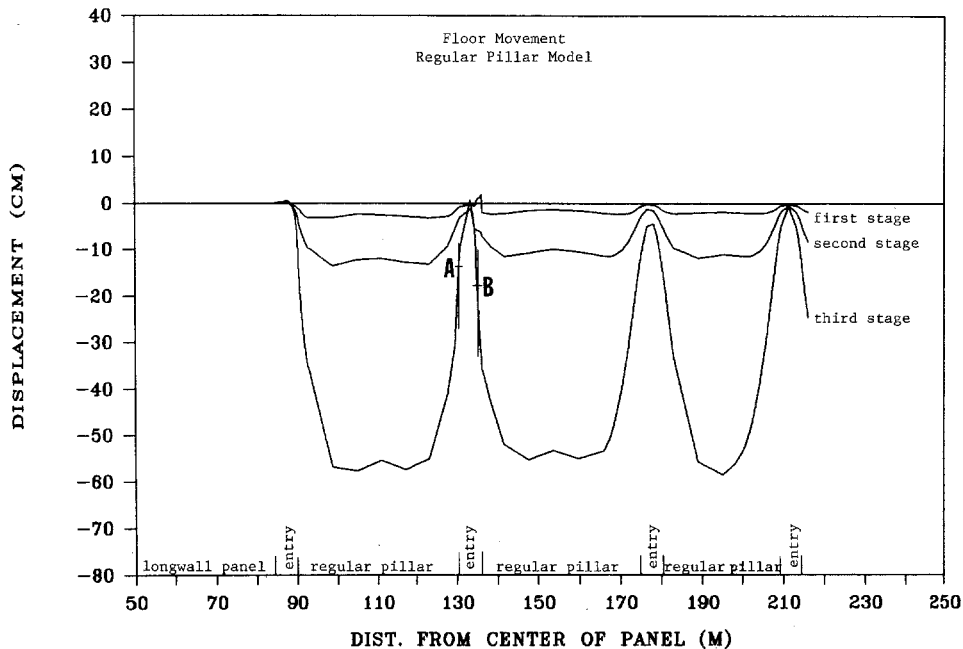


Fig. 6. Floor movement for the Regular Pillar Area.

TABLE 5

Comparison of stresses for the regular pillar system

Stages	Computer program (MPa)		Actual readings (MPa)	
	Gage 5	Gage 7	Gage 5	Gage 7
1	24.13	27.59	—	—
2	27.59	27.59	16.55 *	16.55 *
3	28.97	26.21	22.07 **	17.24 **

* 107 m away from face location

** face location at the gage

from the vibrating-wire gages, one can see from Fig. 4 that only gages 5 and 7 were capable of registering the stresses in the middle pillar even after the longwall face passed the gage location.

Comparing the readings from the two gages and the simulated stress distribution for the three stages, as shown in Table 5 for the middle pillar, gage 5 shows a steady increase in stress while gage 7 shows a relative drop in both the analysis and in the actual gage reading. The third iteration describes a distinct yield zone and a competent inner core area. A layer of rock nearly 1 metre in thickness tends to act as a reinforcement for the pillar as a whole, thus slowing the development of the yield zone around the pillar.

YIELD PILLAR SYSTEM

A comparison can be made between pillar stresses from Fig. 7, according to locations shown in Fig. 1, with the stress distribution generated by the finite element program. Gage 18, which records stresses in the yield pillar, shows a steady fall in stress from 20.70 MPa to 13.8 MPa. On the other hand, the pillar stress distribution in Fig. 8 shows an initial stage which is an instantaneous state of stress as high as 48.28 MPa, while stages 2 and 3 show a drop in stress from 22.07 MPa to 19.31 MPa, which are in close agreement with

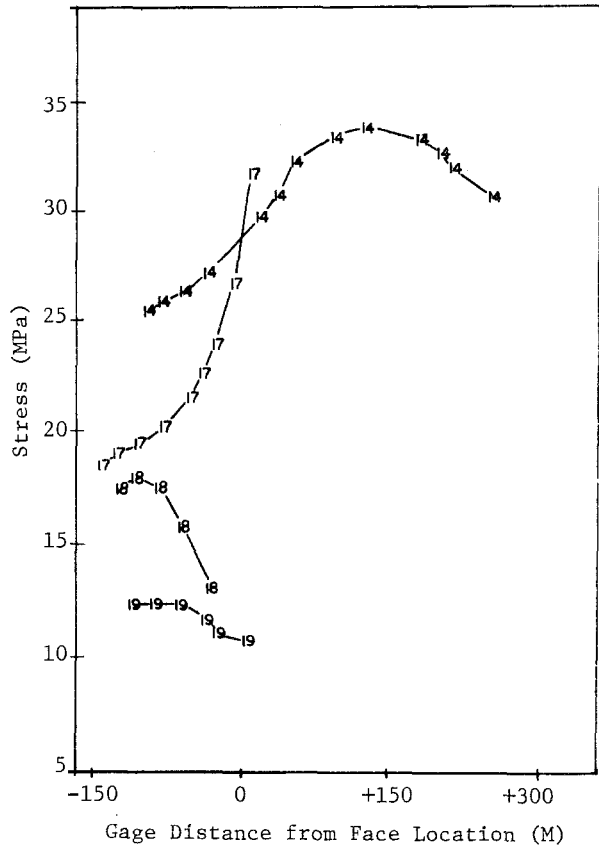


Fig. 7. Stress increase vs. face distance from gages at Yield Pillar Area.

the measured values. A similar comparison can be made at locations in the large pillar and the third pillar represented by gages 17 and 14. Table 6 shows a comparison between the measured and simulated stresses at each location. The second and third stages represent the position of the face relative to the gage at 107 m and 0 m, respectively. In the yield pillar system it can be found that the large pillar yields on the side closest to the longwall panel, while an increase in stress on the other side is produced. The yielding occurs on the right side of the large pillar and through the third pillar. Thus, time is a factor in the stress development through the large pillar.

The presence of a rock layer in the middle of the pillars played an important role in preventing large deteriorations in the pillar

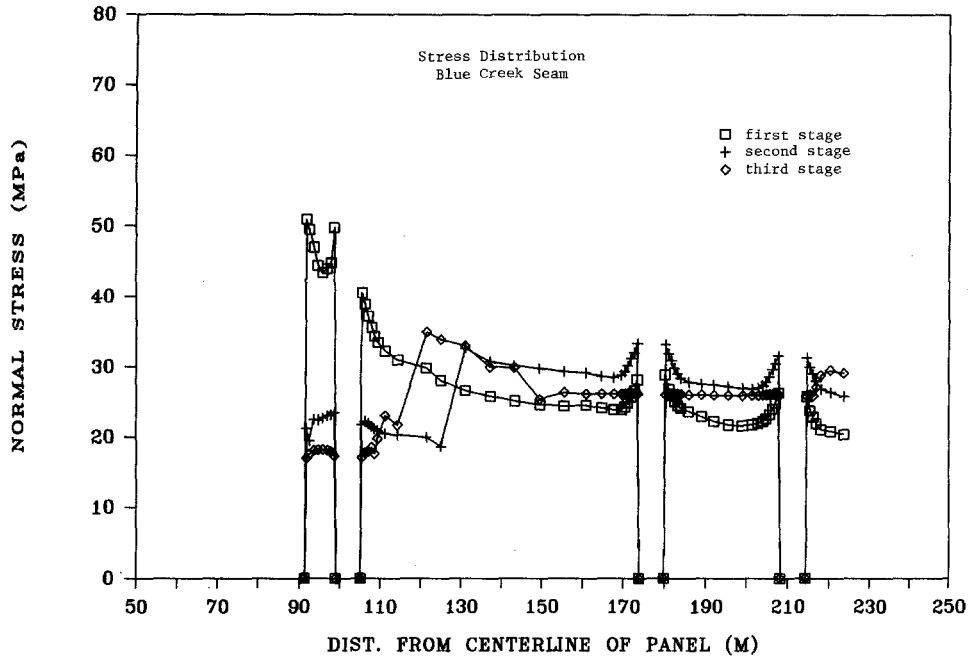


Fig. 8. Stress distribution for the Yield Pillar Area.

ribs, by acting as a reinforcement for the coal seam.

Floor movement, which is of great importance in the design of pillar systems, can be very critical in a mine. Areas of high stress have shown considerable floor heave which can be interpreted as a bearing-capacity failure. Regular pillar systems have shown considerable floor heave in the first and second entries, and this led to the search to find an alternative system which can minimize this floor heave. In comparing Figs. 6 and 9, the second entry in the yield pillar system showed

considerably less floor movement than its corresponding entry in the regular pillar system. This can be attributed mainly to the yielding of the yield pillar, thus shifting the high stresses to the middle of the second pillar. Throughout the three different iterations, the floor movement was much less in the yield-pillar system than in the regular-pillar system. Floor movements in the regular-pillar system, plotted in Fig. 6, show values of 18 and 20 cm at A and B, respectively, at the edges of the second entry, while the yield-pillar system the values for which are plotted in Fig. 9, show

TABLE 6

Comparison of stresses for the yield-pillar system

Stages	Gage 18 (MPa)		Gage 17 (MPa)		Gage 14 (MPa)	
	simulated	actual	simulated	actual	simulated	actual
1	48.28	—	31.04	—	20.68	—
2	22.07	20.68 *	20.68	20.68 *	27.59	27.59 *
3	18.62	13.80 **	33.10	31.04 **	28.97	34.48 **

* 107 m away from face location

** face location at the gage

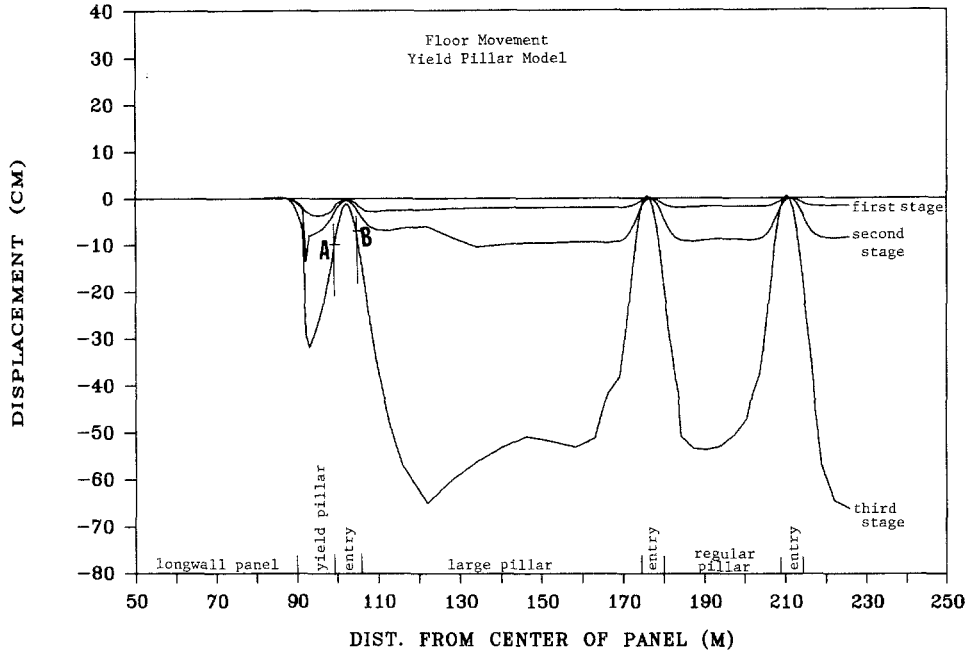


Fig. 9. Floor movement for the Yield Pillar Area.

relatively larger floor movements. In the second entry at locations A and B, movements of 10 and 13 cm, respectively, can be seen. These values do not describe a floor heave accordingly because the computer simulation analysis is based on the linearly elastic concept while the actual failure occurring is plastic. On the other hand, the lower values in the yield-pillar system predict the same trend if a plastic analysis were to be conducted.

CONCLUSION

The finite-element technique presented in this paper produced very promising results corresponding well with field measurement in stresses, and predicted a less critical floor heave in the yield-pillar system than in the regular-pillar system. The stress analysis, through the redistribution of stresses, has actually simulated to a large extent the plastic behavior of the material, resulting in values

relatively close to actual field measurements. Large deformations in the field can be better simulated by plastically deforming the elements after each iteration. Nevertheless, a relative comparison can be successfully made for the displacements in both cases. An extension of this work can be made by analyzing roof-to-floor convergence, which is also of importance in mining. The finite-element method, with its iterative method for progressive failure simulation, has proved to be a valuable tool which can play an important role in the coal industry.

REFERENCES

- 1 N.P. Kripakov and M.T. Melvin, A computer procedure to simulate progressive rock failure around coal mine entries. In: Y.J. Wang and R.L. Sanford (Eds.), Proc. 1st Conf. on Use of Computers in Coal Industry, Publ. West Virginia Univ., Morgantown, WV, 1983, pp. 487-502.

- 2 A. Kidybinsky and C.O. Babcock, Stress distribution and rock fracture zones in the roof of longwall face in a coal mine. *Rock Mech. J.*, 5 (1) (1973): 1–19.
- 3 W.G. Pariseau and I.M. Eitani, Comparisons between finite element calculations and field measurements of room closure and pillar stress during retreat mining. *Int. J. Rock Mech., Min. Sci. Geomech. Abstr.*, 18 (1981): 305–319.