Application of Numerical Modelling to Study the Efficiency of Roof Bolting Pattern in East 1 Main Gate of Tabas Coal Mine

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APPLICATION OF NUMERICAL MODELLING TO STUDY THE EFFICIENCY OF ROOF BOLTING PATTERN IN EAST 1 MAIN GATE OF TABAS COAL MINE

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ABSTRACT

Tabas mechanized underground coal mine, locating in mid eastern of Iran, has been designed to produce 1.5 million tone coal annually. To start driving the first (East 1) panel's main gate and tail gate, a 7+6 pattern of 2.4 m roof bolts was considered to be applied in both gates together with 4 and 3 side bolts at left and right ribs, respectively. In this paper, 2D numerical modelling using FLAC program is implemented to assess the efficiency of the roof bolting pattern in the east 1 main gate of the mine. The output of the modelling, in the form of displacements and strains in 7.2 m extensometers , movements in 5 m long dual telltales and axial loads in roof bolts, will be compared to the results of real monitoring instruments (7.2 m multipoint sonic extensometers, 5 m telltales and strain gauge bolts) installed in the gate.

INTRODUCTION

Tabas Coal Mine no 1 is located in a remote rugged desert environment approximately 85 Km south of town of Tabas in Yazd province in mid eastern of Iran. In 1998, the National Iranian Steel Company (NISCO) issued an international tender for Tabas Coal Mine following which NISCO has selected the Joint Venture Partnership of Iran International Engineering Company (IRITEC) and IRASCO as the preferred bidder. At this time, IRITEC/IRASCO as a contractor has excavated the East 1 Main and Tail Gate to commission the 1st retreat longwall coal face (the East 1 Panel) and produce 1.5 million tone coal annually.

Before driving the 1250 m long roadway into sole roof bolt support, it was decided to carry out computer modelling to assess the efficiency of the roof bolting pattern during driving the road way and also the potential influence of face retreat. The second was done by increasing vertical stress to 200% to simulate the increase in stress ahead of the face as it retreat. In addition, another run was also done to see the behaviour of the roadway with no reinforcement.

In this paper, the east 1 main gate (E1 MG) of the mine will be modeled and discussed to assess the roof bolting pattern and evaluate its efficiency. Telltales, multi-point sonic extensometers and strain gauge bolts are the current instruments for monitoring the gate roads which showing roof movements of less than 16 mm and axial load of less than 20 tone in roof bolts of the 7+6 pattern. These results will be compared to that of the models

ROADWAY DIMENSIONS AND REINFORCEMENT

The gates are being driven in rectangular profile, 4.5 m wide and 3.5 m high. The reinforcement pattern consists of 13 2.4 m AT roof bolts (7+6 pattern) per meter length of the gate which was designed using Rock Confinement Method proposed by Daws, 1992. The ribs in MG are being reinforced with 4 1.8 m fiberglass bolts in left side and 3 1.8 m AT bolts in right side. To start bolting pattern, a 15 meter pretrial section containing 13 roof bolt plus IPB-160 steel frames at 1 meter spacing was considered in which, sides were packed by sheet and sand bags. Then a trial section was started (about 33 m length) with the basic pattern of roof and side bolts plus IPB 160 steel frames at 1 meter spacing. The next trial section (about 37 m length) included the same bolting pattern plus the same frames at 2 meter spacing. Then, the gates went on sole bolting reinforcement.

GEOLOGY AND MINING ENVIRONMENT

The mine is working seam C1. The C1 seam gradient is 1 in 5 to 1 in 2 (11 to 26 deg.) in initial mining area. In E1 MG, the gradient has been observed between 19 and 29 degree. The seam thickness is 1.8 to 2 m in E1 panel. The C1 roof contains 0.1 to 0.2 m thick mudstone, siltstone/sandstone interfaces and sandstone channels in some areas within 3 m which have potential to be water bearing. The floor is about 1 to 1.3 m of weak seat earth/mudstone underlain by stronger mudstones, siltstones/sandstones. The C1 seam coal has a uniaxial compressive strength of less than 6 MPa. There are some other seams C2 and D1 above and B1 and B2 below the C1 seam (IRITEC).

A 4.75 m roof core taken in E1 MG at MM of 270.7 revealed that there is frequencies of siltstone, sandy siltstone and silty sandstone above the roof of the MG. The core data and the other parameters observed in the gate are summarized in table 1 to calculate RMR value (Bieniawski, 1989).

Table 1. Core Data and RMR Parameters

Depth into Roof (m)	Rock Type	UCS (MPa)	RQD (%)	Discontinuity Spacing (m)	Discontinuity condition	Ground Water	Discontinuity orientation	RMR
0-2.12	Sandy Siltstone	32	18	0.06-0.2	slightly rough, separation <1mm	Dripping to dry	Very unfavourable	Class III-IV (30-41) Average = 35.5
Rate		4	3	8	23	4-15	-12	
2.12-3.35	Silty Sandstone	73	26	0.06-0.2	slightly rough, separation <1mm	Dripping to dry	Very unfavourable	Class III-IV (38-49) Average = 43.5
Rate		7	8	8	23	4-15	-12	
3.35-3.80	Sandy Siltstone	32	49	0.06-0.2	slightly rough, separation <1mm	Dripping to dry	Very unfavourable	Class III-IV (35-46) Average = 40.5
Rate		4	8	8	23	4-15	-12	
3.80-4.75	Sandstone	73	43	0.06-0.2	slightly rough, separation <1mm	Dripping to dry	Very unfavourable	Class III-IV (38-49) Average = 43.5
Rate		7	8	8	23	4-15	-12	

According to table 1, there is 2.12 m sandy siltstone over the roof, then silty sandstone from 2.12 to 3.35 m, after that again sandy siltstone from 3.35 to 3.8 m and overlying this, sandstone to the end of the roof core. For simplicity in modeling, all sandy siltstone and silty sandstone were considered as siltstone and sandstone, respectively

CURRENT INSTRUMENTS

Current monitoring devices of the gates of the mine are 7.2 m 20 point sonic extensometers, 5 m dual height telltales and 2.4 m strain gauge bolts which will be used for comparison with numerical modelling results. Their MM are in table 2:

Table 2. Core Data and RMR Parameters

Instrument Type	MM (meter)
Strain gauge bolts station no 2	327.8
Extensometer no 1	309
Extensometer no 2	333
Extensometer no 3	362
Extensometer no 5	1003
Telltale no 3	304
Telltale no 4	319
Telltale no 5	330
The core taken	270.7

IN SITU STRESS

No measured value for the in situ stress is available. The E1 MG was at a depth of about 210 m around the coring position. Then a vertical stress of about 5.7 MPa and the ratio of horizontal to vertical stress K=1/3 were considered for the site, according to tectonic history of the region.

MODELLING

The numerical modeling package used to conduct the investigation was FLAC 2D. The code is restricted to 2 dimensional problems, hence only cross sections through the roadway are presented.

Rock Mass Properties

To provide input parameters (rock mass properties) for the models, RocLab program (working based on GSI classification, GSI=RMR-5) was used to estimate the parameters of rock mass surrounding the gate. Intact rock and rock mass properties are listed in table 3.

Table 3: Intact Rock (IRITEC) and Rock Mass Parameters

Depth into roof (m)	Intact Rock		Rock Mass								
	UCS (MPa)	m *	GSI	m	s	C (MPa)	ϕ (deg.)	Tensile Strength (MPa)	Compressive Strength (MPa)	E (GPa)	υ
Coal	5	1	25	0.1	0.0002	0.1	20	0	0.5	0.7	0.26
0-2.12	32	7	30.5	0.58	0.0004	0.5	21	0.02	0.5	1.7	0.26
2.12-3.35	73	13	38.5	1.45	0.0011	1	44	0.05	2.2	3.5	0.25
3.35-3.80	32	7	35.5	0.7	0.0008	0.6	31	0.03	0.8	2.7	0.25
3.80-4.75	73	13	38.5	1.45	0.0011	1	44	0.05	2.2	3.5	0.25

* Assumed, (constant in Hoek and Brown criterion)

Furthermore, short encapsulation pull test results were used to provide proper roof bolt bond properties (ITASCA, 2005) as shown in table 4.

Roof layers were modeled according to roof core log (tables 1 and 3) taken in MG. Siltstone was considered in the model's floor (Borehole no BH43A, (IRITEC)). The model roadway profile and the reinforcement pattern are shown in Fig. 1.

Table 4: Bolt and Bond Properties (IRITEC)

Parameter (unit)	Value
Diameter (mm)	21.7
Elastic Modulus (GPa)	207
Tensile Yield Load (tone)	25
Tensile Failure Strength Limit (%)	10
Shear Stiffness of Bond (KN/mm)	65
Compressive Strength of Bond (MPa)	5
Normal Stiffness of Bond* (KN/mm)	100

* Assumed

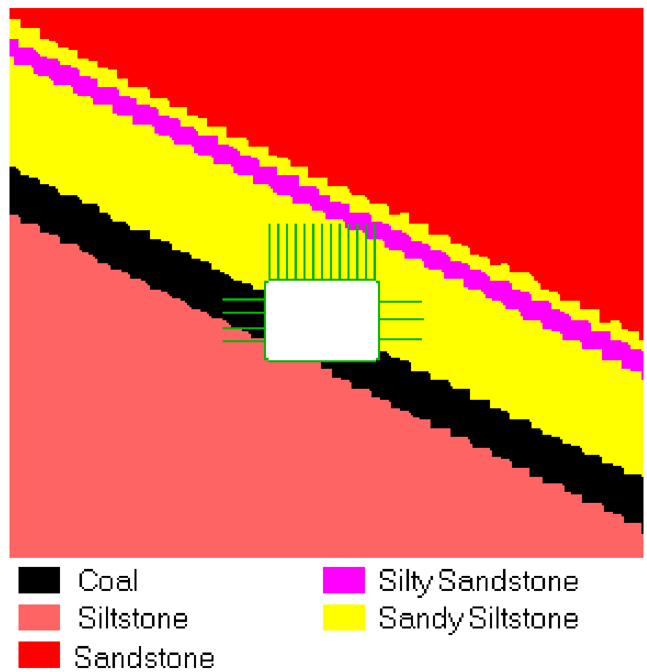

Fig. 1. The model roadway profile and reinforcement pattern

Closure of the Gate

Figure 2 shows the total movement of the ribs, roof and floor. It is clear that the total movement of floor is independent of the existence of reinforcement and also the face retreat. But rib and roof movements are strongly affected by the mentioned parameters. The total vertical and horizontal closures of the model gate are listed in table 5. The closures are not very large and will cause no major problem during driving and retreat.

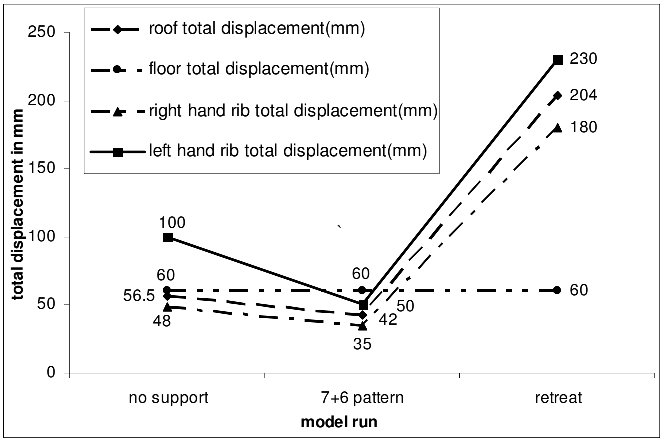

Fig. 2. The roadway total closure (units in mm)

Table 5. Total Vertical and Horizontal Closure of the Roadway

Model Run	Total Vertical Closure (mm)	Total Horizontal Closure (mm)
No support	116.5	148
7+6 pattern	102	85
Face retreat	264	410

Real and Model Extensometers

With the vertical and lateral stress within the range expected for the gate road, any significant softening confined to within the roof bolting height. Figures 3 and 4 demonstrate the behavior of roof in the models.

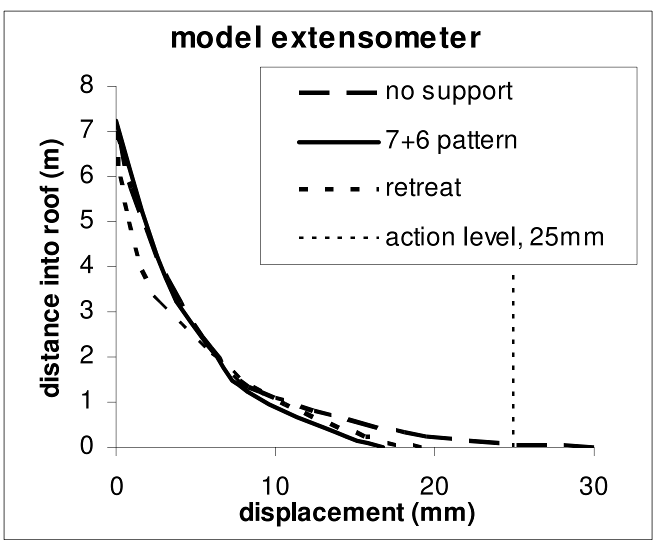

Fig. 3. Modeled extensometer response in the form of roof displacement

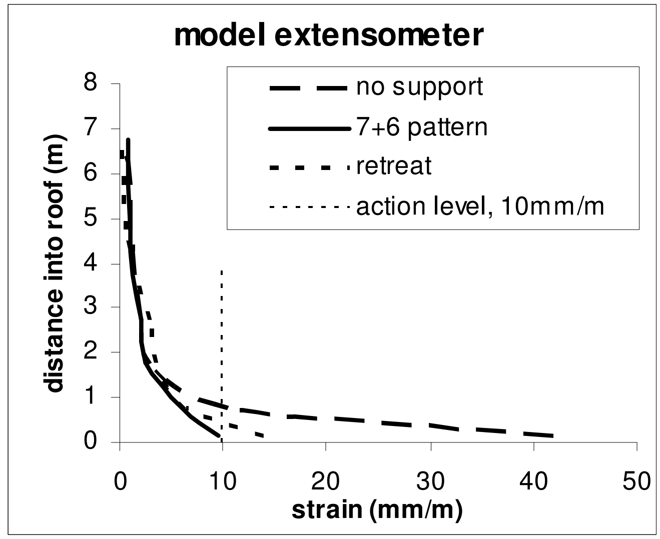

Fig. 4. Modeled extensometer response in the form of roof strain

Figure 3 indicate that, roof displacement exceeds the action level of the mine (25mm) in the no reinforcement model, but those of the reinforced roof model during driving and also face retreat are still in the acceptable range (Fig. 3).

Figure 4 indicates that roof strain is less than the action level of the mine (10mm/m) in 7+6 pattern and reveals good efficiency of the reinforcement pattern. Roof strain of both no support and face retreat models exceeds the action level. Critical height of softening in the face retreat model is restricted to the roof bolting height and it seems that some extra roof bolts will be enough to control roof deformation. But some more models will be needed to make sure about that. For comparison, the results of the 3 extensometers (no 1, 2 and 3) close to and an extensometer (no 5) far from the coring position together with the model extensometer for 7+6 roof bolt pattern are shown in fig. 5 and 6.

It can be observed in the Fig. 5 that the displacement graphs show good agreement of real and model extensometers. The small difference between the strain graphs in fig. 6 is due to the existence of layers in the roof (discontinuous rock mass) causing separation in some layers, while the rock mass was considered as a continuous media in the models. But all the strains are less than action level of the mine (10mm/m). It is notable that in both displacement and strain graphs, the line of model is approximately the upper envelope.

Real and Model Telltales

Also telltales no 3, 4 and 5 around the coring position show total displacement (A+B) of about 16, 16 and 11 mm, respectively while that of the model is 17 mm which shows good agreement.

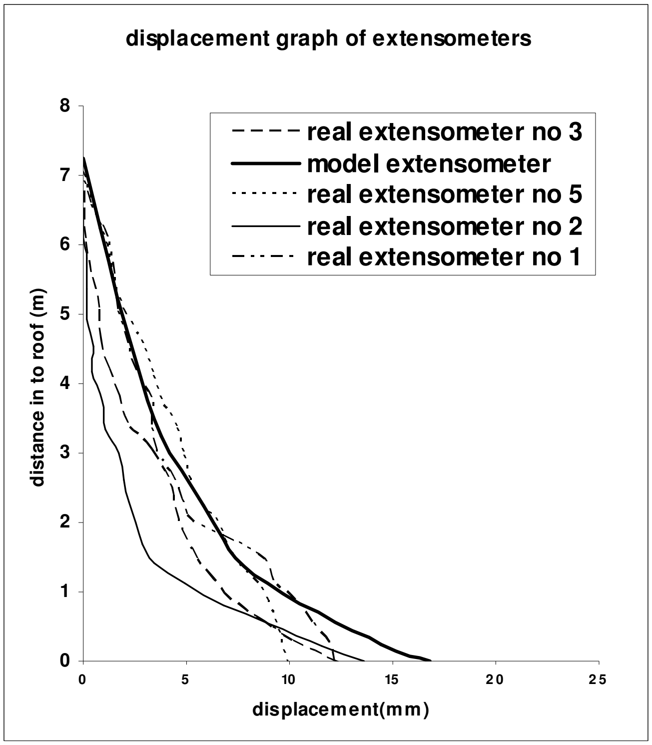

Fig. 5. Displacement graph of 4 extensometers close to and far from the coring position and the model extensometer for 7+6 pattern

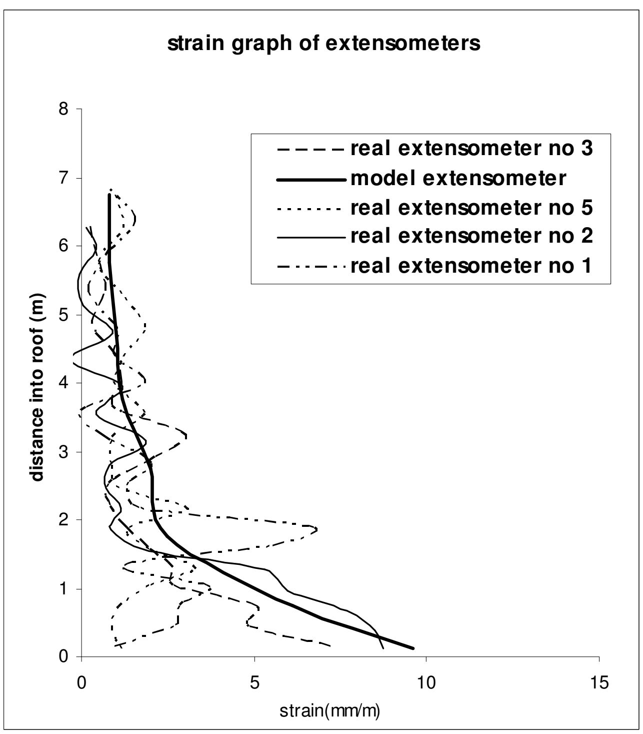

Fig. 6. Strain graph of 4 extensometers close to and far from the coring position and the model extensometer for 7+6 pattern

Axial Loads in the Real and Model Roof Bolts

In addition to deformations, axial loads in the model roof bolts are compared with that of a strain gauge bolt station around the coring position (Fig. 7). According to Fig. 7, axial loads of the strain gauge bolts station no 2 show good agreement with the model roof bolts around center of the roof. It can be due to discontinuous nature of the rock mass which considered as continuous in the models. It can cause separation to concentrate on some layers in left part of the roof and consequently, concentration of load in some parts of the bolt length at that side (It should be reminded that the layers are inclined in the model profile.), while axial loads in the model roof bolts are equal in all bolts.

Therefore despite of allowable axial load in model roof bolts in the face retreat model, it can be said that the actual axial loads of the roof bolts during actual face retreat will be higher. Regarding the strain graph of the face retreat model in Fig. 4, it is clear that more roof bolts (or other reinforcements) will be needed during face retreat to control the softening in the roof bolting height.

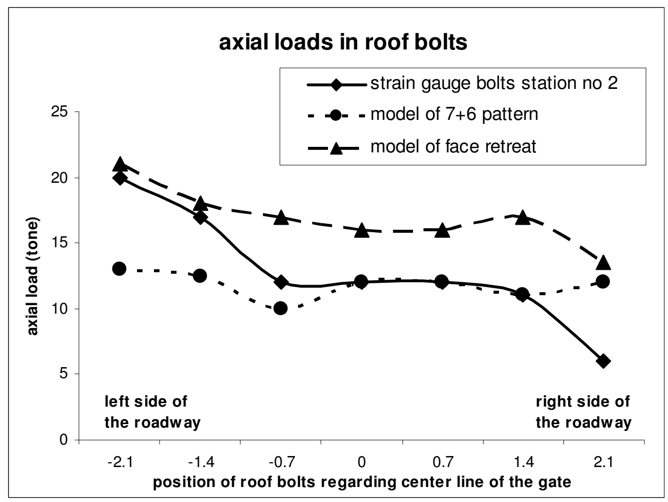

Fig. 7. Axial loads in model and real roof bolts

Shear Strain

Shear strains of the 3 models, no support, 7+6 pattern and face retreat are illustrated in Fig. 8, 9 and 10, respectively. Maximum shear strain in no support and 7+6 pattern model is 7% and is showing independency to roof support. Maximum shear strains in these 2 models concentrate at left side rib and right side of the floor. It can be observed in the form of deformed plastic plates of the fiberglass bolts at left rib of MG (Fig. 11). The shear strain value increased to 20% in the face retreat model and surely will cause the bolt plates to fail. Also, the sheared zone is extended in right side rib. Depth of sheared zone in left rib is between 2.5 and 3 meter and put more bolts longer than this length in ribs is much difficult. Resin injection in left rib can be a suitable method to increase strength of the coal during face retreat.

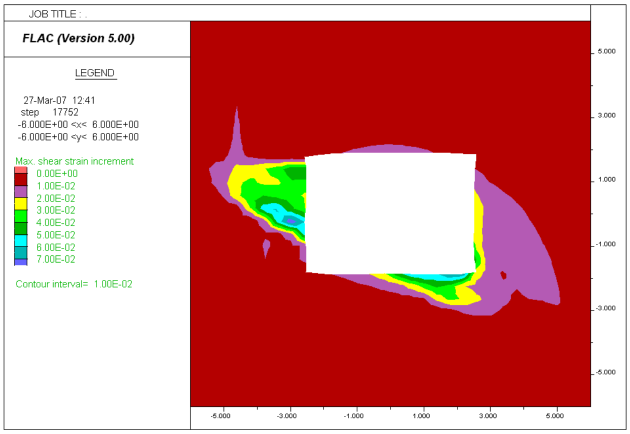

Fig. 8. Shear strain of the no support model

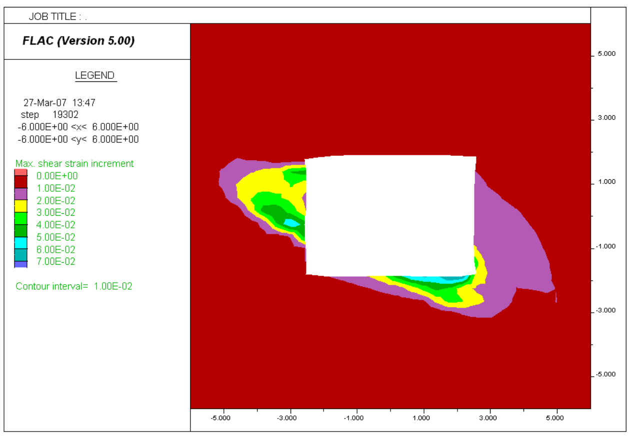

Fig. 9. Shear strain of the 7+6 model

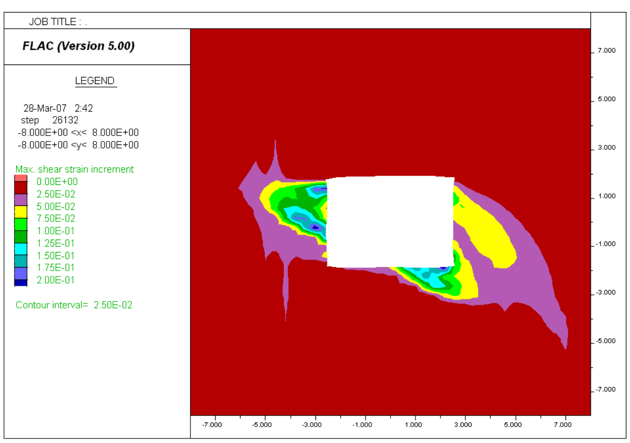

Fig. 10. Shear strain of the face retreat model

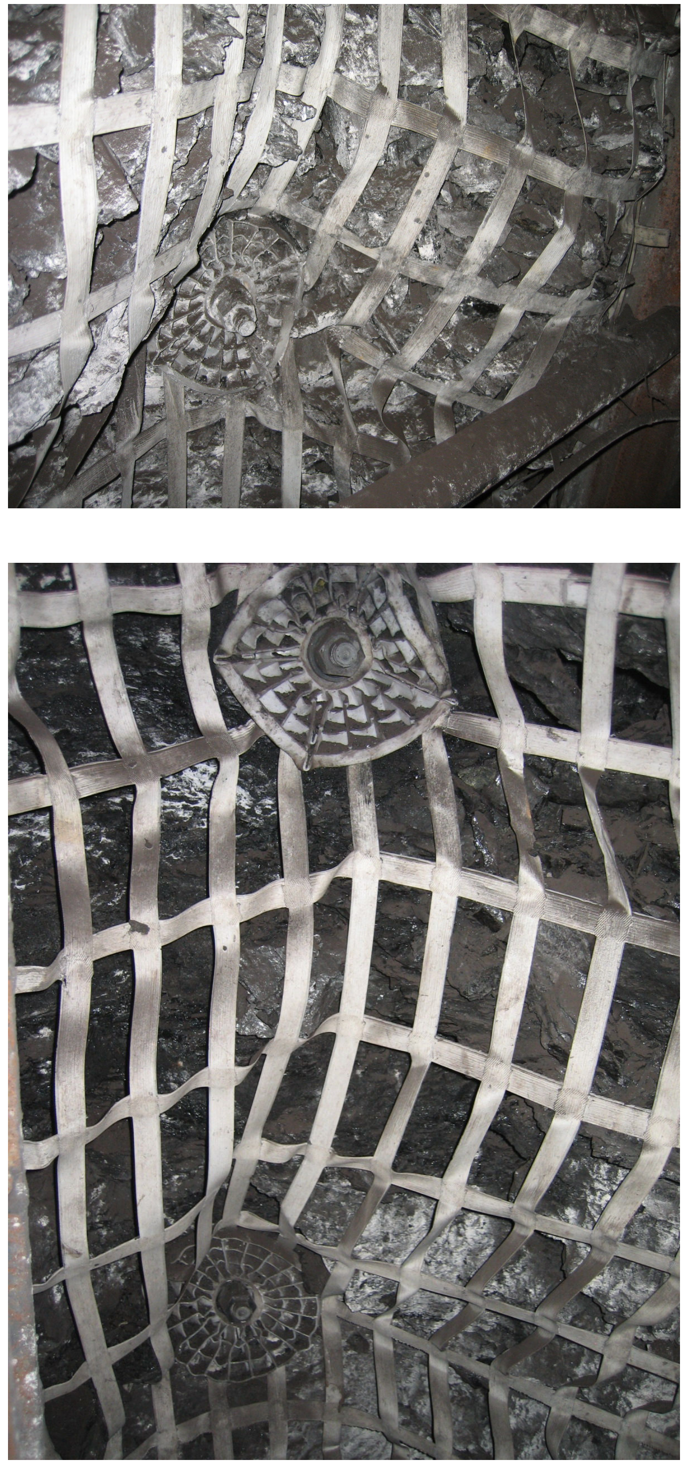

Fig. 11. Deformed plastic plates observed at left side rib of MG showing failed coal

CONCLUSION

On the basis of the information and results presented and discussed in the previous sections of this paper, the following statements can be made:

1. Models run showed that no significant problems will be occurred due to total closure of the gate during driving and retreat.
2. Good agreement of real monitoring results and the model reveal proper estimation of rock mass properties for modeling.
3. Floor heave of MG is independent of existence of reinforcement in ribs and roof and also face retreat.
4. The 7+6 roof bolt pattern acts well to reinforce the gate during driving.
5. More roof bolts will be needed to control roof movement during face retreat.
6. Left side rib will need more reinforcement during retreat. Resin injection is a good choice for that purpose.

At this time, the mine has finished the E1 MG while more than 1000 meter of the gate road is successfully supported by the new pattern (13 roof bolts and 7 side bolts) with roof movements of less than 16 mm. except in 25 m of the gate from MM of 960 to 985, in which telltales showed total movement of 30 and 31 mm due to out of date-resin usage.

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