SCALE MODEL STUDİES TO INVESTIGATE THE EFFECTS OF PACKS AND STRESS FIELD ON ROADWAY STABILITY

DOLGU SİSTEMİ VE GERİLMENİN MADEN TABAN YOLLARININ DURAYLIUĞINA ETKİSİNİN MODEL ÇALIŞMALARIYLA İNCELENMESİ

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ABSTRACT

This paper deals with the use of the scale model technique to investigate the effects of the packs and different stress field on the closure of mine tunnels and roadways. Closure characteristics can be seen from graphs of applied vertical stress versus percentage closure and cracks development from the photographs shown.

ÖZET

Bu bildiride maden taban yollarının de formasyonunda rolü olan dolgu sistemi ve gerilme etkisi model çalışmalarıyla incelenmektedir. Koni ^rjans karakteristikleri fotoğraflarda görülen çatlakların gelişiminden ve konverjans-gerilim grafiklerinden görülmektedir.

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1. INTRODUCTION

The efficiency ana economy of longwall mining operations depend largely upon the stability and degree of deformation of the gate roadways. The majority of underground roadways and tunnels in the UK are driven in Coal Measures strata. As a result of deep coal mining, strata control problems have increased, and consequently, more research was required to investigate the actual behaviour of the broken rocks around an excavation- Closure İn gate roadways has thus become one of the most important aspects of underground rock engineering. Such access roadways especially driven at great depths are virtually always supported by steel linings owing to the weak nature of Coal Measures rocks and the relatively high degree of closure experience.! J jring the entire life of the gate roadways.

Mining practices, particularly in the domain of strata mechanics, often give rise to many problems which cannot be explained by İn-situ field observations or by mathematical studies. The use of scale mode! techniques can provide a useful basis for the design engineer either İn the pre-planning stage of underground workings or İn the interpretation of phenomena during mining operations. The object of this paper was to investigate the effects of the following factors on the closure of gate roadways with the aid of a series of scale model tests: (a) pack width and composition; (b) roof and floor strengths; (c) roadway shape; and (d) ratio of applied pressure.

2. GENERAL CHARACTERISTICS OF GATE ROADWAY CLOSURE

Coal mining tunnels and roadways driven in weak rocks are normally subjected to high stress fields which often exceed the strength of the Coal Measures rocks. This results in rock failure taking pa l ce around such excavations. The percentage of closure is also increased due to the banded character of Coal Measures rocks. The working of deeper coal mines with increased loading has naturally resulted in deteriorating floor strain conditions, and worsening geological conditions, thus resulting in the need for stronger steel supports and appreciable modifications in packing systems.

2.1. Packing

The overall closure of the gate roadways isa result of a number of factors. Amongst those factors is the support complex which includes support system, packing method and rib pillar design which itself plays an important role. Compilation of roadway closure measurements together with pack convergence values in various collieries can give useful information on the performance of the support complex. Packs with high strength are always desired in order to allow the roof strata to bridge across the roadway. The role of goaf-side pack is of vital importance since it İs required to provide early and effective resistance to prevent further deterioration of roof strain. The pack width also plays an important role in terms of roadway stability.

2.2. Rock Strength

The strength of the strata above and below the coal seam is another contributing factor to the stability of the gate roadways. As far as UK coal mining conditions are concerned immediate roof and floor strata are generally fairly weak. Bearing this fact in mind different strength values were used for the scale model tests. Special attention must be given to the condition of soft floor material since they possess low shear resistance and tend to heave into excavations.

2 3. Roadway Shape

The most commonly used shapes for mine roadways and tunnels are of the rectangular, arch and circular cross-sections. A high narrow excavation has stability advantages in weakly laminated rock conditions in comparison to a low wide one. The use of a longer cross-section involves heavier sections of steel supports and hence incurs higher cost.

A rectangular profile offers ease of installation and allows the greatest rate of advance to be achieved. However, it has limited applications due to its inability to offer sufficient support in weak strata conditions, especially the roof; it cannot always give a tolerable degree of closure whilst retaining its support resistance to yield. Steel roof girders and props of rectangular roadways will deform dramatically under highly critical strata stress conditions.

Steel arches are regarded as the most popular type of support throughout European coalfields and have gained popularity due to the fact that they posses significant strength to provide support even after substantial deformation. In longwall advance mining the gate roadways in the UK are arch-shaped and normally supported by H-section rigid arches (1). Sudden or total failure of such roadways is extremely rare. Their proven reliability under a wide variety of conditions has given confidence in them to be employed for longwall gate roadways throughout the world.

Circular tunnels are chiefly supported by steel rings but concrete segments are being used in the main roadways to a limited extent. A steel-lined circular tunnel is superior to the arch profile in terms of its excellent lining yield capacity. A concrete-lined tunnel offers the highest strength, but it possesses poor lining yield capacity. Effective backfilling between rock and lining, and fairly uniform distribution of strata loading are required for a stable circular tunnel with concrete segments. Research into the predicted and measured closures of circular tunnels in UK coal mines is being carried out (2).

2.4. Stress Field

A further important factor mentioned in the following sections is the influence of the ratio of principal stresses on the closure of mine tunnels. In-situ measurement of virgin stress is not an easy task- There are several commercially available instruments to carry out stress measurements in underground coal mines (3).

3. EXPERIMENTAL PROCEDURE

All the preliminary studies and scale model tests have been conducted in the laboratories of the Department of Mining Engineering at the University of Nottingham. The biaxial model test rig used in all the experiments possesses 16 rams and 4 loading plates.

The model strata were represented by varying proportions of sand, plaster and water. The determination of scale factors for the model is given in Appendix A. The sand-plaster slabs were dried at 150°C in order to minimize the moisture content.

Two series of tests were conducted throughout the investigations: (i) The influence of packs; and (ii) the effects of the ratio of vertical stress to horizontal stress on the closure of gate roadways. The geometry of the models is discussed in the fol lowing sections

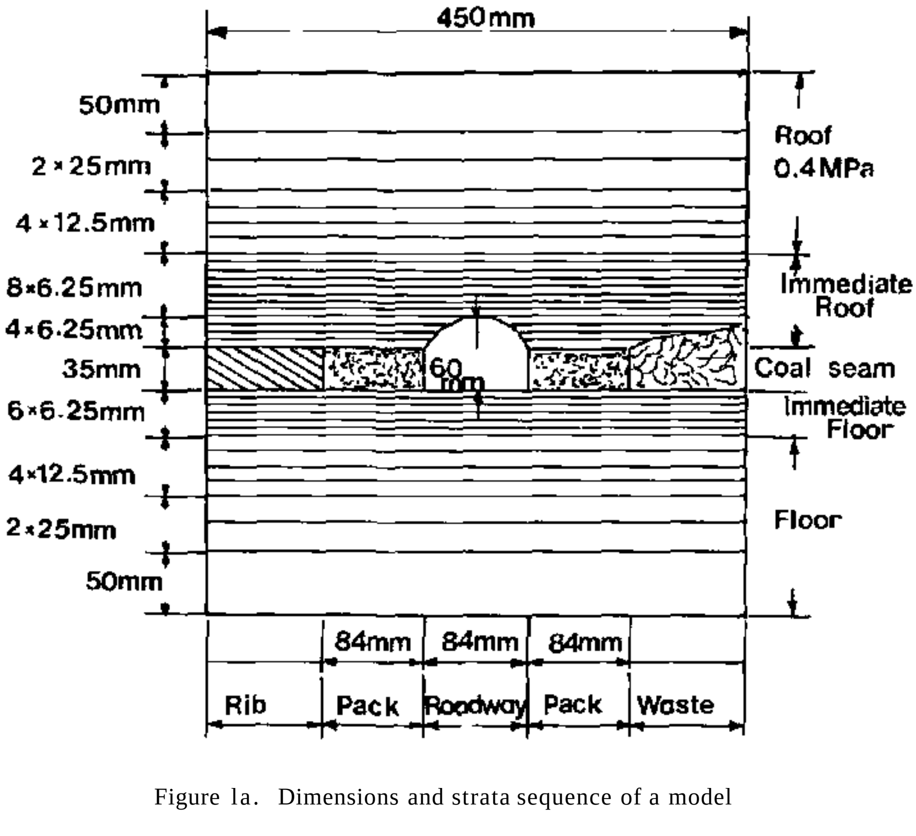

Figure la. Dimensions and strata sequence of a model

4. EFFECTS OF PACKS ON GATE ROADWAY CLOSURE

The series consisted of models of a rectangular or an arch-shaped roadway with various combinations of packs. The dimensions and strata sequence of a typical model are shown in Figure 1 Table 1 shows the details of eight scale model tests selected for comparisons.

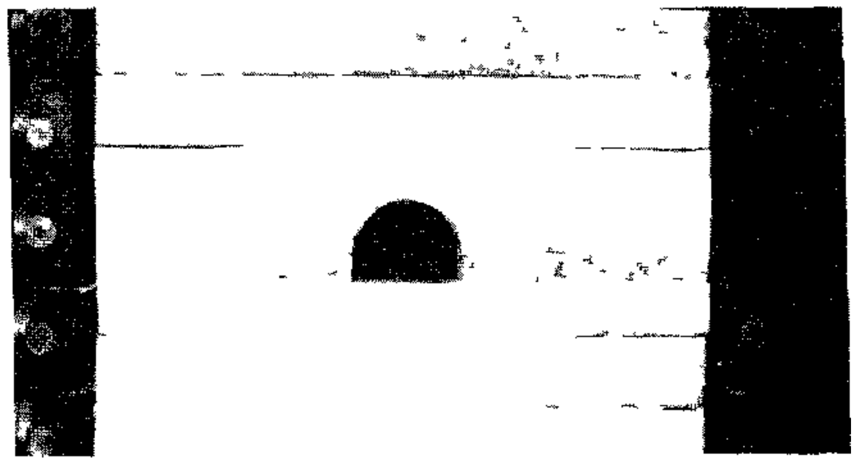

Figure 1b. Photograph of the model 7 before test.

4.1. Closure Measurements of Rectangular Roadways with Packs

Four model tests were selected in order to make comparisons. Goaf-side packs normally consisted of two 12 to 15 mm pack walls. The ratio of the applied pressures was selected to be hydrostatic for this series of tests. The roadways were not protected by any kind of support. The results of closure measurements are illustrated İn Figure 2.

4.1.1. Roadways

Model No 1 has the least amount of closure due to the use of a wider goaf-side pack. In Model No. 2 the immediate roof and floor layers were badly fractured and caused the closure to reach up to 47 %. A dummy roadway was used between the goaf-side pack and the goaf. In Model No- 3 weak floor strata resulted İn tensile cracks in the immediate roof and floor strata. The roof bowed dramatically and excessive floor heave occurred. Excessive spalling of the roadway walls took place. In Model No. 4 the weak roof strength caused considerable roof lowering and tensile cracks in the roof.

4.1.2. Packs

All the packs showed little resistance against applied pressure, consequently high pack closures were observed. Closures of goaf-side packs were significantly higher

Table 1 - Details of the Eight Scale Model Tests for the First Series of Investigations.

	No. 1	No 2	No. 3	No. *A*	No. 5	No. 6	No. 7	No. 8
Roadway shape	Rectangular	Rectangular	Rectangular	Rectangular	Arch	Arch	Arch	Arch
Roadway Size (ram)	65 x 40	65 x 40	65 x 40	6 5 x «	84 x 60	S4 x 60	61 » M	64 x 60
Ratio of vertical stress to horizontal stress	1	1	1	1	1	1	2	?
Strength of roof strata (MPa)	n.4	o.a	*O.A*	0 25 (weak roof)	0.25 (weak roof)	0 25 (weak roof)	0.25 (weak roof)	0.1B (Very weak roof)
Strength of floor (MPa)	0.4	0.4	0.35 (weak floor)	0.4	o.ia (very weak floor)	0.25	0 40	0.25 (weak floor)
Strength of Coal Seam (MPa)	0.4	*O.Pb*	0 *i*	0.25	0.4	0.25	0.25	0.25
Pack Construction	Granular material. Not filled up to roof level	Granular material Not filled up to roof level	Granu]ar material 2. 5 ram in dia. Loose pack	Granular material 2 5 im in dia Loose pack	Low strength granular material	Hvgh strength Solid pack	Hvgh strength Solid pack	High strength Solid pack
Width of goaf-side "pack fmm)	105	65	65	65	84	84	65	6b
gp rwy	1.5	1	1	1	1	1	0.3	0.8
Width of rib-side pack (mm)	Not used	Not used	65	65	8Ü	Not used	65	62
rp rwy	'	-	I	1	1	-	0.8	0.8
Ultimate vertical Closure (Roadway1 %	38	47	40	45	40	40	31	29
Ultimate horizontal Closure (Roadway) *	9	11	14	12	13	17	8	7
Ultimate closure Hib-side pack *	—	-	29	28	30	-	13	a
Ultimate closure Goaf-side pack %	35	30	32	39		29	20	21
Renarks	Excessive closure	Excessive closure	Excessive closure	Excessive closure	Excessive goaf-Bide pack closure	Severe floor heave	Decrease in floor heave	Roof lowering dominant

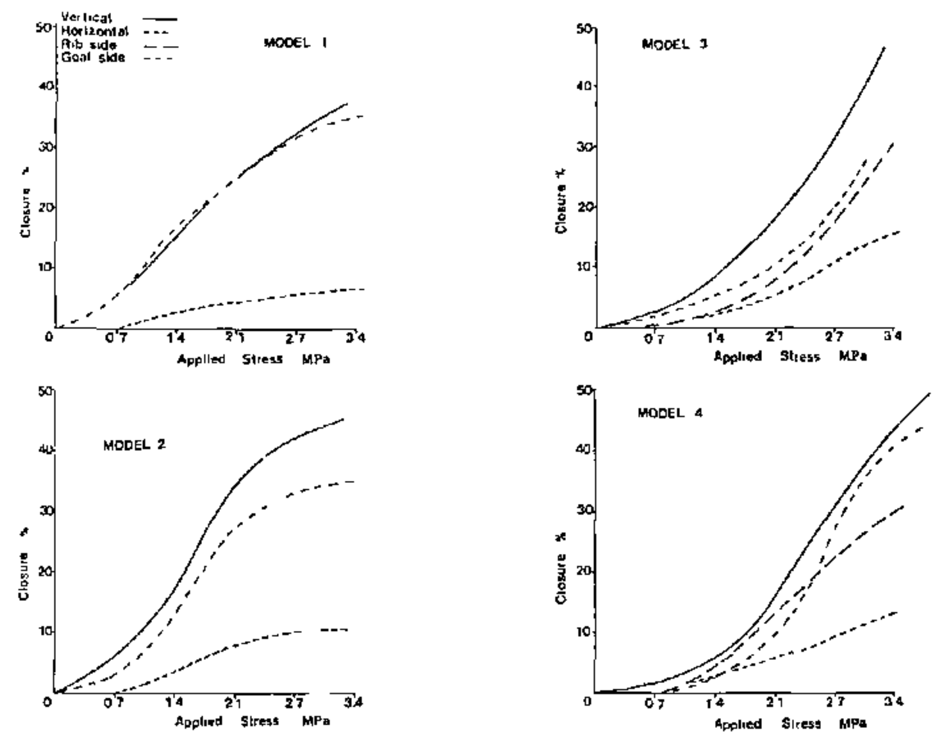

Figure 2. Roadway and pack closures versus applied stress for rectangular profile (hydrostatic stress field).

than those of the rib-side packs. Such high closures can be contributed to the nature of loose packing material.

Generally, at the later stage of loading the vertical closure predominated and side slabbing increased dramatically. Loose pack material resulted in excessive closure, therefore, stronger pack systems were used for the following four model tests.

42. Closure Measurements of Arch-Shaped Roadways with Packs

Preparation of model materials and model configurations were modified. A predominantly vertical stress field ($a_v = 2 a_n$) was also used for Model Nos. 7 and 8 to compare the results with Model Nos. 5 and 6 tested under hydrostatic compression. Figure 3 shows the closure and applied pressure curves for the four models.

Referring to test 6, the absence of the rib-side pack resulted in severe floor lift. Roadway side closure was the highest among all the tests carried out (see Figure 4, photograph (b)). In Model No. S excessive closure of the goaf-side pack was observed due to very weak floor strata (Figure 4, photograph (a)).

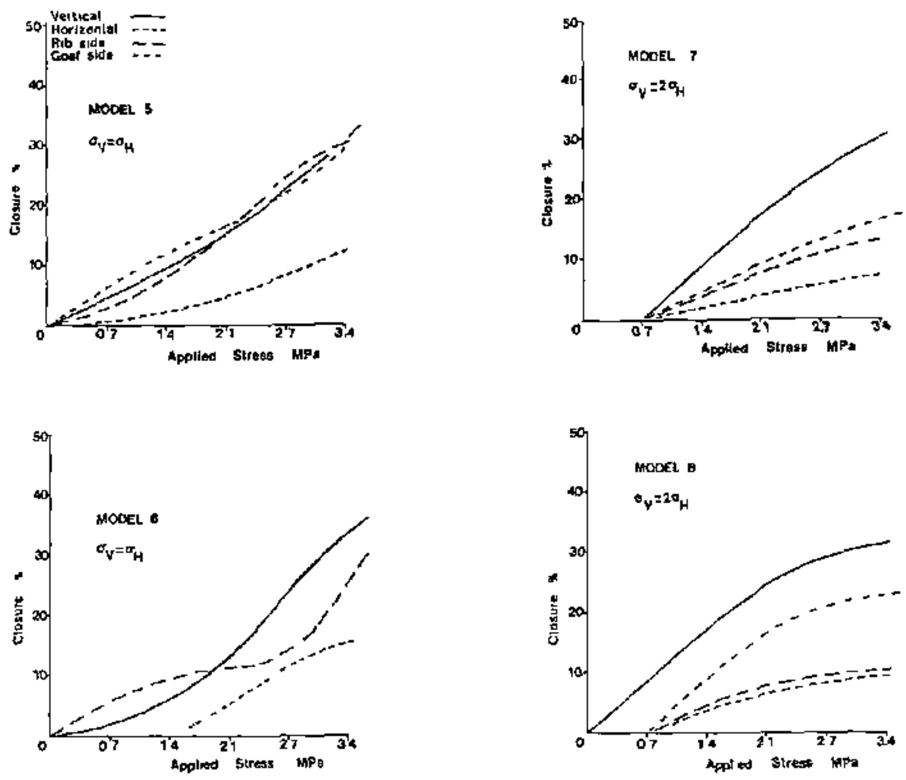

Figure 3. Roadway and pack closures versus applied stress for arch profile.

The application of a predominantly vertical stress ($a_v = 2cr_n$) for tests 7 and 8 caused the roof to bow; roof lowering was significant (Figure 4, photographs (c) and (d)). In test 7 bed separation in the floor was observed due to the weak floor layers. During the tests of Model Nos. 7 and 8 roof lowering was predominant and little floor heave was experienced. For the tests 7 and 8 the *use* of solid packs with high strength material (0.4 MPa) caused the packs to respond to the pressure at an earlier stage of loading, hence both roadway and pack closures were less than those of the previous tests.

Considering all the eight tests collectively it was observed that pack compaction could significantly change the degree of closure in both hydrostatic and predominantly vertical stress conditions. Providing an effective and well constructed pack material is used and pack widths between one or two times the extraction height employed then these should be adequate to minimize pack closure. This investigation showed that the absence of a rîb-sïde pack or the existence of a very weak floor and/or roof strata could cause severe closure even under hydrostatic stress conditions (Test 5 and 6).

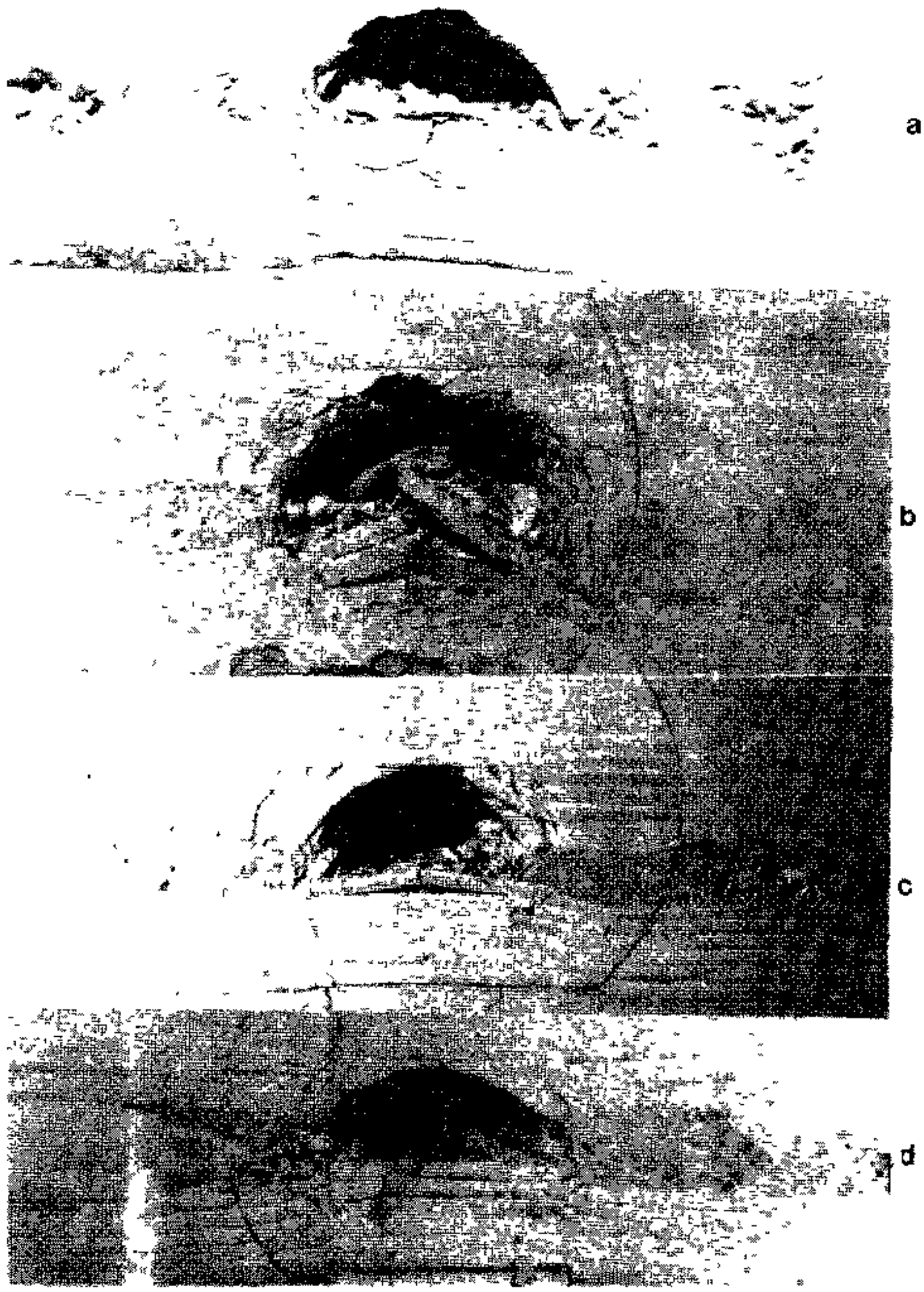

Figure 4. Photographs of arch-shaped models after the completion of tests (no 5 to 8)

5. ARCH AND CIRCULAR ROADWAY PROFILES UNDER DIFFERENT STRESS FIELDS

A programme of investigation has been conducted in order to compare the closures and fractures around the arch and circular-shaped tunnels. The stratified sequence of rocks employed in this series of tests is given in Appendix B. The main results are shown in Figure 5. Photographs of some of these model tests are given in Figure 6 in order to demonstrate the occurrence of floor lift, and side spalling.

The results given in Figure 5 and 6 indicate the degree of tunnel closure in relation to the vertical stress *(o_V)* applied to the model. The details of the scale factors are similar to those given in Appendix A. The following conclusions can be drawn from these results:

— The uniaxial (a⌊⌋ = 0) condition resulted in appreciable side spalling,particularly in the case of the arch-shaped tunnel. Both the circular and arch-shaped tests indicated significant closure changes after 2 M Pa, although up to this point closure had been of a fairly gradual nature. The horizontal closure of the circular profile was significantly less than that of the arch profile.

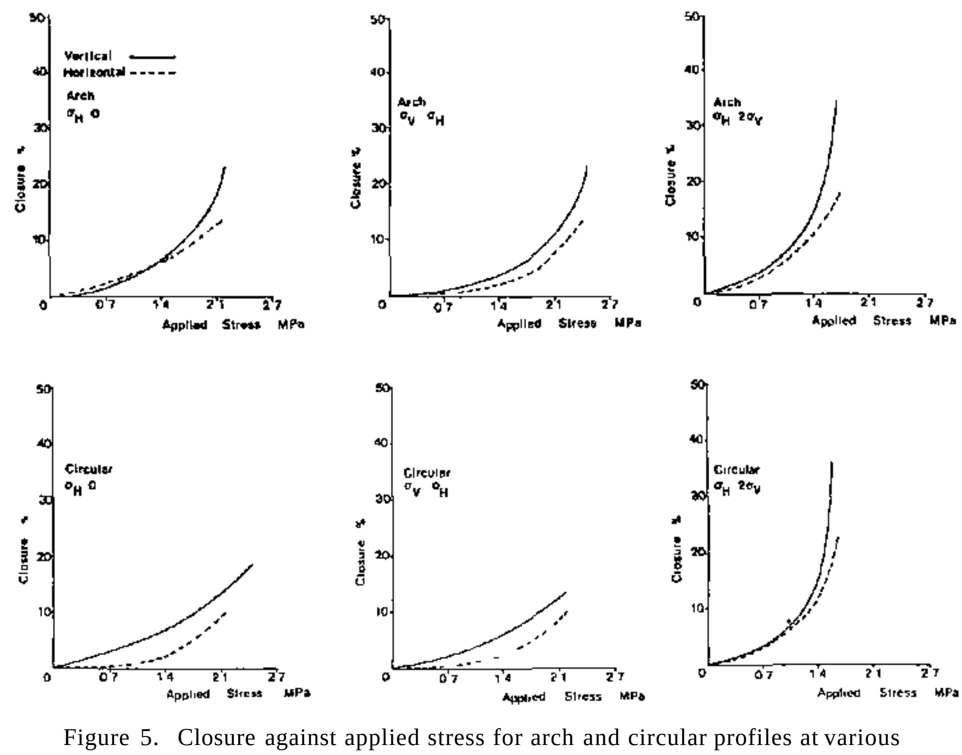

Figure 5. Closure against applied stress for arch and circular profiles at various stress fields.

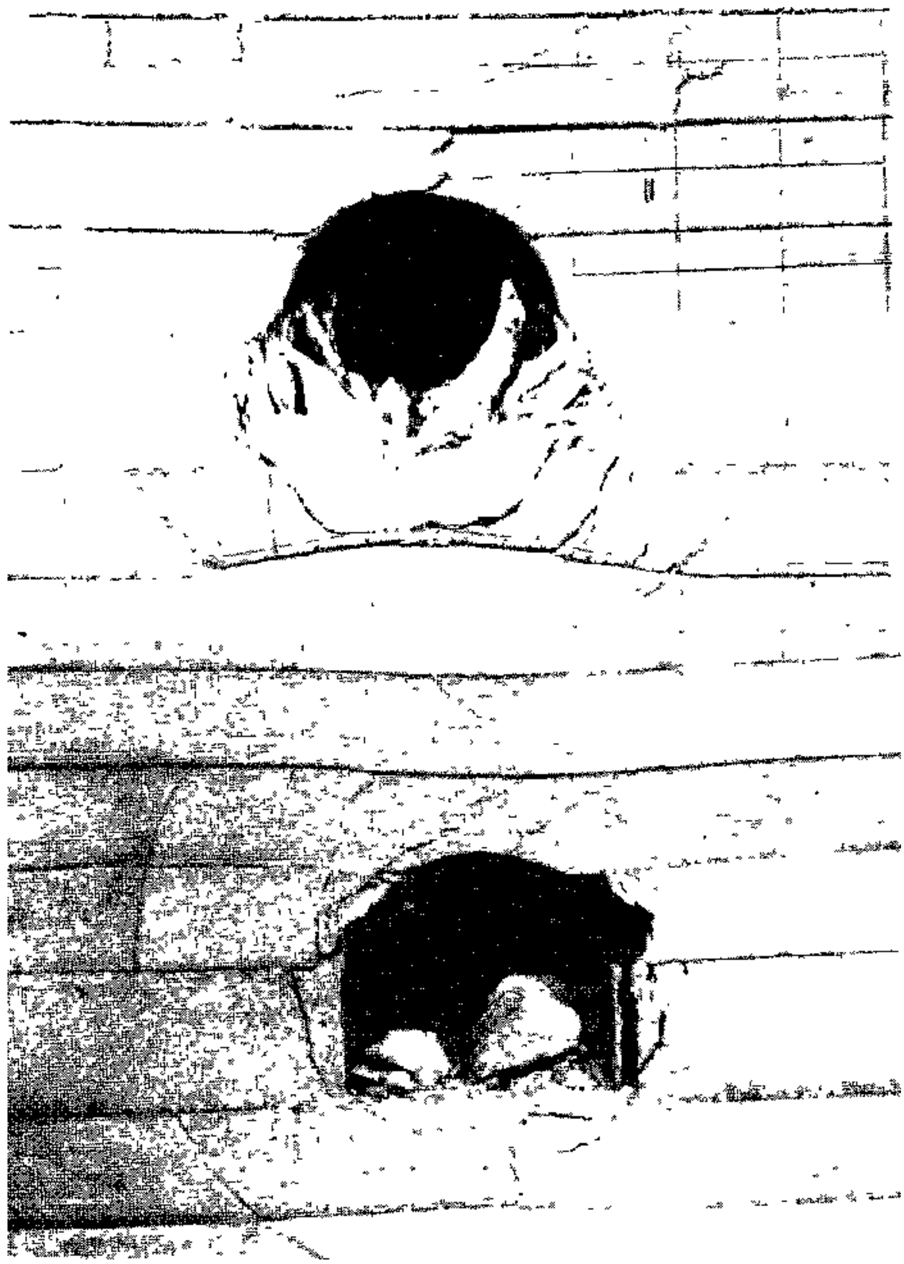

Figure 6. Models after testing : a) Circular profile (ff_v = ff_h);b) Arch profile (O_v = O_h)

— The hydrostatic stress field provided better stability by comparison to the uniaxial stress case for both the arch and circular profiles, this being particularly the case at the onset of the loading. Stability of the circular profile was apparently superior to that of the arch.

— The predominantly horizontal stress condition indicated a sudden change in stability after 1 MPa. It appeared that such a sudden change in closure was due to the stratified nature of the model material. Once marked failure had been initiated, it appeared that closure progressed at an acce la rating rate.

6. CONCLUSIONS

The first series of experiments demonstrated that the influence of pack compaction and strength is of vital importance in relation to the closure of gate roadways. Rectangular profiles can result in serious support and stability problems, therefore the detailed design of a rock reinforcement method such as rock bolting should be made with the aid of the excavation fracture patterns. The influence of the different stress field on the stability of arch-shaped and circular tunnels indicates that although they are more stable compared to the rectangular profile the onset of the first major failure can result in excessive closure. This emphasises that, apart from a well-designed packing system, the early installation of the support system is essential to prevent or control the onset of the major fractures around mine tunnels and roadways.

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APPENDIX A

(a) The biaxial test rig:
Model dimensions: 450 x 450 x 75 mm

(b) Model material :
(i) Sand 55 % Plaster 20 %, water 25 % by weight
(Ü) Sand 57.5 %, Plaster 17.5 %, water 25 % by weight.

(c) -Model material density : 1383 kg/m^3 and corresponded to full-scale rock of 2500 kg/m^3.
Thus, the density scale factor = 1383/2500 = 0.553

(d) Geometrical scale = 1/60

(e) The strength factor is thus given by : 0.553x1/60 = 1/108

Strength parameter	Model	Full-scale equivalent
UCS (MPa)	0.4	43
UCS (MPa)	0.25	27
E (MPa)	45	4860

(f) (1) Model rectangular roadway :
Dimensions : width = 65 mm; height = 40 mm
Such an opening corresponds to 3.9 x 2.4 m

(2) Model arch-shaped roadway:
Dimensions: (i) width =84 mm; height = 60 mm
giving full-scale equivalent dimensions of 5.0 x 3.6 m

APPENDIX B

The stratified sequence of the model material for the second series (stress field influence on tunnel stability) of tests is given as follows:

Stratum thickness (mm)		
37.5	37.5	Floor of tunnel
50	25	
50	50	
25	50	
25	50	
25		