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RESEARCH ON THE COAL BENEATH THE NETHERLANDS

III CONVENTIONAL DEEP MINING RESEARCH

ROCK SUPPORT BY A DESTRESSED RING OF ROCK AROUND A GALLERY UNDER SEVERE STRESS[1].

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ABSTRACT

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A short review is given of a research project carried out at the Rock Mechanics Laboratory in Delft.

The aim of the project is to control the fracturing process of rock surrounding underground galleries under severe stress conditions. Model experiments indicate that a considerable decrease of convergence of galleries will occur if a circular zone of rock with a certain width around the gallery is artificially weakened and destressed. An underground field test confirmed that a destressed tubular rockmass around the excavation could support serious stress deviations of the surrounding bedrock, so that the gallery remained practically undamaged. It is expected that procedures following the lines of the described tests will improve the economy and the extent of deep coal mining.

INTRODUCTION

At great depths the sidewalls, roof and floor of tunnels, galleries or other underground excavations tend to move into the excavated space. This phenomenon is known as 'convergence'. In collieries the competent rocks have a predominantly brittle character and convergence occurs in accordance with their cataclastic-plasto-elastic behaviour.

When driving a tunnel tangential stresses will concentrate at the periphery of the excavation, where they will cause primary cracks and fractures in the rock material attended by a small increase in volume. In a later stage secondary fracturing will occur, while also material further away from the tunnel wall will become affected. The strength of the rock mass gradually decreases so that the rock tends to fail. At the same time the volume of the now broken rock mass increases significantly and movements, such as sliding of slabs and blocks, take place. The shape of the tunnel or gallery is seriously affected and the situation becomes unstable.

To prevent this to happen and to maintain the shape of the excavation the roof and the side walls of the tunnel have to be supported. In coal mining steel arches or concrete blocks are used for applying a limited counter-pressure to the broken rock. This counter-pressure, together with the friction within the broken material, generally provides, at depths which are not too great, sufficient equilibrium in the surrounding rock mass as a whole. This equilibrium, however, is in many cases only temporary and can be disturbed by fluctuations in rock pressure as a consequence of tectonic movements or as a result of other mining activities. Figure 1 shows the deformation of a tunnel brought about by nearby coal extraction.

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Fig. 1
Considerable horizontal and vertical convergence of a gallery as a result of the exploitation of a nearby coal seam.

A DESTRESSED SUPPORTING ZONE AROUND AN EXCAVATION

The support by means of steel arches becomes insufficient with increasing depth. Despite its application instability and deformation of tunnels occur increasingly, entailing expensive remedial work and thus limiting the depth of economic mining activities. In order to make coal mining at greater depth feasible, a scheme has been worked out in the Rock Mechanics Laboratory at Delft, whereby the stress, normally concentrated close to the edge of the excavation, is spread over a much broader zone around the tunnel so that the rock mass remains everywhere within the limits of cataclastic stability (ROEST & GRAMBERG, 1981a). This has been achieved by inducing a primary deformation in a large volume of rock around the tunnel.

This primary deformation is brought about by slots or rows of boreholes drilled for a certain distance from the wall of the gallery into the surrounding bedrock. They weaken the rock mass, accommodate the limited amount of convergence, and cause a redistribution of the stress within a tubular zone of rock around the tunnel. The stresses in this largely destressed zone can be kept low enough so that the rock mass remains within the limits of cataclastic stability and thus local overloading and secondary fracturing, with its attendant unfavourable or disastrous consequences, is prevented. The excavation is protected against further convergence by the support of the surrounding destressed rocks, which now carry the general rock pressure.

The operations described will be effective in principle when homogeneous conditions prevail in the bedrock, which is never the case in the Carboniferous formations of Western Europe. Here additional support by rock bolts is still needed to prevent roof falls of loose slabs of the often thinbedded formations.

The principle of the destressed supporting zone of rock seems independent of the depth as long as one is dealing with undisturbed solid rock material.

MODEL TESTS

The principle of destressing was tested in the laboratory at Delft (ROEST & GRAMBERG, 1981b). Tests were carried out on models at a scale of 1:100. Five identical slabs measuring 300 × 300 × 24 mm, consisting of rather weak concrete mortar without gravel, were provided with a central hole 36 mm in diameter, representing a tunnel. Two slabs were fitted with slots emanating from the tunnel and filled with wood; the third slab had slots, half as deep, which served as a transition to the last pair of slabs without slots. The five slabs were combined in a single block which was loaded in three axial directions simultaneously. The effect of the simultaneous loading on each slab was thus perfectly comparable. The tunnels with a destressed zone showed much less convergence than those without slots (compare figures 2 and 3).

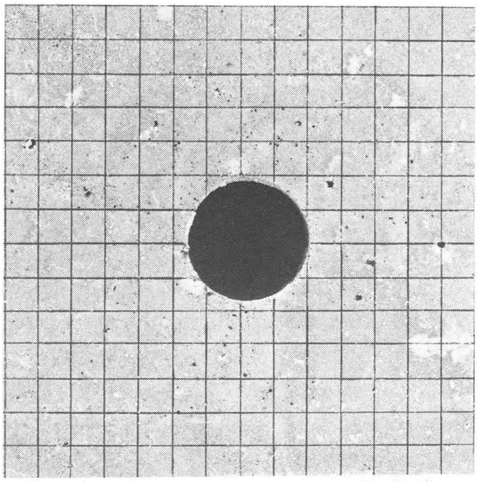
Further tests were carried out at the Forschungsstelle für Grubenausbau und Gebirgsmechanik (FGG) in Essen (Fed. Rep. of Germany) on a scale 1 : 10 (OLDENGOTT ET AL., 1981). In these models the excavation had the shape of a real underground roadway complete with metal supports. The stratified nature and the compressive strength of the Carboniferous strata were also imitated on a scale 1 : 10 (Fig. 4a).

The conventional model without destressing showed already considerable damage at simulated depths of 1000 m and 1200 m (Fig. 4b and 4c). Floor heave and the secondary fracturing of the sidewalls were clearly demonstrated. The convergence expressed as a percentage of the original height of the gallery was about 42 per cent at a simulated depth of 1200 m (Fig. 6). Four slots, two vertical and two horizontal, were introduced into the roadway of an identical model. They were filled with polyurethane, a product generally used in mining. Its pressure-yield characteristics seemed perfect for the purpose. In addition roof, side walls, and floor were secured by model rock bolts in order to eliminate the effect of the anisotropy of the formation (Fig. 5a). After having been subjected to increasing pressures it appeared that this model remained undamaged at simulated depths of 1400 m to 1450 m (Figs. 5b, 5c, and 5d). It appeared that at a depth of 1600 m the convergence in the vertical sense remained below 13 per cent (Fig. 6). The extra rock bolts contributed also to the favourable behaviour of the strata around the model gallery.

The test indicated that it should be possible to maintain a gallery practically undamaged at a depth of 1500 – 1600 m in usually well-bedded Carboniferous formations of Western Europe.

UNDERGROUND FIELD TEST

During 1980 a field test was carried out underground in the coal mine Sophia Jacoba at Hückelhoven in Germany close to the Dutch border. In an ordinary deep gallery the stress will under normal conditions remain constant for a long time, so that it would be impossible to expect results from a test



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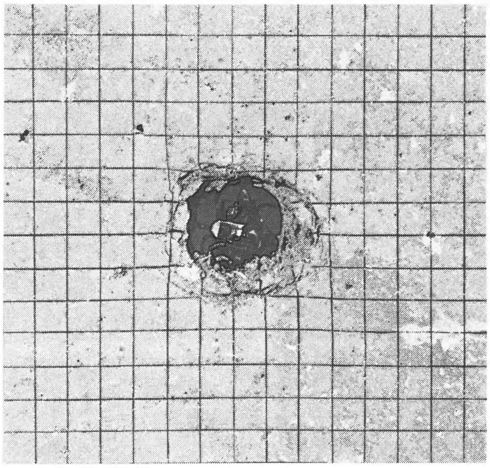

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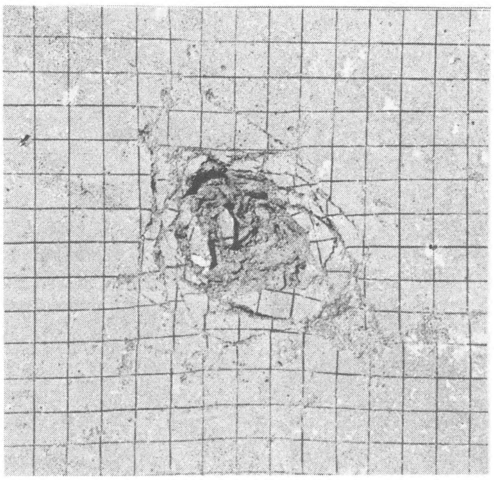

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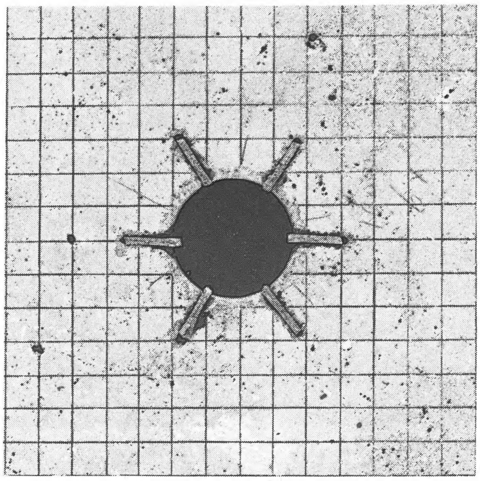
Fig. 2 (top a to bottom c)
Experiments carried out in Delft on an un-destressed model with a tunnel, scale 1 : 100.
a) unloaded.
b) after triaxial compression up to 2.38 MN the walls of the tunnel show considerable slabbing.
c) after triaxial compression up to 2.45 MN the walls of the excavation have collapsed completely. The excavation has closed.



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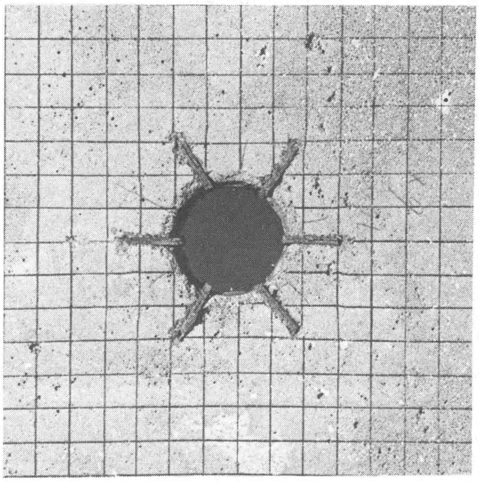

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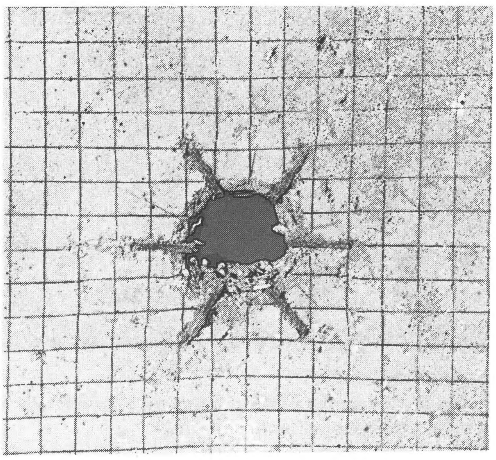

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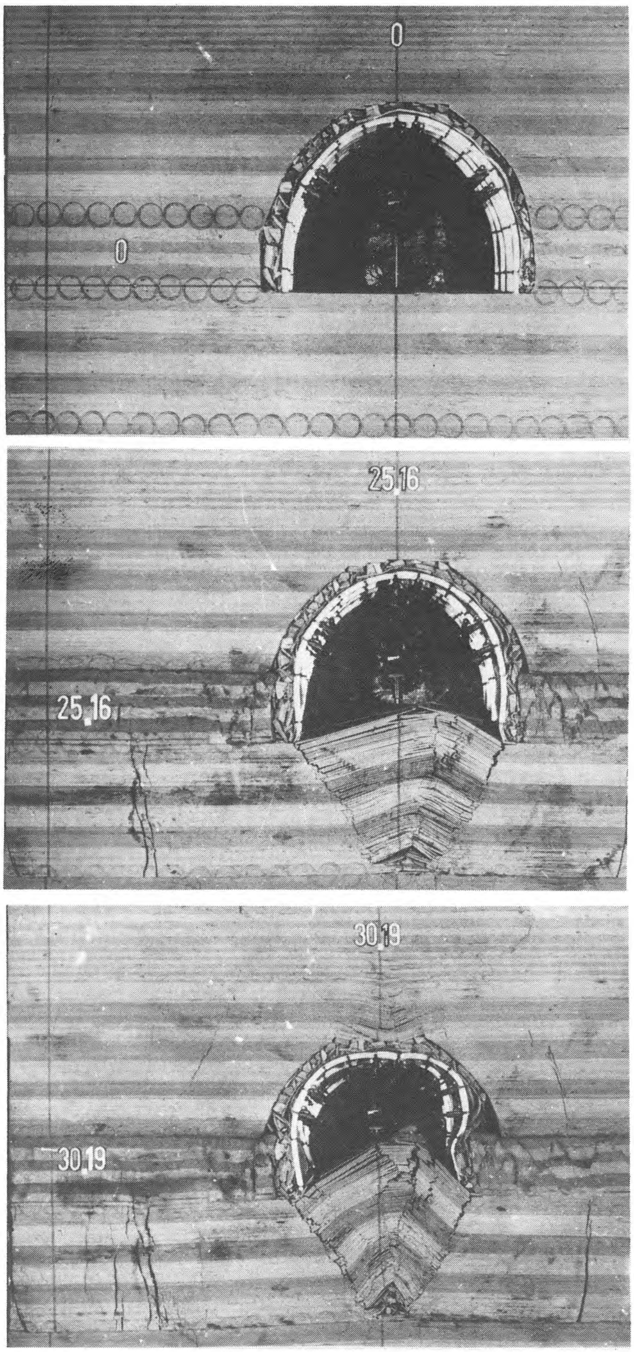
Fig. 3 (top a to bottom c)
Experiments carried out in Delft on a similar model as in figure 2, but destressed with six slots.
a) unloaded.
b) after triaxial compression up to 2.38 MN the tunnel is still undamaged.
c) after triaxial compression up to 2.45 MN the tunnel is still open in a stable way.



a
b
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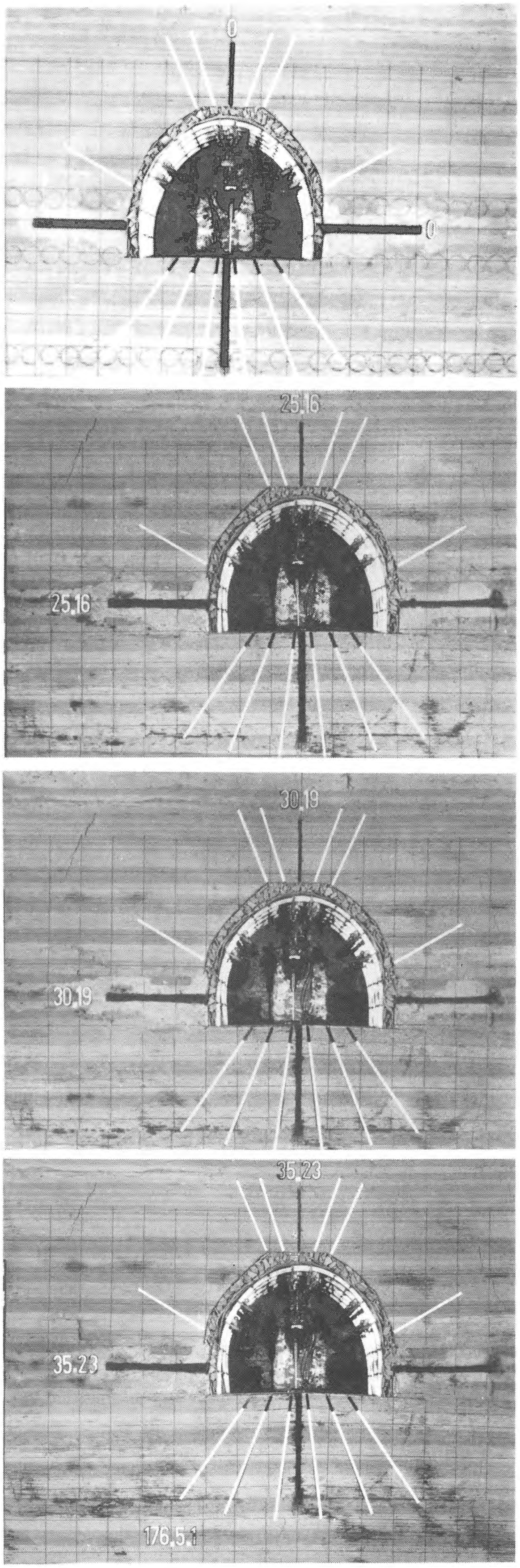
Fig. 4 (top a to bottom c)
Experiments carried out by FGG in Essen on a model scale 1 : 10 of a roadway with conventional arch support.
a) unloaded, corresponding depth 0 m.
b) loaded, corresponding depth 1000 m; floor heave.
c) loaded, corresponding depth 1200 m; severe damage, situation unstable.

Fig. 5 (top a to bottom d; adjacent column→)
Experiments carried out by FGG in Essen on a model as in figure 4, but destressed with four yielding slots (black) and with rock bolts (white). (design Roest)
a) unloaded, depth 0 m.
b) loaded, depth 1000 m.
c) loaded, depth 1200 m, stable situation, no damage.
d) loaded, depth 1400 m, still stable situation and no damage.



a
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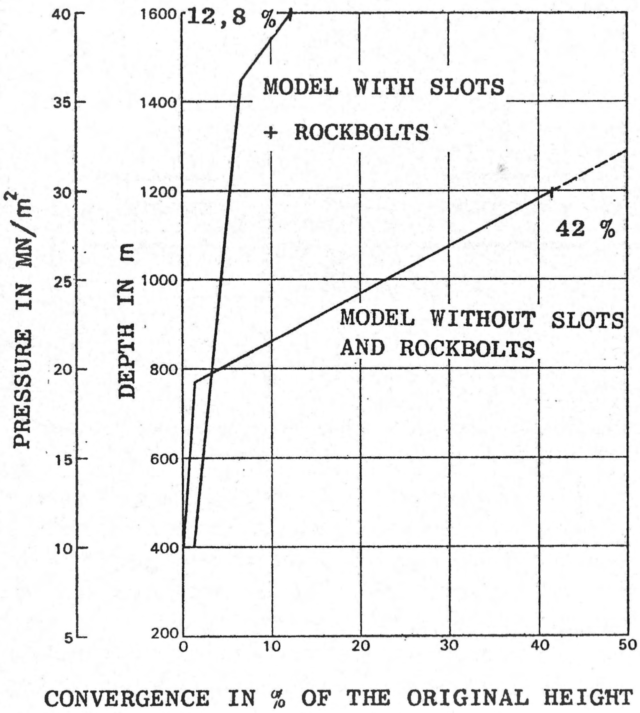

Fig. 6
Relation of pressure to vertical convergence in two different models of a gallery both with conventional arch supports. One model with extra slots + rock bolts (Oldengott et al., 1981).

involving a destressed self-supporting zone of rock within a relatively limited period. Therefore a test was carried out in a gallery where a change in the pressure could be foreseen as the consequence of the passage of an active coal face some 50 meters below it. During the passage the strata of the bedrock near the gallery would be subject to a considerable so-called S-shaped movement. This movement is accompanied by a temporary pressure increase which causes in principle an intensified fracturing and a further volume increase of the rock around the gallery. This may be expected to result in a considerable convergence.

The test was carried out in a 100 m long section of a gallery with a roughly half circular cross section in which the necessary measuring apparatus had been installed. A 50 m length of tunnel was left as it was, while the rock of the remaining 50 m was destressed in four zones of the gallery. The existing support system of the gallery consisted of steel arches not more than 80 cm apart. It was thus impossible to make continuous slots. Rows of parallel boreholes with a diameter of 148 mm, three between two arches, were drilled instead. The pattern of the perforations was adapted to the direction of the expected vertical stress wave. Two such zones were directed upwards with a 50° inclination, the holes 2.5 m deep, while two lower zones were directed downwards with a 4° inclination, with holes 3 m deep. The rock left intact between the boreholes covered 45-50 per cent of the entire length of the perforated zone (Fig. 7). Rock bolts were not used.

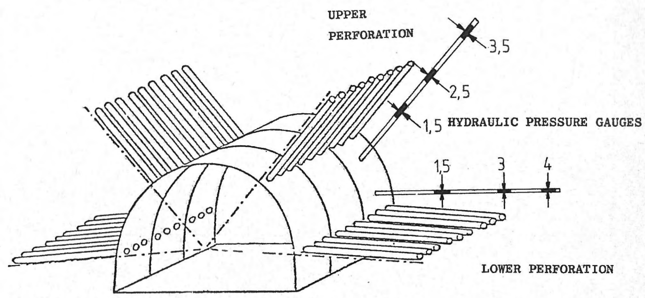

Fig. 7
Location of four perforated zones and six pressure gauges in the destressed part of the underground fieldtest in the Sophia Jacoba mine.

Finite element calculations were made by the FGG to indicate and check the stress behaviour foreseen during the passage of the coal face.

RESULTS OF THE UNDERGROUND TEST

The tangential component of the rock pressure at different distances from the sidewall was measured continuously during the passage of the face, as indicated in figure 7.

The results shown in figures 8 and 9 are limited for the sake of simplicity to two situations, namely a distance from coal face to gallery of 308 m and of 53 m. In the non-destressed part of the gallery a pressure peak occurs – as expected – near the wall of the excavation (Fig. 8). In the destressed area the pressure peaks shifted away from the gallery wall and were located near the point of deepest penetration of the boreholes, i.e. 2.5 m for the upper perforations and 3 m for the lower ones. The hydraulic pressure gauges used were not designed to give absolute values but gave relative pressure differences only. These gauges broke in the non-destressed part of the gallery much sooner than in the destressed part, most probably due to uncontrolled shearing deformation, which obviously occurred at an earlier stage and to a greater extent than under destressed conditions. Also the vertical and horizontal convergences were smaller in the destressed area

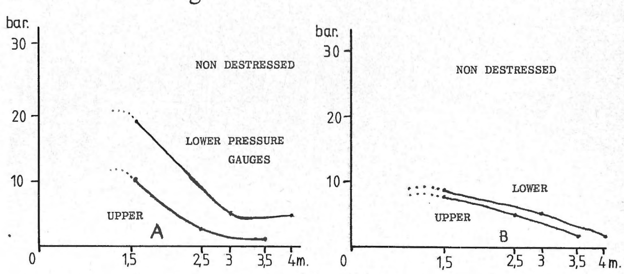

Fig. 8
Underground field test at Sophia Jacoba mine; pressure measurements in un-destressed section of roadway.
a) distance to coal face 308 m.
b) distance to coal face 53 m.

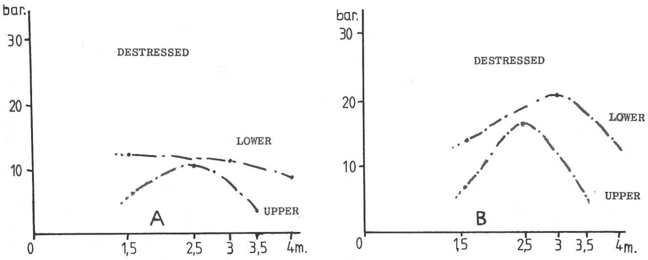

Fig. 9
Underground field test at Sophia Jacoba mine; pressure measurements in destressed section of roadway.
a) distance to coal face 308 m.
b) distance to coal face 53 m.

(Roest, 1982). The rock pressures registered in the lower row of perforations were systematically higher than those measured in the higher row, as expected.

It is clear from the above that as a consequence of the rows of perforations a circular zone of diminished controlled stress has been created around the excavation. This circular zone apparently supports the stresses that occur in the rock without failing so that the shape of the gallery is hardly affected by the passage of a coal face nearby (Fig. 10).

FUTURE ACTIVITIES

Research on the destressed rock zone by the Rock Mechanics Laboratory in Delft, working in close collaboration with FGG, is continuing. The FGG in Essen is experimenting with destressing to prevent floor heave whereby perforations are being limited to one row in the floor only. Plans are being made to follow up the present results by the development of a destressed half circular lower zone of a gallery with three slots, in combination with a rock arch reinforced with rock bolts (Fig. 11). A model test is planned by FGG in the near future. Finite element analyses are required before an underground test can be undertaken.

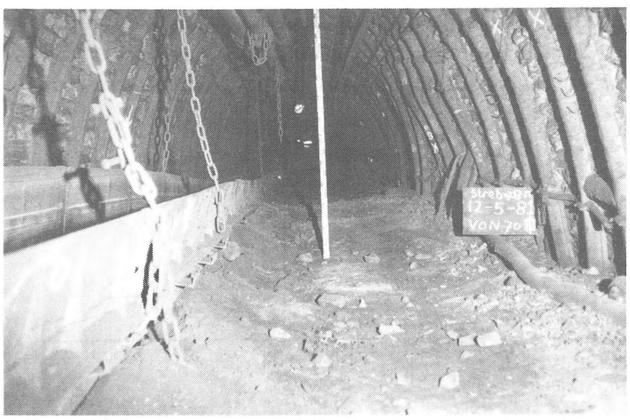

Fig. 10
Destressed part of the gallery at Sophia Jacoba mine after the passage of the coal face, located 78 m distant.

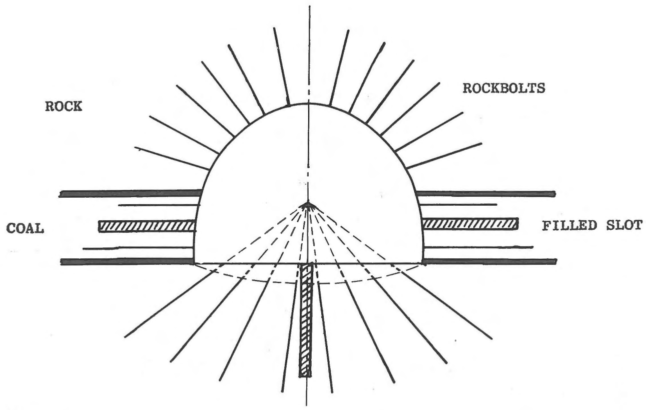

Fig. 11
Proposed support system for a gallery with a lower zone destressed by three slots, combined with an upper reinforced rock arch.

The Delft Laboratory hopes to continue basic research on the behaviour of rock and perforated zones to arrive at a quantitative theory regarding the supporting capacity of destressed circular zones of rock. It is expected that the application of this procedure will prove economic for transport galleries under severe stress conditions. It may well be applied in the first place to transport- and ventilation galleries in the coal seam. Several firms are already engaged in developing a machine for cutting continuous slots and looking for cheap filling material with the required characteristics.

ACKNOWLEDGMENTS

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