6. EFFECT OF STRUTTING ON SUPPORT STRENGTH

The H—section steel girder, from which almost all UK mine roadway supports are manufactured, has a strength radio beween the X and Y planes of around 3 to 1 respectively. Therefore any H—section support is usualy inherently weak in the Y plane or out-of-plane direction. The introduction of effective strutting significantly increases the out of plane support stability. With weak strutting the supports tend to fail by buckling out-of-plane at loads substantially below their maximum potential strength, (2).

Struts also serve as spacers between each support setting but their role as promoting the structural stability of steel arches is of great importance. The struts are most frequently required to promote stability by acting as compressive members, but their tensile strength especially at the attachment bracket must also be carefully considered. A well designed strut system can increase the overall strength performance of a group of steel arch supports by up to 50 % even more depending on the conditions.

7. EFFECT OF LOAD DISTRIBUTION ON STRENGTH OF STEEL SUPPORTS

The importance of ensuring that well distributed loads are carried by the roadway supports is widely recognized. Point loading at the crown of supports significantly decreases their ultimate load carrying capability. Recent investigations have indicated that up to a 5-fold increase İn collapse load can be achieved by increasing support loading area from the crown point condition to 67 % at the support bearing area (3). Improved load distribution can be achieved by:

— A close fit between support and strata walls which is best achieved by a machine cut profile.

- Effective backfilling between strata and support to maximise the contact area.

8. EFFECT OF SUPPORT WIDTH AND SECTION SIZE ON SUPPORT STRENGTHS

Both support width and size of H—section have an effect on the load bearing capacity of steel arched support systems. These aspects of support have been discussed by Whittaker and Hodgkinson, (4), from which Figure 2 has been reproduced, and represents a family of curves relating the collapse load of a steel arch support to both support width and 'H' section size. It facilitates a method of support selection which is related to likely strata loading conditions. Curve A represents the concentration of load along a roadway resulting from an ellipsoidal envelope of rock of height D above the support. This is representative of the most common strata loading conditions experienced in practice. Curve B represents good strata support loading resulting from strong roof strata and a well distributed load. The diagram can be used for support selection as indicated by the following example.

If a 4,2 m (14 ft) diameter roadway using 10 x 10 cm (4 x 4 in), H—section, 2 piece steel arches spaced at 0.9 m intervals is experiencing excessive roof closure in strata conditions corresponding to curve B, then to remedy this situation one of the following courses of action are possible on the basis of Figure 2.

— Decrease the arch diameter to 3.7 m (12 ft)

— Increase the section size to 11 x 11 cm (4 *Vi* x 4 *Vi* in)three piece or 12 V_2 x 11 cm (5 m 4^1/Î in), two piece arches of 4,2 (14 ft) diameter.

— Decrease the arch spacing by the ratio of the arch collapse load to the strata loading curve (B), in this case 20%.

9. V-SECTION YIELDING SUPPORTS SYSTEMS

The V-section yielding support system has and is being used extensively throughout the European coalfields for roadway support, but has found limited application with the UK. V—section yielding supports are designed to provide effective strata resistance at an early stage, but are able to yield at a specified load whilst retaining the original support profile, and therefore promotes stability. A maximum

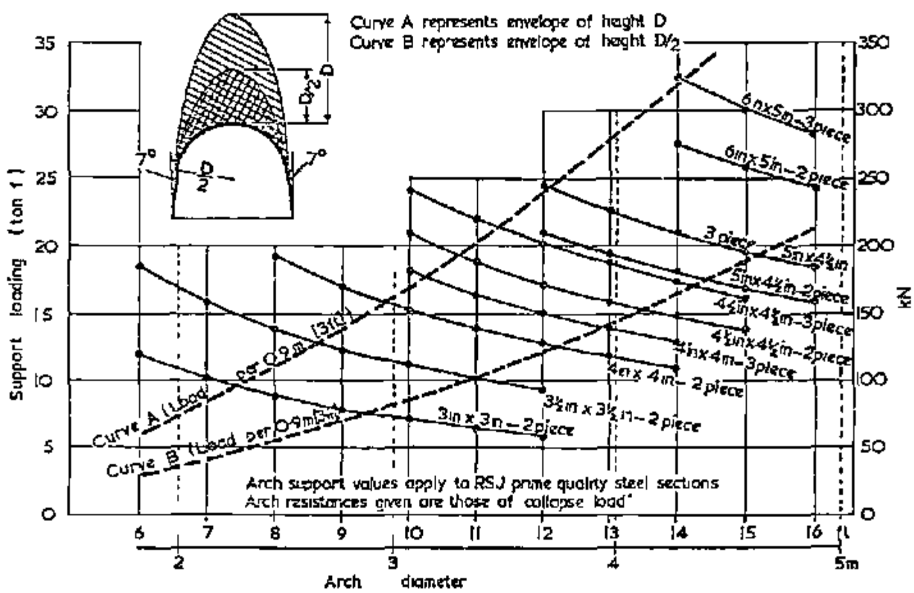


Figure 2. Arched profile design loads (after Whittaker and Hodgkinson (4)).

of 30 % vertical deformation can be incorporated into the supports without any individual support element suffering major permanent deformation. In recent years there has been renewed interest, within the UK in this system. There have been several trials with yielding supports in UK coal mines.

Table 1 provides a comparison between the V—section yielding and H—section rigid steel arched supports.

Table 1 — Comparison Beetween The V—Section Yielding and H-Section Rigid Supports.

	V — Section Yielding Supports	H—Section Rigid Supports
1	More expensive, mainly due to complex connecting elements.	Less expensive, cheap connecting element in the form of fishplates.
2	Highly resistant to out-of-plane deformation due to comparable section moduli in X and Y planes, therefore less need for highly effective strutting.	H—section prone to out-of-plane deformation as the ratio of section moduli in X to Y planes is 3:1 respectively.
3	Capable of large scale yielding with out plastic deformation of any support number.	A degree of yield can be catered for by the use of stilts.
4	Can be easily dismantled and re-erected	Once deformed, supports are difficult to remove and re-erect.
5	Very flexible size range, supports easily adapted to many strata control problems, i.e. they are very versatile.	Flexible size range in both section and support size.
6	Very good joint strength due to overlapping nature of the yielding joints.	Poor joint strength, especially when supports are severely deformed.
7	Yielding load can be set at higher levels therefore the system is suited to heavy strata loading.	Lower limit to yielding load that can be achieved by stilts.
8	Difficult to clamp struts and other fittings to the section.	Easy to strut or attach clamps and various fittings.
9	TTieir cost has discouraged wide application in the UK	Cheapness and simplicity coupled with familiarity of a well proven support system continues to promote its wide acceptance in UK coal mines.
10	Yielding mechanism prone to highly variable yielding load, clamp seizures can be a major problem in certain conditions.	Yield loads using stilts can be confidently predicted.

10. CONCRETE SEGMENTAL LININGS

The use of concrete linings for shafts and shallow civil engineering tunnelling applications is well accepted. Their use in deep mined Carboniferous roadways, subject to great strata movement, is generally considered to be still in the proving stages, although isolated applications have been carried out in the mining industry since the early part of the present century.

Concrete roadway linings can be divided into two types, prefabricated segmental linings and monolithic supports, as used in many metal mines around the world. It is with the former that this section of the paper concentrates.

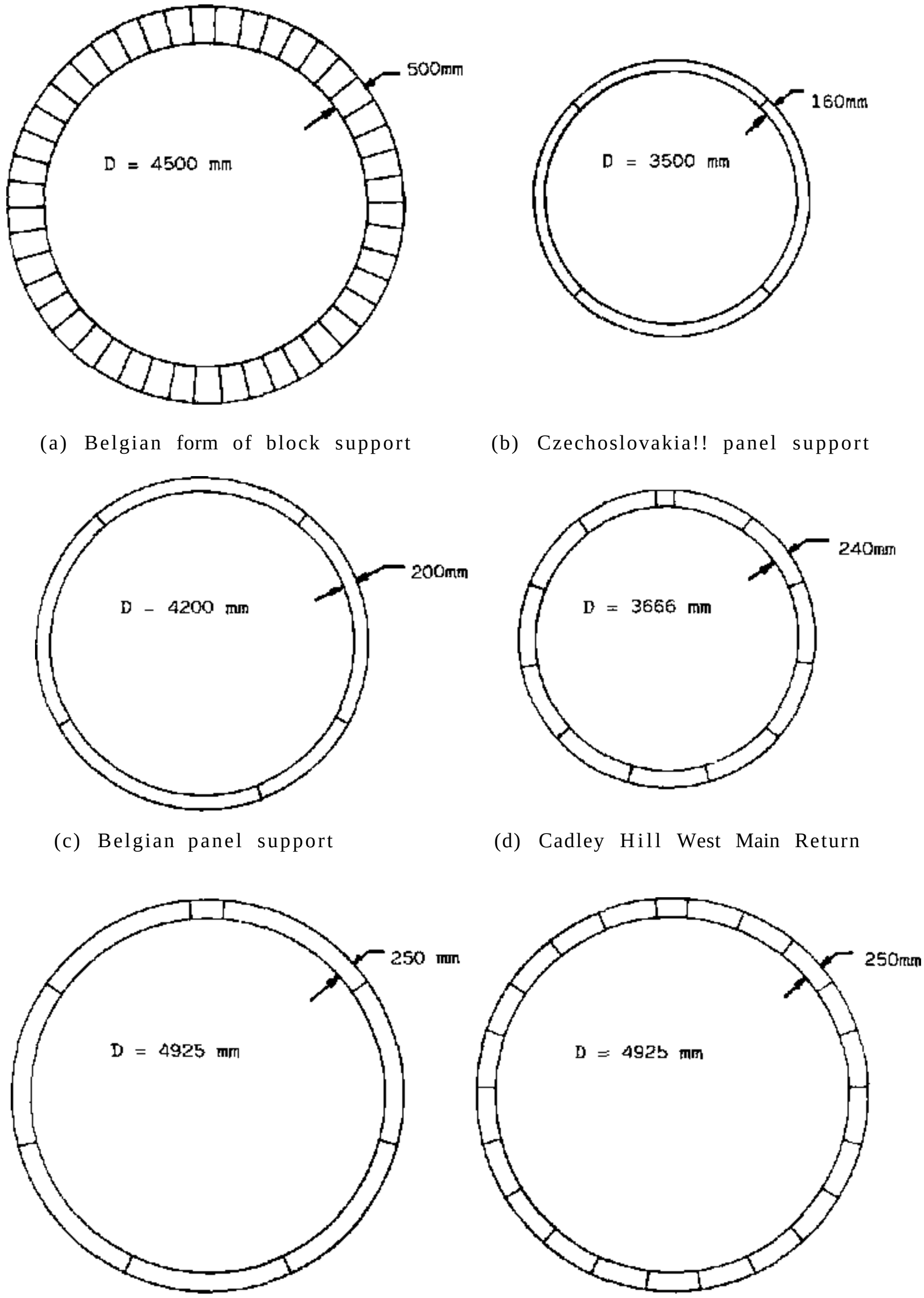
In the UK there has been in the past successful use of concrete block linings for support of areas prone to high strata loads. Thome Colliery in the Yorkshire Coalfield used such tunnel supports for about 30 years at a depth of around 800 m.

The experience of the Belgium coal industry in the use of concrete supports is worth considering because as early as the 1930's the Belgians had developed a concrete lining for their roadways, (5). The Belgian Cam pine Coalfield was first exploited in the early 1920's. The coal seams are 1 to 3 metres thick, often located in weak rocks liable to creep, especially under the action of water and moist air. The deposits are overlain by a non-Carboniferous overburden, of a thickness varying between 500 and 600 m. The support was originally of steel arches and to overcome the strata control problems the support density had to be increased to, in the worst cases, 3 arches per metre. Despite this expense back ripping and dinting of the roadways was frequently unavoidable.

In order to develop economically the Campine, Coalfield research was carried out to design a circular lining much stronger than steel supports.

The lining developed consisted of a concrete block type support, see Figure 3(a). The blocks were of classical stone arch shape and were totally unreinforced. Initially the internal diameter of the roadway was between 3 and 3.6 m though this was subsequently raised to 5.4 m to meet transport and ventilation requirements. The number of elements per ring varied from 50 to 90. Each segment was separated from its neighbour by a crush ab le wood insert. Because of the number of elements per ring, the manual setting of the supports limited roadway advance *to less* than 1 metre per day. This performance was improved by partial mechanisation to two metres a day.

By the late 1960's the support system had to be improved by reducing the number of elements in each ring in order to reduce the construction costs and speed up development. A system of prefabricated reinforced panel «mnnrt had to be developed.



(a) Belgian form of block support (b) Czechoslovakia!! panel support

(c) Belgian panel support (d) Cadley Hill West Main Return

(e) Cadley Hill, 7 segment support (f) Cadley Hill, Multiblock support

Figure 3. Geometrical aspects and dimensions of prefabricated concrete tunnel Immgs.

A system was developed İn Belgium based upon a Czechoslovakian reinforced concrete panel support. The Czechoslovakian support consisted of four panels and had an internal diameter of 3.5 metres, see Figure 3(b).

The Belgium system was made up of 5 panels, four of equal length, subtending an angle of 80 degrees, and 1 of half the length, subtending an angle of 40 degrees, see Figure 3(c). The inside diameter of the support was 4.2 m to meet transport and ventilation requirements. The panels were also conveniently handled by means of a threaded tube embedded in the concrete. Into this a spherical head was screwed so that the head was situated precisely at the centre of gravity of the panel. The head could then be gripped by a knuckle joint of appropriate dimensions on the arm of the setting machine and the panel could then be easily placed in any desired position. The threaded tube was then used subsequently for the injection of grout and also for fixing pipe brackets.

In the UK several trials of reinforced concrete segmental linings have been carried out. The first took place in December 1979 at Cadley Hill Colliery, (6). The Colliery had a history of severe unpredictable faulting, often with large local variations in throw. A 46 m length of the West Main Return was re-lined with pre-cast concrete segments. The roadway had been placed 10 m above the coal seam in a attempt to reduce the large closures encountered in adjacent in-seam drivages. The roadway was originally lined with 4.3 x 3 m steel arches, and by the time the concrete supports were placed much dinting had been required to recover the original floor level.

The roadway lining consisted of 75 rings with an internal diameter of 3.66 m and a thickness of 24 cm. Each ring comprised of 11 segments and a key piece in the crown, see Figure 3(c).

The trial experienced limited success as the lining failed due to the abnormally high and non-uniform loading. This was due in part to a cavity in the roof that was formed when withdrawing the steel arches. Although this had been grouted with as much as 6.25 tonnes of grout per metre, failure of the lining was due to the lining being forced into the void.

Subsequently at Cadley Hill Colliery a concrete segmental lining was used to line the north west drivage. The linings was being placed behind a full face tunnelling machine designed by the National Coal Board's Mining Research and Development Establishment at Bretby. At first two types of lining were tested. One consisted of seven segments, each subtending an angle of 50 degrees and a key stone subtending an angle of 10 degrees, see Figure 3(d). In the other design, referred to the 'multiblock* system, each of the seven segments was composed of 3 sub-segments, see Figure 3(e). The tunnelling commenced in late 1982 and by October 1985 the first phase of 1500 m section was completed. Only 100 m of the roadway is composed of the multiblock system as quite early on, a decision was made to use the larger panel configuration. This was because the setting time of the multiblock support was much greater than that for the seven segment support.

Several of the rings in the Cadley Hill circular tunnel were instrumented with vibrating wire strain gauges so that the Mining Research and Development Establishment at Bretby could monitor the long term performance of the lining and also to provide early warning of excessive strain development. A full deformation survey of these rings is at present being carried out by the University of Nottngham to complement these measurements.

The early results of the strain gauge measurements are well covered elsewhere (7) *and it is* too early *to comment on the* correlation of the deformation survey. The lining has on the whole stood up well to the strata loads at Cadley Hill. However, a failure of the panels has occurred at a section of the tunnel within a very faulted zone. Around 30 metres of the roadway has had to be under ringed with steel supports. Much of the failure observed is associated with the keystone in the crown of the ring. It has been suggested that in a mining application the keystone İs obsolete and only causes excessive movement of the panels in the crown, leading to premature failure of the ring.

Figure 4 illustrates modes of failure of concrete linings.

11. DESIGN REQUIREMENTS

The design of any support system is governed mainly by two factors:

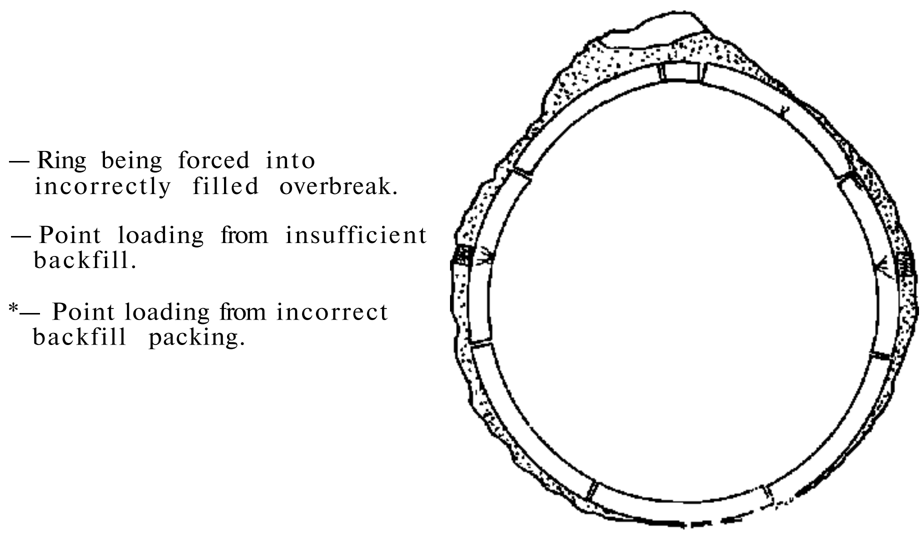


Figure 4. Modes of failure of a concrete segmeutal support. (After Whittaker et al (11))

11.1. Support Requirements

The support must be able to withstand the ground pressures and be able to maintain the roadway without appreciable reduction in cross sectional area.

A segmental lining, as has been seen consists of a number of reinforced concrete panels separated from each other by crushable wood inserts. The purpose of these inserts is as follows:

a) To provide yield in the system, and thus permits movement of the panels to more evenly distribute the loads around the ring. Where there are many segments in a ring, e.g. Multiblock, the segments can move to keep the bending moments within a panel to a minimum.

b) To reduce the high stresses caused by two concrete faces coming into contact with each other which can result in giving rise to high stress concentrations.

Due to the nature of concrete the faces at the ends of the panels are rough and if two concrete faces are placed together their roughnesses give rise to considerably high stresses, and thus lead to failure at low loads. To compensate for this the packing must beat least 20mm thick, (8).

It should be noted that excessive thickness of the crushable insert can lead to over reduction in cross sectional area of the roadway and to over displacement of the panels. Also if the displacement of the panels is too great then this can also lead to failure of the ring.

11.2. Operational Requirements

The support needs to be easily handled for both erection and transport. The erection operation itself should be quick and not interfere with the tunnelling operation.

In order to reduce handling of the support it should consist of as few pieces as possible; as a consequence of this requirement the panels should be as large as possible. This conflicts with the requirement that the panels should be easily handled, as the larger a panel the heavier it becomes. Conversely as explained in the support requirements section the lining should consist of as many segments as possible to adequately distribute loads and reduce bending stresses.

12. BACKFILLING

When designing a segmental support system it is essential that the load is distributed as evenly as possible around the lining. This is usually achieved by using some form of backfilling behind the panels. Results from Cadley Hill and experience in Belgium both show the necessity for early and adequate backfill. The effects of cavities and point loading are accentuated by deficiencies and delays in grouting.

At the NW drivage at Cadley Hill Colliery up to 2.8 tonnes of grout were required per metre of roadway. Several types of grouting methods were used in the NW drivage. The materials used were pea gravel, anhydrous and gypsum products, and proprietory cement grouts. It was found that the most efficient method was to use a dry blown material as close as possible to the machine followed by a wet grout material injected through the panel at a later date, (9,10).

Where large overbreaks occur it is usually necessary to fill these cavities at the face using some stronger form of packing.

13. PROPOSED DESIGN PROCEDURE FOR CONCRETE SEGMENTAL LININGS

When choosing a support system it İs important to ensure the lining İs adequately designed without being overdesigned.

In designing the lining it must be assumed that all diametric closure is due to compaction of the wood packing as the concrete will only be negligibly deformed relative to the wood packing.

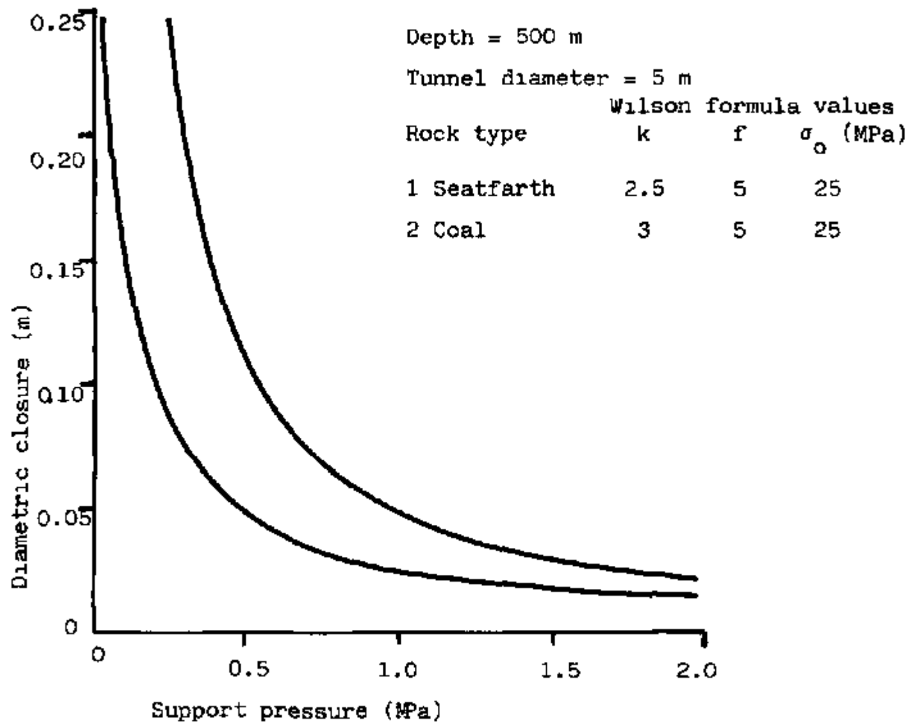
Closure İn mining tunnels can be predicted using Wilson's Formula, for the rock type within which the lining will be placed. A curve showing radial closure of the roadway against the support pressure is presented in Figure 5a.

For a given rock type, permissible closure and tunnel radius, it is possible to directly read the support pressure required.

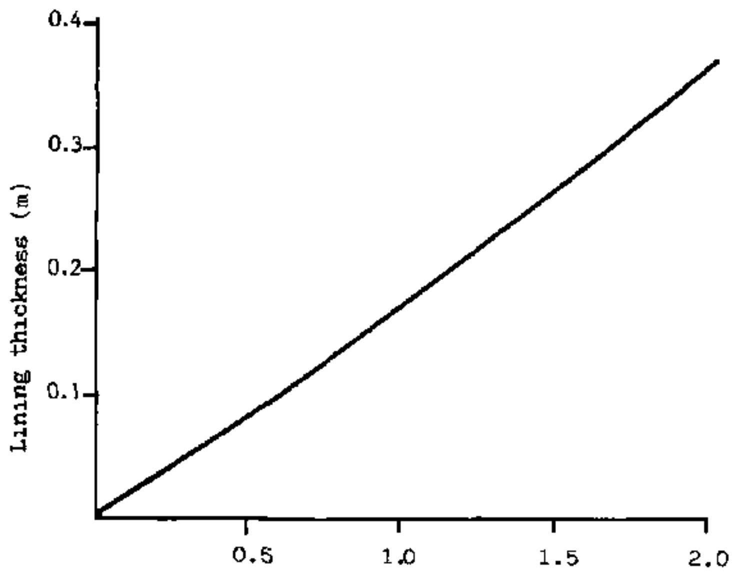
Having determined the support pressure required and assuming that at the maximum permissible closure the wood packing has the same strength as the concrete, it is possible to calculate, using cylinder strength formula the thickness of concrete lining required. Note that the influence of light reinforcing elements İn the lining is not taken into account as the reinforcement plays a very important role in controlling and distributing the stresses and cracking in the lining but it does not significantly increase the stiffness.

If the thickness of the panels is to great then the analysis may be repeated but using a greater permissible closure. The initial thickness of wood packing between panels can then be calculated using the physical properties of the wood, or packing material. If the initial thickness of the packing is to great, and would be likely to cause instability (i.e. greater than 40 mm) then the analysis would need to be performed again but using a reduced permissible closure. The thickness of the packing could also be reduced by increasing the number of panels.

An example of such an analysis is shown in Figure Sb.



a) Predicted closure versus support pressure using Wilson's Formula (12).



b) Predicted thickness veisus support pressure

Figure 5. Design graphs for concrete segmental linings.

14. FURTHER DESIGN PARAMETERS

At the University of Nottingham a series of modelling tests have been carried out to examine the effect of panel geometry on the stability of a concrete segmental tunnel lining. The models have all been loaded under similar conditions and the mode of failure has been observed.

It is interesting to consider the modes of failure observed. The load was applied to the model by means of a hardwood loading shoe. The sides were restrained and the vertical displacement of the arch was recorded continuously against the load. The arrangement is shown in FigLre 6.

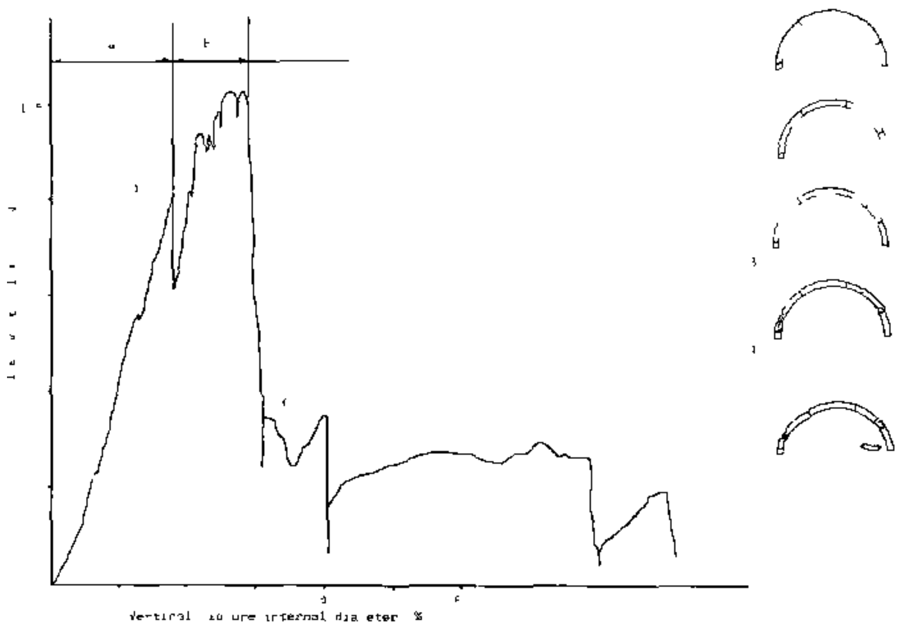
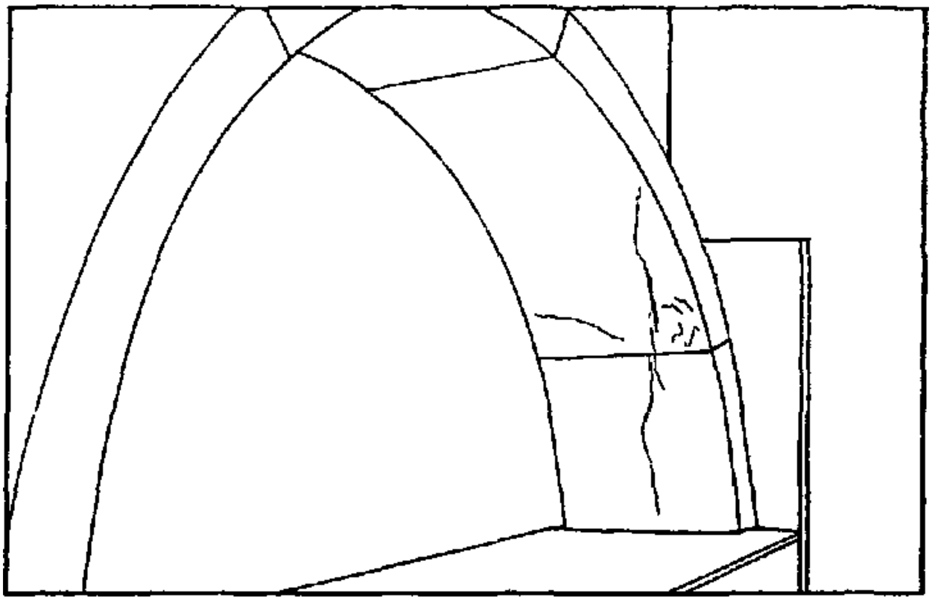


Figure 6. Load-displacement graph for model concrete arch support.

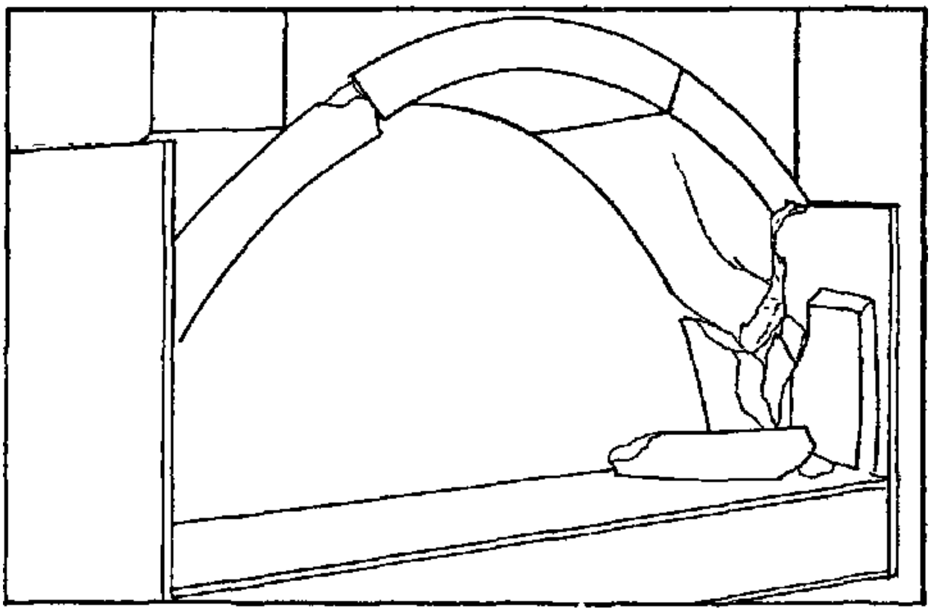
The graph can be divided into three basic sections as shown.

- Linear deformation as the arch takes load. This continued to a load of 23 kN when fracturing was first observed. Ât 95 kN the first major failure occurred on the right hand side of the model. The mode of failure was by shear across the panels, see Figure 7. On failure the load dropped to 80 kN.

- The load built up again fairly quickly. The shear failure on the right hand side developed whilst rotational failure occurred on the left hand side. The load increased to maximum value of 127 kN.



a) Initial failure of concrete linings (95 kN)



b) Failure at completion of test exhibiting residual arching strength and mode failure at RHS of support.

Figure 7. Model concrete arch failure characteristics.

- Although sudden failure occurred at the peak load, the arch did not fail catastrophically but still took a residual load up to a maximum deformation of around 3.5 %.

This mode of failure is of special interest. The weakening effect that caused the ultimate failure of the lining, i.e. the shear failure on the right hand side, occurred before the peak strength had been reached. The rotational failure in the left hand side was probably due to a large bending moment building up in the panel caused by the shear failure on the right hand side. Once this bending moment was of sufficient magnitude the panel failed by rotation.

15. CONCLUSION

The types of mine roadway and tunnel support used in the UK coal industry continue to be predominantly steel lined consisting of mainly rigid H—section steel arches. Such steel supports offer considerable flexibility, reliability and good supporting characteristics in wide ranging mining conditions, especially in gate roadways. Concrete lined mining tunnels are still at an early stage in the UK although they have proved highly effective in heavy squeezing ground conditions. Choice between concrete segmental blocks or steel members for tunnel lining is difficult in view of the rate of drivage, supplies handling and degree of tunnel stability sought needing consideration amongst other factors. However, it is anticipated that more concrete lined tunnels will be used in the future in special conditions where strength, stability and durability in the long term are major factors. Steel supports offer the greatest advantages to relatively short-term projects or where durability and strength are not decisive factors.

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