Thesis
on
the effects of roof pressures in mines
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INTRODUCTION.
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INTRODUCTION.

Whatever be the initial state of stress in the strata, mining operations impose new forces and it is with these that the mining engineer is directly concerned.

Up to the present time, it has been found impossible to determine the magnitude of the forces induced by mining, or the areas on which these forces act, and hence the intensity of the stress produced by them is unknown.

By the comparison of strata movements induced by mining operations and the influence of the applied supports on these movements, the effects of roof pressures can be deduced. From the records of strata movements and from what knowledge we possess of the strength properties of the beds, the intensities of the forces which cause the movements can be inferred. Moreover, little is known of the strength properties of the various beds and hence their reactions to the forces induced are difficult to assess.

In this paper an account is given of strata movements induced by mining operations. The effects of removal of the coal, which is regarded as the removal of support, are dealt with and then consideration is given to the application of supports as a means of controlling the movements of the strata by resisting the pressures induced.

The design of these supports, with a view to making them as effective as possible, is then dealt with.

The investigations were conducted in 23 seams at a group of 15 collieries belonging to The Fife Coal Company, Limited.
(2). MOVEMENTS INDUCED BY MINING OPERATIONS.
In various seams, convergences of the roof and floor have been measured as well as relative lateral movements of the sides. Both in the roof and floor, bed separation has been observed, showing that forces may be concentrated at the perimeters of the cavities formed between beds during mining operations.

In any working the factors controlling convergence are the relation between the removal and the application of support. The removal of material may be regarded as the removal of support, and the immediate consequence is the lowering of the roof which transmits pressure over the sides, tending to cause lateral movements of these sides. In turn the sides transmit the pressure to the floor, causing it to tend to heave.

Where the working is wide as in longwall, the movements induced extend for considerable distances, both in advance and behind the face.

A typical record of roof and floor convergence is shewn in fig. 1, which also shews the relative movement of the roof and of a bed 4'9" above. The convergence recorders were set 26' ahead of a longwall face in seam H, colliery O, in a road 6' wide. Convergence was taking place from the time of setting the recorders.

During the first five days, while the face advanced to 9' from the instruments, the convergences were fairly uniform, and measured between roof and floor 13", and between upper bed and floor 10".

From that time there were distinct increases in the rate of convergence, while the machine was undercutting. Where this increase occurs is particularly important, because it may be regarded as the position of the plane, about which the general movement is taking place in relation to the corresponding position of the face. As the face advances, this plane moves forward by approximately the same amount.

When the recorders were in line with the face, seven days after/
CONVERGENCE TEST
COLLIERY No. 10,
SEAM H.

SECTION 3 No. 8 at
End of Stripping

SECTION 3 No. 8 at
Commencement of Stripping

SECTION ALONG CENTRE ROAD.
after being set, the roof and floor convergence measured 0.75", while the upper bed and floor convergence was 0.6", the difference being probably accounted for by swelling of the beds as no separation could be detected.

On the ninth day, the recorders were 4½' behind the line of face and convergence amounted to 2.2" and 1.58".

From then until the fourteenth day this part of the face only advanced 2' by hand work, but convergence continued throughout the period to totals of 3.2" and 2.1".

On resumption of regular coal-cutting, the narrow road which had been continued in advance of the face, collapsed. The convergences were very rapid and continued so during the following week in which the face was undercut five times.

On the twenty-first day the total convergences amounted to 13.85" between roof and floor and 11.8" between upper bed and floor. Thus there was a difference of 1.95", obviously indicating bed separation, and there were distinct indications of lateral movements between the roof beds. This influences the behaviour of supports applied at the face on roads.

From this stage, although the effects of machine cutting were still visible, the movements diminished. On the fortieth day the recorders were 64½' back from the face and the total convergence of roof and floor amounted to 20.52", while that of the upper bed and the floor amounted to 18.2", the difference being 2.32". The percentage height reduction was 45.5% of the original height.

From these records, it is clear that convergence goes on in advance of a longwall face. The largest rates of movement are associated with the removal of support by undercutting.

Relative lateral movements of the beds were definitely observed and not only is there bed separation, but there would appear to be permanent increase in thickness of some of the roof beds.
The very rapid movements induced by the machine cutting on the fourteenth day, shew the very serious consequences of stopping or slowing down of a rapidly advancing face.

Although actual deflection of the beds was not measured, there must be deflection where the rate of convergence is changing. Thus the strength properties of the beds in advance of the face, where convergence is taking place, are reduced as deflection increases. Hence the residual strength of the beds exposed at the face will be less than the original strength. Any steps taken to reduce the rate and magnitude of convergence will help to preserve the strength properties of the beds.

Beds which have not actually fractured may be expected to recover their strength properties to some extent during the subsequent period when convergence is gradually diminishing.
(3). REMOVAL OF SUPPORT.
Removal of Support:

As convergence is definitely related to the removal of support, that is, working of the coal, this factor requires to be considered. Removal of support can be divided into the rate of actual removal of support and the intervals between removal operations. The complete cycle of operations involving the removal of a strip of coal along the length of face is regarded as the rate of advance, but it is necessary to consider rate of removal of actual support, for instance, as by coalcutting. It is useful to ascertain the average rate of removal of support per minute. It is also important to find the average rate of removal over the period taken by a complete cycle of operations.

For instance, on a face 100 yds. long, undercutting by coal-cutter to a depth of 3' may take 5 hours. This is a rate of removal of support of 180 sq.ft. per hour. The complete cycle of operations on the same face may take 24 hours giving a rate of removal of support of 37 ½ sq.ft. per hour. By undercutting to a depth of 6' in the same time, the actual rate of removal of support would be 360 sq.ft. per hour, and the movements induced would be correspondingly increased. If, however, the 6' undercut necessitates a 48 hour cycle, then this increased rate of movement being continued for double the period will result in a greater magnitude of movement about a plane, and more liability to damage to the beds, despite the fact that the rate of removal of support throughout the cycle would be 37 ½ sq.ft. per hour as before.

Thus increasing the depth of undercut without altering the complete cycle period will merely increase the rate of movement about the plane for each position of the face line. But as the planes are placed further apart, the actual movement per inch may be smaller and the damage to the beds may not be less than that caused by the shorter undercut with the planes closer.

On
On the other hand, if the complete cycle period is increased, any adverse effects of increased depth of undercut would be augmented.

It would appear from the convergence records that there would be advantages in reducing the rate of actual undercutting as this determines the rate of removal of support with a given depth of undercut. But if the decreased rate of undercutting necessitates a longer complete cycle, such benefit may be wholly lost.

With modern machine-mining, the period of actual undercutting can not conveniently be reduced.

In seam /\ colliery No. 9 - coal was extracted to the depth of 3 ft. in 24 hours, the average rate of advance of the face being 1\(\frac{1}{2}\) ins. per hour. An advance of 6' in 24 hours gives an average of 3 ins. per hour.

In 5' seam convergence was recorded at a point 3 ft. from the face when the instrument was set. The convergence recorded was 1•5 ins. and 2•1 ins. in the respective cases in 24 hours, a full cycle of operations having been carried out. The face was supported in the first case by 4\(\frac{1}{2}\) straps and in the second by 6' straps as shewn (Fig. 27 ( ). No roof penetration took place in either case, but floor penetration of the props was increased in the second.

The seeming increase in convergence when the coal face advanced more quickly should be shewn, in relation to the rate of advance, viz. - with 3' advance, average convergence was at the rate of •017 ins. per inch advance per hour, and with 6' advance, average convergence was at the rate of •012 ins. per inch advance per hour.

This clearly indicates that with the greater rate of advance relative convergence is slower and that though the position of stability might be reached in a shorter period of time, this position would be at a greater distance from the face than the position related to the slower advance.

The rate of advance in this particular face was decreased to 4\(\frac{1}{2}\) ft. in 24 hours, an average of 2•25 ins. per hour. This was done /
done because of eventual transport difficulties which reduced the time in the cycle for brushing and packing to such an extent that roadside buildings and packs were often too far behind.

From a similar position as before, the convergence during 24 hours was measured to be 1.9 inches giving a relative convergence of 0.014 ins. per inch advance per hour.

As far as could be seen, conditions were similar in all three cases, the number of props in use being unaltered, and the size of packs and waste spaces being unchanged.

In the case of the 6 ft. advance, the packs were probably less efficient than in the other cases.

Further investigation of this influence will proceed whenever a suitable subject is available.
THE APPLICATION OF SUPPORT. (FACE SUPPORTS).

(a) Sprags.

(b) Face Props. (Selection of face props). (Prop Caps). (An endurable prop).

(c) Roof and Floor Penetration Tests.
   (1) Floor Penetration Tests. (Various Seams). (Sandstone Floor, wet & dry). (Fireclay Floor, wet). (Comparison with prop caps).
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   (4) Swinging of Props.

(d) Strengths of Various Supports.
   (Compression tests on composite steel & wooden props).
   (Comparative tests on tubes without and with wood cores and also with end caps).
   (Tests on tapered steel tubes.
   (Straps.)

(e) Conversion from wood to steel props.

(f) Propping Systems.

(g) Chocks.

(h) Packing Systems.
   (Packing from road brushing).
   (Packs built from material obtained from waste).
   (Changing from road brushing to packing from waste).
The application of support:

Not only should supports be of ample strength but they should have sufficient contact area to distribute the resistance and avoid local damage to the strata. Early application of supports contributes appreciably to their effectiveness. Desirably, the supports should be easily transported, erected and withdrawn.

The most important factor is the relation between the time of removal of resistance and the time when the applied supports develop resistance.

FACE SUPPORTS: Convergence records have shown that the maximum rate of movement on a longwall face advancing regularly takes place near to the position of the coalcutting, i.e., when the natural support of the coal between roof and floor is being removed. Hence it is of vital importance that this movement should be retarded at this position without delay. Sprags or gibs driven into the undercut as successive short portions of coal are cut are the first supports that can be applied to retard this movement.

Sprags

Wood or steel sprags with flat faces, having a large contact area between top and bottom of the undercut, and being of sufficient depth to prevent vertical movement of the coal should be used. A sprag should also have the wedge portion shaped so that the wedge itself will give support, i.e., not too pointed and yet allow of fairly easy entering into the cut. The horizontal portion should be long enough to give support when driven in, even when the face of the coal may fall off, as often happens.

Suitable sprags have been found to be about 2' long, having a taper of half the depth in a length of 1 foot and of section 6" x 6", 5" x 5" and 4" x 4" in the case of wood, and 6" x 5", 5" x 4½" and 4" x 4" in the case of steel, to suit the thickness of undercut. The use of broad flange steel joists for sprags is important.

Fig. 2 shows forms of sprags in satisfactory use. Form (a) is made by making a saw drift in the web in a plane off
that perpendicular to the web, so that when the joist is pressed in a bending machine the faces of the saw drift slide over each other, and the wedge is formed as shown. Fig. 2 shows a portion of the web completely cut out and the flange bent over.

In a seam with a weak floor, it was customary to use the tubular face props as sprags, but the sides gave little contact area. These were seen to sink into the floor, offering small resistance as support to the cut coal, and hence to the roof. Joist sprags were introduced to offer greater resistance. This was further increased by shortening the distance between sprags.

In another seam where face props of 4" x 3" joist section were used as sprags, there was considerable swinging of props between the hard floor and soft roof. Roof penetration of the straps was common and the face was altogether in poor condition. Careful examination of the supports in use showed that the 4" x 3" sprags were not deep enough in section to fill completely the undercut close up to the coalcutter. This was only noted when spragging was done by the man following the coalcutter, as when spragging was done by the strippers on the succeeding shift, there was difficulty in driving in the 4" x 3" sprags. An immediate advantage in roof control was gained when sprags of 6" x 4 ½" joist were driven into the undercut by a machineman immediately after each short length of coal was cut.

From the above, and many other similar examples, it has been seen that sprags must be applied early, as near as possible the coalcutter, and must be of a section large enough to fit tightly into the undercut and to have a large contact area, top and bottom, to be of the greatest advantage. Each sprag should be withdrawn immediately before the portion of coal that it supports is to be worked. The practice of withdrawing all the sprags at the beginning of the stripping shift is to be deprecated.
FACE PROPS: Face Props are set at a coal face to limit the rate of convergence of roof and floor as far as possible until such time as the roadside packs and intermediate packs, if any, have developed sufficient resistance to control the general movement of the strata, so that excessive movement and consequent damage are avoided. Thus the function of props is to preserve the beds in the area at the face where men are working thus keeping the roof in good condition.

If this function is performed as it should be, the liability to fracture and therefore to falls will be greatly diminished.

On this principle, it is of the greatest importance that the props should be set systematically, effectively, and as early as possible, so that the strength properties of the beds will be preserved to the greatest possible degree.

To achieve this object, props should develop resistance as soon as possible after being erected. They should sustain the highest possible resistance from the time of setting till withdrawal. Violent fluctuations in resistance are detrimental as they allow of localised changes in the rate of convergence and hence damage to the immediate roof and floor beds.

Prop penetration tests have shown that the resistance developed by props is directly related to the nature of roof and floor against which they are set and to the areas and nature of contact, rate of convergence and the characteristics of the props themselves.
In selecting face props, the load producing failure, together with the end contact areas are important. Even with careful setting of face props, it is impossible to avoid unaxial loading because of inclination, uneven floor and roof, etc.

During convergence, which is usually a maximum during coal cutting, the rate of loading varies. Relative lateral movements of the roof and floor cause unaxial loading, and, during penetration, if any, props may slide along a bed in the floor material, thus adding to unaxial loading. Therefore, unaxial loading rather than direct loading has to be considered.

To determine the length of prop required, the original height of the seam, the nature of the roof and floor, and the maximum convergence of the roof and floor between the place of setting and withdrawal are the important factors. Consideration should be given to the possibility of reducing the period between setting and withdrawal to a minimum so that convergence in this interval is minimised.

Roof penetration is undesirable and should be avoided by increasing the contact area of the supports with the roof.

When floor penetration is improbable where the floor is very hard, it is necessary to introduce lids of suitable thickness according to the amount of convergence or even to use sliding props to avoid damage. The length of prop necessary will be equal to the height of the seam less the thickness of the lid and strap.

In most circumstances, part at least of the height reduction is taken up by floor penetration. To ensure that sufficient resistance is developed by the props during penetration, the shape and area of end contact must be adjusted according to the nature of the floor beds to a depth of at least 12".

The section of the prop should next be considered. In a tubular prop the diameter and gauge of the metal have to be determined.
The largest diameter gives the greatest resistance to unaxial loading, but other factors such as height of seam, weight and space occupied, limit this diameter.

In a thin seam, particularly in the process of erection and withdrawal, the large diameter prop turning about its base tends to rise an amount related to the diameter, and thus adds to the difficulty in erection and withdrawal.

The gauge of the metal is determined by the maximum resistance which the prop is likely to develop according to the nature of the floor and the design of end contact area selected.

Within limits, it is possible to standardise diameter and thickness provided end contact area can be varied to suit floor conditions.

Similar consideration should be given to the selection of joist or other section props. It is to be remembered that the joist section offers high resistance to unaxial loading applied in one direction only, and the resistance to deflection from the plane of the web is small.

**PROP CAPS.** Suitably designed caps or feet for steel props not only protect the ends of the prop from damage, but provide a means of adjusting the end contact areas and may also tend to give axial application of the load.

Fig. 3 shews various shapes of end fixings which have been tested.

**Tubular Types.** The pressed steel cap Fig. 3 A, to some extent reduces the eccentricity of the load. It prevents tearing of the metal at the ends. Its rounded edges distribute the load and avoid concentration of stress at those edges; otherwise there would be a tendency to cut the floor material as with the uncapped tube.

A cast steel foot Fig. 3 B, attached to the prop by a bolt, the tube being slotted to avoid the possibility of the bolt being in shear, is an attempt to give a variation in end contact area. The dotted portion in the illustration shews a variation. The edge of the foot is rounded and the face is flat./
Steel Prop Caps

Tubular Types

Pressed Steel Cap  Cast Steel Foot  Reduced End

Joist Types

Flange Turned Over Plate Inserted  M.S. Plate ½ Welded on  ½ Plate Welded on

Cast Steel Plate Cap  Riveted Channel Cap  Welded Channel Cap  Pressed Steel Cap

Fig 3
Such feet are easily attached and detached, but they add to the weight of the prop.

A simpler device to reduce the end contact of the tubular prop is to taper the end Fig. 3 C, and to insert a core suitably turned. Props so fashioned have been tested with considerable success when the taper reduced the diameter of the prop by one inch, in a length of taper equal to 1" less than the diameter of the tube. This taper may be applied to the end of the prop set to the strap to give easier erection in a thin seam. It is to be noted that the resistance of the prop to eccentric loading is not reduced.

When no caps or feet are used on tubular props it is usual to have the core protruding at the ends of the props. Tests have been made which prove the importance of this in increasing the buckling load.

**Joist Types.** A cap with flanges turned over to meet in centre is shewn in Fig. 3 D. As under test this was subject to distortion and did not protect the web from unaxial loading, a plate was inserted as shewn in Fig. 3 E. This was an improvement but welded end caps were evolved, Figs. 3 F. and G. The former, with a plate \( \frac{1}{2} " \) thick on a 5" x 4\( \frac{1}{2} " \) joist, was liable to bend on the free sides parallel to the web, causing the weld to fail. It was found that the latter was not wholly satisfactory as the web of the girder was not fully protected. In this connection it was found that one of the functions of end caps was to prevent the web of the joist from being directly loaded.

A further development was a cast steel cap with lugs attached to the web by a bolt to keep it (Fig. 3 H) in position, but arranged so that the load was not transmitted directly to the web, but to the flanges. The cap was easily attached and detached.

Another form of cap Fig. 3 J. fitting on to the flanges with four rivets also proved satisfactory.

The same form of cap welded on Fig. 3 K. was successful, but it could not be easily detached.

All the above caps have the defect that if the props penetrate/
penetrate into the floor, their withdrawal is rendered difficult by the floor material spreading over the caps. To surmount this difficulty a cap of pressed steel (M) has been tried, the sides of which surround the joist. There are no sharp edges to cut into the floor, and, because of the shape, the cap can be made from material thinner than usual.

As illustrating the importance of suiting the prop to the nature of roof and floor in a typical instance where both roof and floor were very hard, props both tubular and joist with end caps having contact areas of approximately 20 sq. inches, were damaged before they penetrated the floor. Joist props, with ends as cut, in contact with the floor, giving a contact area of 5.3 sq. inches were not damaged and ample resistance was developed during the penetration of the props into the floor. By contrast, in a seam with a very weak floor, joist props with a floor contact of 2.8 sq. inches which had been substituted for wooden props of 12.5 sq. inches offered less resistance than the latter, and the roof condition deteriorated. In addition, the joist props were subsequently buckled due to excessive swinging.

In another case, where the roof was weak and the floor stronger, using 4" wide wood straps and 3" diameter props, the straps penetrated the roof which crumbled between and over the straps. When 4" x 3" joist props with the end contact area only 2.8 sq. inches compared with 7 sq. inches of the wood props were installed, the roof remained undamaged because the props penetrated the floor more easily. In this case what was apparently a bad roof became a good one. Probably the same improvement might have been obtained by using wider straps.

Similar improvements have been attained by the use of 10" wide straps consisting of pairs of 5" wide straps welded together (Fig. 2/†) or by system of cross strapping (Fig.2/†).
AN EXTENSIBLE PROP.

The need for a prop capable of easy extension of its length by about 6" was felt on a number of faces where the thickness of the coal varied.

By testing, it was found that the load on the props on many of these faces did not exceed 7 1/2 tons. For conditions where this load was not exceeded, a simple extensible prop (Fig. 4) capable of bearing 10 tons, was evolved. It consists of joist prop, two slotted 1/2" plates, two bolts and nuts, and a washer plate. The bolts apply a friction grip and are not in shear. This prop though limited in its field of usefulness is giving satisfaction by avoiding the need for many changes of props due to variation in the thickness of the coal.
Fig. 4.
ROOF AND FLOOR PENETRATION TESTS.

In conjunction with the investigators of the Safety in Mines Research Board, Dr. Winstanley and Mr. H. Wilson, penetration tests were carried out in various seams.

The apparatus used consisted of a hydraulic pump, with oil, and a ram connected by a flexible tube, Fig. 5. The prop to be tested was erected between the floor and the ram, as shown, and the roof strap was placed between the ram and the roof. Pressure was applied gradually by operating the pump and the pressure gauge was calibrated to give the load in tons corresponding to pounds per inch of oil pressure.

FLOOR PENETRATION TESTS IN VARIOUS SEAMS - COLLIERY No. 14.

As an aid to the selection of the most suitable end contact areas of props and arches, series of penetration tests were made (Figs. 6 a, b) of standard joist sections 5" x 4½" and 5" x 3" with and without end caps.

In seam P. on a fireclay floor the 5" x 4½" joist with plain end developed a resistance of 25 tons while penetrating ½" when the resistance decreased to 8 tons. There were then numerous fluctuations in resistance until 31 tons was reached with 2½" penetration. The 5" x 4½" joist with the flanges turned over developed a resistance of 31 tons for .3" penetration.

Similar contrasting results were obtained with the 5" x 3" joist but the penetration was greater for a given load.

These show that on this floor props and arches should have end caps, but for props the one next the floor may be of 5" x 3" or even smaller.

In seam Q. with a soft clay floor the 5" x 4½" joist with plain end offered resistances varying between 6 and 9 tons while penetrating 3½" and the maximum resistance developed amounted to 24 tons with 4" of penetration. With the ends turned over the resistance reached 31 tons with .2" of penetration (Fig. 7)

The results obtained with 5" x 3" joists showed that the capped end area was too small for arches on this floor.

Thus/
Thus the 5" x 4½" section with caps would be required for arches but a smaller cap would be suitable for props.

In seam S. on a coal floor both the 5" x 4½" and the 5" x 3" joists with plain ends cut into the floor and developed fluctuating resistances with violent bumps. These sections with ends turned developed about 33 tons with less than ¼" of penetration (Fig. 8).

As props on longwall faces the resistances developed by the sections as cut were sufficient to justify their use but not for arches where floor penetration is to be avoided.

In seam T. on a strong blae floor the 5" x 4½" joist as cut developed a maximum resistance of 22 tons while penetrating 3.6". The 5" x 3" resisted only 12 tons for 3½". Similarly, with the ends turned over, the 5" x 4½" reached 32 tons for .3" of penetration while the 5" x 3" reached 22½ tons during 5" of penetration and then decreased. See Fig. 9.

The results showed that the 5" x 3" capped section would be suitable for props but 5" x 4½" capped section would be necessary for arches.

In seam R. on a fireclay floor a wood prop 4" diameter developed a maximum resistance of 6 tons and continued to offer a resistance of about 4½ tons, until the penetration reached 3½". By comparison the joist prop 4" x 3" with plain end penetrated 1½" at the maximum load of 2 tons and its resistance had only reached 4 tons when the penetration was 3½".

When undercutting, 2" or 3" of coal were sometimes left on the floor and some props were set on this. In the penetration test on this coal, the wood prop 4" diameter penetrated .4" while developing a resistance of just over 20 tons. The prop split and bulged and the resistance decreased to 10 tons at which load penetration continued to 1½". By contrast, the joist prop 4" x 3" as cut off, developed a maximum resistance of 9 tons during penetration, amounting to 3½".

These results show that the deterioration in roof condition which occurred when the joist props were substituted for the wood could be attributed to the smaller resistances of the joist props.
Penetration Tests

Colliery No.
SEAM P.

N°1 5" x 4½" H Section Plane
N°2 5" x 4½" Section Flange Turned Over

Penetration in inches.

N°1 5" Plane cut off
N°2 5" Flange Turned over

Fig. 6
Penetration Tests

Seam Q
Sect 5'x4' Flange Turned Over x
5'x4' Plane Cut Off 0

Penetration in Inches

Sect 5'x3' Flange Turned Over x
5'x3' Plane Cut Off 0

Penetration in inches
Penetration Tests

Colliery No. 14.  
Seam S.

Section 5' x 4'6 Flange Turned Over X
Section 5' x 4'6 Plane Cut Off 0

Penetration in inches

Section 5' x 3' Flange Turned over X
Section 5' x 5' Plane Cut Off 0

Penetration in inches

Fig. 8
**Penetration Tests**

**Colliery**

**Seam T.**

- **Test Pieces Section 5.12 Flange Turned Over**
- **Test Pieces Section 5.18 Plane Cut Off**

![Graph of Penetration in inches](image)

**Coal 3'**
- **Rib Stone 10'**
- **Parrot Coal 1'**
- **Coal with thin stone Rib 3'**
- **White Rib 5'**
- **Coal 7.2'**
- **Pavement**
- **Dark Blary Strong 26'**
- **Hard Wain Rib 2.6'**

**Test Pieces Section 5.18 Flange Turned Over**
- **Test Pieces Section 6.18 Plane Cut Off**

![Graph of Penetration in inches](image)

**Fig. 3.**
FLOOR PENETRATION TESTS.

Sandstone floor wet and dry.

At Colliery No. 10, Seam H, 3'6" thick with a hard sandstone floor and fakes roof, joist props 5" x 4½" section with both ends turned over were used. These props were being damaged despite the use of 2" x 6" x 6" wood lids between the props and straps. Composite Tubular Props 5" O.D. ¼" thick were substituted for these as it was found by test that the former sustained 100 tons (the capacity of the test machine) while the latter buckled at 90 tons. The tubular props buckled in the same way but not to the same extent as the joist type.

Convergence tests were made (fig. 1) which shewed convergence between face and waste amounting to 3.6 inches and as the props were set 3 feet back from the face and withdrawn at the waste edge the convergence over this distance would be approximately 3 inches. Floor penetration tests (fig. 10) shewed that the joist prop 5" x 4½" section even with the end cut off developed a resistance of 31 tons while penetrating to a depth of ¾" into the floor. This clearly shewed the need for a smaller contact area for the floor and single capped 5" x 4½" joist props were installed and behaved satisfactorily.

Further penetration tests where the sandstone floor was wet (fig. 10) disclosed that the sandstone was considerably weakened by water. A 5" x 4½" single capped joist prop penetrated the floor under a load of 25 tons, the floor was ruptured, and the prop resistance fell to 10 tons. Thereafter the resistance increased to 31 tons for a total penetration of 1¾".

Where such conditions were encountered in this seam, the tubular prop was not buckled and gave the best results.
Seam H.
Colliery No. 10

Floor Penetration Tests

Inches Penetration.

Fig. 10.
WET FIRECLAY FLOOR.

In Colliery 11, Seam K, penetration tests were made on a wet fireclay floor. Fig. 11 shows the results obtained in using 5" x 4\(\frac{3}{4}\)" and 5" x 3" joist sections capped and uncapped.

The maximum resistance recorded was with the 5" x 4\(\frac{3}{4}\)" capped section, and amounted to 7 tons for a penetration of .4 inches.

The results showed the need for the use of chocks. Understraps between the prop and the floor are also necessary, particularly as the roof is of massive sandstone.

The effect of water in weakening the floor is also apparent.
Penetration Tests.

Collery 11
Seam K

Test Piece Section 5.5 x 4.5 Flange Turned Over X
Test Piece Section 5.5 x 4.5 Plane Cut Off 0

Penetration in Inches.

Inclination of Seam 1 in 8
Damp

Fig. 11.
"PREMIER" SQUARE BELLOWS CAMERA.
C.P. Finlayson, Esq.,
The Library,
University of Edinburgh.

Dear Sir,

We thank you for your esteemed enquiry of the 15th June, and have pleasure in enclosing an illustration and specification of our "Premier" Square Bellows Camera. The price of this camera in the half-plate size, complete with three double book-form dark slides, the camera and slides brass-bound, is £43. 12s. 6d. Extra brass-bound double dark slides are £4. 12s. 6d. Packing, carriage and insurance extra at net cost. Delivery at the present time is 6 - 8 weeks from receipt of order.

Assuring you of our best attention to your further instructions, we are,

Yours faithfully,
W. WATSON & SONS LTD.
THE "PREMIER" SQUARE BELLOWS CAMERA for plates or flat films 6½" x 4⅝" or smaller was designed for technical and scientific photography where lightness and portability are not the chief requirements. It is most solidly constructed in well-seasoned mahogany and the extra weight gives the highest degree of strength and rigidity, yet with every facility for rapid and accurate work; for strength and durability it has no equal. It is specially recommended for use in ship-yards, technical and clinical laboratories, process and commercial studios, museums and galleries.

SPECIFICATION

EXTENSION is effected by rack and pinion of the back to move in either direction. The teeth of the rack being cut diagonally gives a perfectly smooth movement free from back-lash. The back also slides in grooves along the travelling frame for quick focusing, and is clamped into position by clamping screws, the models from 12 x 10 ins. upwards are made to adjust by a quick acting central screw, these sizes being too large for rackwork to act satisfactorily.

SWING MOVEMENT is provided to the back which may be swung in either horizontal or Vertical position. The front is rigid.

RISING AND FALLING FRONT is obtained by means of the main front panel moving in either direction. Cross movement is obtained with the lens panel. The size and solidity of the front allows large and heavy lenses to be fitted with safety.

THE BELLOWS are square and made with leather lined with special fine linen.

THE REVERSING FRAME is easily manipulated and is fitted with a hinged focusing screen.

THE DOUBLE DARK SLIDE are the book-form type and fitted with flush stops and springs to the shutters. These leave the slides quite clear inside for the reception of flat film holders and adapter carriers. The springs automatically hold in the shutters when closed after exposing a plate. The slides are made to standard gauges and extra slides can be obtained.

½-plate "PREMIER" CAMERA complete with three book-form slides
the camera and slides brass-bound - £43. 12. 6.

W. WATSONS & SONS LTD.

In Seam J.1, on a soft clay floor, composite steel props 5" diam. only resisted from 3 to 5 tons while penetrating 4" after resisting 10 tons with ½" of penetration.

The same prop with an end cap fitted (fig. 12a) built up a resistance of 15 tons with 3.9" of penetration.

When erected on coal left on the floor by the machine both props ruptured the floor at 19 to 21 tons and the resistances then decreased to less than 10 tons. On such a soft floor even these large diam. props do not resist as much as is desirable.

In Seam L.1, similar tests to the above were made and again the very soft floor offered such small resistance to penetration that even the large section props used were not satisfactory. See Fig 12b.

These are cases where chocks were found to be a useful supplement to the propping system.

Test on soft clay floor
1 8-in. steel tube with end cap
2 5-in. steel tube wood filled

Test on coal floor 1 ft thick, above soft clay floor
3 8-in. steel tube with end cap
4 5-in. steel tube wood filled.

Coal bursting up around prior.

STRATA.

Inches penetration.


Test on soft clay floor
6 3-in. steel tube with end cap
7 5-in. steel tube wood filled

Tests on 1/6 of coal left above soft clay floor.
1 5-in. steel tube with end cap
2 5-in. steel tube wood filled
3 6-in. steel tube with steel end cap

Coal forming and coal floor bursting up.

Floor cracks forming.

Inches penetration.

Fig. 12.
ROOF AND FLOOR PENETRATION, COLLIERY 11, SEAM H.1.

In Seam H.1 with a blaes floor and a soft coal roof, wood props, 4" diam. and 3'9" long with 4" broad wood straps, were in use. Considerable crumbling of the roof above the straps was noticeable and the roof coal collapsed occasionally between the straps. The wood props were often broken after penetrating the floor for 3". It was considered that the introduction of 4" diam. composite steel props would be beneficial. A 4" diam. 7/16" thick steel prop was tested on the blaes floor. At first, resistance was built up steadily to 3 tons but while penetration continued to about 3'9" the resistance offered by the prop fluctuated. This fluctuation increased and the floor was crushed to a distance of 12" round the prop till a maximum resistance of 25 tons was developed for 4.8" of penetration. Thereafter the resistance decreased.

The wood props often broke after penetrating 3" into the floor. The steel prop developed a resistance of 10.5 tons for 3" of penetration. This resistance is much less than 25 tons, which is the buckling load for such a wood prop. Evidently the wood props were broken by unaxial loading.

A 5" x 4\(\frac{3}{4}\)" joist with end cap was erected on the same floor and the usual 5" broad steel strap on a 2\(\frac{1}{2}\)" x 6" x 6" wood lid was set to the roof. Three measurements were taken against load, viz. floor penetration, the crushing of the lid and the total lid and roof penetration. From the latter, the actual roof penetration was determined. In Fig. 13A it can be seen that up to a load of 33 tons the joist had penetrated about 7⁄8" with little fluctuation, whereas the total roof penetration fluctuated considerably due to the irregular behaviour of the hardwood lid. The actual roof penetration increased steadily to about 1 inch while building up a resistance of 31 tons. Thereafter, penetration increased to 1.2" for a resistance of 33 tons.

In this test it is noticeable that the crushing resistance
- ROOF AND FLOOR -

- PENETRATION TESTS -

1. Roof and pavement tests 5'4'2 F.T.O
   - Roof penetration with 7'4' wooden lids.
   - Actual roof penetration.
   - pavement test with 7'4' wooden lids.

Penetration in inches

2. Roof and pavement tests 5'4'2 F.T.O
   - Roof penetration with 7'4' wooden lids.
   - actual roof penetration.

Penetration in inches

Fig. 13.
of the thick lid causes very large fluctuations.

In a similar test using a hardwood lid 1\(\frac{1}{4}\)" thick, (Fig.46) these fluctuations were smaller, presumably due to using a thinner lid which had a smaller influence on the resistance developed.

Thus the "cushioning" effect of hardwood lids though beneficial in protecting the props from damage, allow of severe fluctuations of resistance. This should be considered before very thick lids are utilised.

In both the above tests, roof penetration was greater than floor penetration for any given resistance.

Similar penetration tests were made on a 5" x 3" joist with end capped and without a wood lid under the steel strap. Roof and floor penetrations were measured directly. The joist developed a resistance of 24\(\frac{1}{2}\) tons while penetrating the floor for .4 ins. At this load the resistance decreased to 21 tons, rising thereafter to a maximum of 26 tons, while penetrating to .6 ins. The resistance fell in stages to 5 tons for 1" of floor penetration and fluctuated to 11\(\frac{1}{2}\) tons for nearly 5" of penetration.

The amount of roof penetration, however, increased regularly with the resistance until a maximum was developed of 24 tons while the strap penetrated .6 ins. into the roof. The roof penetration was, however, less than the floor penetration for a given resistance. When a 4" x 3" joist with end as cut was tested (Fig.14a) a maximum resistance of 18 tons was developed with considerable fluctuation for a total floor penetration of 3.7 ins. thereafter the resistance decreased. A resistance of 2 tons was developed for a roof penetration of .1". At this stage the amount of roof and floor penetration was equal. Roof penetration increased to .2" for a resistance of 3.5 tons, thereafter resistance was built up to 27 tons without appreciable roof penetration.

Here again roof penetration was less than floor penetration for any given resistance.

In all the above tests on roof and floor penetration the roof/
Floor Penetration Tests

No XI Colliery
Seam H 1

X Test Piece Section Flange Turned Over
O Test Piece Section 5 x 3 3/4 Plane Cut Off

Penetration in Inches

X Section 5 x 3 F TO
O Section 5 x 3 P CO

Penetration in Inches

Inclination 1 in 3
Seam Danae
Very liable to heave

Fig. 14
roof contact was through the medium of a 5" wide corrugated steel strap.

From these tests, it will be noted that the roof penetration decreases as the floor contact decreases and simultaneously the floor penetration increases.

In a face on this seam, it was not possible to prevent roof penetration while 4" diam. wood props were in use. The roof contact area could not be increased, but by the introduction of 4" x 3" joist props with end as cut, the floor contact area was reduced thereby obviating much roof penetration but increasing the floor penetration. No lids were used between steel prop and steel strap.
To ascertain the relative penetration of a prop into the roof and floor, the apparatus shown in fig. 15 was used. The recorders were set 3" from joists at various positions along a coal face in Colliery No. 14, Seam P, with a coal floor and roof. No lids were used between the joist and the strap or floor. Props were set 4' apart and the inclination along the face was 1 in 3.

The results obtained in test No. 3 where the recorders were set opposite a pack and 7' from the face are shown in fig. 16 graph 3. It can be seen that the prop was penetrating both roof and floor in the early stages, later most of the penetration was in the floor.

In test No. 4, the results of which are shown in graph 4, there was little floor penetration but considerable roof penetration during the first hours. Afterwards roof penetration almost ceased and floor penetration continued.

In test No. 5, the results of which are shown in graph 5, fig. 16, roof and floor penetration were nearly equal during the first twelve hours, after which roof penetration was largest.

In test No. 6, the record was taken over a period of forty-eight hours instead of twenty-four hours as in previous cases. Roof penetration was considerable and the roof was badly broken up. The total floor penetration only amounted to about 1".

On this face single capped joist props of 5" x 4½" section and 5" broad steel straps were in use. The floor coal was hard while the roof coal was very weak.

As the contact areas of the props with the floor were already small and it was not possible to obtain wider straps, chocks were used to supplement the propping system.

ROOF AND FLOOR MOVEMENT TESTS IN COLLIERY No. 14.

To ascertain approximately the change of deflection between roof and floor between props, a joist prop was fitted with angle brackets as in fig. 15.

Two/
INSTRUMENT SET FOR ROOF AND FLOOR PENETRATION

SCALE 1\(\text{"")} 70\(\text{"")}\)

- ANGLE IRON
- PROP
- PLUG
- TELESCOPE TUBES
- CLOCK
- STRAP

2'-0"
Roof and Floor Penetration:

Colliey No. 14, Seam P.
Two recorders were used. One was set between the roof and lower bracket, and the other from the floor to the upper bracket.

The records obtained by this arrangement shewed approximately the movements of roof and floor relative to the prop.

In Seam R, with a weak biaes roof and a coal floor, the joist prop was erected to a strap as a face prop 3' from the face with the brackets parallel to the face. During the first twenty-four hours the recorders were 3" from the joist and shewed very little roof or floor deflection relative to the prop. See fig. 17, graphs 1 and 2. During the next twenty-four hours the recorders were again set 3' from the face and 12" from a similar joist prop. The total deflection of the roof amounted to $\frac{3}{4}$" in twenty-four hours. The floor deflection was still very small. During the following twenty-four hours the recorders were again moved forward to a position 3' from the face and 24" from the joist, and were thus midway between adjacent props. The roof deflection measured was $1\frac{1}{2}$" and the floor deflection was still very small.

These results indicate that there may be considerable local deflection between props and shew the need for systematic strapping with short spaces between props.

Before the straps reached the waste edge in this seam, the straps had often penetrated into the roof itself and the weak biaes fell out from between the straps.
Convergence and extensive breaks in massive Sandstone roof.

In Colliery No. 11, Seam K, with massive sandstone roof over 30 feet thick, series of records of convergence, figs. 18, 19 were taken between the face and the wastes and opposite packs. Over periods of 48 hours the convergence in each case was approximately one inch. This is very small in relation to the thickness (6 feet) of the seam, and shews the rigidity of such massive sandstone roofs. Periodically there were violent bumps and extensive fractures were formed in the sandstone as shewn in figs. 18, 19. The sudden lowering of the mass on the waste side of the break forced the props into the floor. To prevent these breaks from extending over to the face, hard wood chocks were used at the waste edges.
COLLIERY NO. 11. SEAM K.

CONVERGENCE RECORDS
BETWEEN FACE AND WASTE.

Record No. 1:

Machine Passed

Record No. 2:

Machine Passed

Record No. 3:

Machine Passed

Record No. 4:

Machine Passed

---

FIG. 18.
COLLIERY II
SEAM K

BREAKS IN MASSIVE SANDSTONE OF ROOF AT FACE

SECTION ON LINE A-H

FIG. 19.
SWINGING OF PROPS.

To reduce unaxial loading, relative lateral movements should be reduced to a minimum.

The results of tests on the swinging of props in Colliery No. 9, seam H. are shewn in Fig. 20.

All the props were swinging at the head towards the face and towards the dip. Opposite the well built packs, the swinging was least, and it was greatest opposite the wastes.

When packing was relatively poor in quality and waste spaces were approximately 35' wide, the props swung to a greater degree than was the case where the packing quality was good and with waste spaces reduced to 30'. Quite definitely, in this as in other cases, it is proved that swinging and hence unaxial loading of props has been reduced as the effectiveness of packing has been improved.

The results obtained on swinging of props in seam J4 Colliery 9 are shewn in Fig. 21.

All the props were swinging uphill at the head during the first twenty-four hours. After this, the movement was downhill, even with initial underset of 30'. At right angles to the face in every case except Prop C initial swinging after setting was towards the coal, even when the props were set initially towards the waste. After this, movement was towards the waste at the head. This occurred when the props were 7½' from the face.

From the results of these tests and from the observations made in conjunction with them, the following conclusions are drawn.

Effective packing reduces swinging and unaxial loading.

Provided packing is really effective, props gave the most satisfactory results when set to the normal.

In highly inclined seams, it was found desirable to set the props in recesses in the floor.

Where the floor is very weak, excessive penetration leads to unaxial loading even when relative lateral movement is small.

This is the consequence of fixing of the prop ends in the floor.

By/
**Colliery No. 9, Seam H.**

**Top Bank Seam. Observations on Prop Swinging.**

**Height of seam 4 ft. Undercut to 4 ft. 6 in. Depth. M/C always cutting uphill.**

<table>
<thead>
<tr>
<th>Position of Prop</th>
<th>Prop No. 1</th>
<th>Prop No. 2</th>
<th>Prop No. 3</th>
<th>Prop No. 4</th>
<th>Prop No. 5</th>
<th>Prop No. 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section</td>
<td>Section</td>
<td>Section</td>
<td>Section</td>
<td>Section</td>
<td>Section</td>
<td>Section</td>
</tr>
<tr>
<td>Parallels to Pe. Angles</td>
<td>Parallels to Pe. Angles</td>
<td>Parallels to Pe. Angles</td>
<td>Parallels to Pe. Angles</td>
<td>Parallels to Pe. Angles</td>
<td>Parallels to Pe. Angles</td>
<td></td>
</tr>
<tr>
<td>Coal Face</td>
<td>Coal Face</td>
<td>Coal Face</td>
<td>Coal Face</td>
<td>Coal Face</td>
<td>Coal Face</td>
<td>Coal Face</td>
</tr>
<tr>
<td>Initial Setting</td>
<td>Set from Face</td>
<td>Unset</td>
<td>Set from Face</td>
<td>Unset</td>
<td>Set from Face</td>
<td>Unset</td>
</tr>
<tr>
<td>After 24 Hours</td>
<td>Tilt 1/3</td>
<td>Tilt 1/3</td>
<td>Tilt 1/3</td>
<td>Tilt 1/3</td>
<td>Tilt 1/3</td>
<td>Tilt 1/3</td>
</tr>
<tr>
<td>1/2 from coal</td>
<td>75° down hill</td>
<td>75° down hill</td>
<td>75° down hill</td>
<td>75° down hill</td>
<td>75° down hill</td>
<td>75° down hill</td>
</tr>
<tr>
<td>After 50 Hours</td>
<td>1/2 from coal</td>
<td>75° down hill</td>
<td>75° down hill</td>
<td>75° down hill</td>
<td>75° down hill</td>
<td>75° down hill</td>
</tr>
<tr>
<td>75° from coal</td>
<td>75° down hill</td>
<td>75° down hill</td>
<td>75° down hill</td>
<td>75° down hill</td>
<td>75° down hill</td>
<td>75° down hill</td>
</tr>
<tr>
<td>Remarks</td>
<td>Set opposite a waste which was falling freely. Prop swung downhill and towards the coal.</td>
<td>Set opposite a waste which was falling freely. Prop swung downhill and towards the coal.</td>
<td>Set opposite a waste which was falling freely. Prop swung downhill and towards the coal.</td>
<td>Set opposite a waste which was falling freely. Prop swung downhill and towards the coal.</td>
<td>Set opposite a waste which was falling freely. Prop swung downhill and towards the coal.</td>
<td>Set opposite a waste which was falling freely. Prop swung downhill and towards the coal.</td>
</tr>
<tr>
<td>Observation</td>
<td>Prop A</td>
<td>Prop B</td>
<td>Prop C</td>
<td>Prop D</td>
<td></td>
<td></td>
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<tr>
<td>-------------</td>
<td>--------</td>
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<td>--------</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Position</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Prop</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height of Scan 4'-6&quot;</td>
<td>3'-3 1/2&quot;</td>
<td>3'-3</td>
<td>3'-3</td>
<td>3'-3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angle to Coal Face</td>
<td>2&quot; 10' 30&quot;</td>
<td>2&quot; 10' 30&quot;</td>
<td>2&quot; 10' 30&quot;</td>
<td>2&quot; 10' 30&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remarks</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>

Fig. 21
By adjusting the shape and area of prop ends to suit the nature of the floor beds, and by reducing convergence to a minimum, excessive penetration can be avoided.
STRENGTHS OF VARIOUS SUPPORTS.

TESTING PRESS.

The machine used was a horizontal hydraulic press with a 12" diameter ram. The adjustable carriage was held in position by two arms fixed to the cylinder and passed through lugs in the carriage. Pressure was supplied to the ram by a hand pump which was fitted with a pressure gauge calibrated to give load in tons in terms of pounds per square inch pressure.

TESTS ON PROPS.

Series of compression tests were made on composite steel props and wooden props to ascertain the buckling loads for various lengths and diameters.

The results are shewn in Fig. 22 and are used for reference in the selection of props. It will be seen that the buckling loads decrease with increase in length and rise with increase in diameter.

STRENGTHS OF JOIST SECTIONS.

The joist sections used for props and arches are shewn in fig. 23. The moments of inertia about the xx and yy axes are given and they shew the comparatively small resistances of joist sections to loads applied perpendicular to the webs.

Using Rankine's formula for struts with fixed ends the buckling loads have been calculated for four feet lengths of joist, rail, channel and tubular props.

4" x 3" /
Compression Tests

on Composite Steel Props without Caps.

All Props Hardwood Filled.

Compression Tests on Wooden Props.

Fig. 22.
Ixx = 14.28 inch units.
Iyy = 1.69 inch units.

Ixx = 12.56 inch units.
Iyy = 1.48 inch units.

5 x 3 x 12 lbs

5 x 3 x 3.7 lbs

4 x 3 x 0.5 lbs

4 x 4 x 13.5 lbs

5 x 4.5 x 18 lbs.

Fig. 23.
4" x 3" Girder x 10 lbs./ft. 48" long.

\[ p = \frac{S}{1 + \frac{1^2}{25,000 \times R^2}} \]

\[ = \frac{25 \times 2240}{25,000 \times 48 \times 48} \]

\[ = 20.8 \text{ tons/sq.in.} \]

But sectional area = 2.79 sq.in.

\[ \therefore \text{Total buckling Load} = 23.3 \times 2.79 \]

\[ \frac{23.3}{9} = 58 \text{ tons.} \]

\[ \frac{S}{1 + \frac{1^2}{25,000 \times R^2}} = \frac{25 \times 2240}{25,000 \times 48 \times 48} \]

\[ = 19.1 \text{ tons/sq.in.} \]

But cross section area = 3.1 sq.ins.

\[ \therefore \text{Total buckling Load} = 21.4 \times 3.1 \text{ tons.} \]

\[ \left(\frac{21.4}{9}\right) = 59.2 \text{ tons.} \]
Channel 5" x 2½" x 10.22 lbs/ft. 48' long.

\[ p = \frac{S}{1 + \frac{12}{25000 \times R^2}} \]

\[ = \frac{25 \times 2240}{48 \times 48} \]

\[ = \frac{21.3 \text{ Tons/ sq. in.}}{} \]

But sectional area = 3.23 sq.ins.

\[ \therefore \text{Total buckling load} = 23.9 \times 3.23 \]

\[ = 78.7 \text{ tons.} \]

Tube 4" O.D. x ⅛" thick 10.013 lbs/ft. x 48" long.

\[ p = \frac{S}{1 + \frac{12}{25000 \times R^2}} \]

\[ = \frac{35 \times 2240}{48 \times 48} \]

\[ = \frac{33 \text{ tons/ sq.in.}}{} \]

But sectional area = 2.9 sq. ins.

\[ \therefore \text{Total buckling load} = 33 \times 2.9 \]

\[ = 95.7 \text{ tons.} \]
Comparative tests on tubes without and with wood cores and also with end caps.

The high tensile steel tubes were 5" diam. and 5' long. The loads were applied by the horizontal press, and compressions of the tubes were measured by micrometer dial indicators between pins screwed into the tubes 3' 11" apart along the tubes and 90° apart in section. The results obtained are shown in fig. 24.

The unfilled tube (No. 1) without end cap began to buckle under a load of 86 tons. When fitted with end caps (No. 2) unaxial loading was clearly shown when the load reached 70 tons and continued to cause gradual buckling until the load reached 86 tons when definite failure occurred.

With a wood core which was protruding initially by 3" and 1,15/16" at the ends (No. 3), the core alone was compressing until the load reached 33 tons, and the wood had then been pressed into the tube a total distance of one inch. As the load was increased, both the core and the tube were compressing separately until the load reached 87 1/2 tons, when the wood core was protruding 1/16" at one end and nothing at the other end. The buckling load was not reached when the load amounted to 100 tons, which was the capacity of the press.

With a wood core which was not protruding and with end caps fitted (No. 4), the buckling load was not reached and the yield was 16" when the load reached 100 tons.

With a wood core which was not protruding and without end caps, unaxial loading was showing effects at 78 tons and continued until the load reached 100 tons but definite failure did not occur. A comparison of this result with that obtained with the core protruding (No. 3) shews the value of the reinforcement obtained as the wood core is pressed in to fill the tube completely. However, the ends must not protrude initially by more than 1" in 5', otherwise the bursting action on the tube near the ends becomes severe.
WOOD AND STEEL COMPRESSION SIMULTANEAUOUSLY.

BUCKLING LOAD

5'0"
TUBE EMPTY

5'0"
TUBE EMPTY

5'2"
WOOD CORED

5'0"
WOOD CORED

WOOD CORE FLUSH

NOTE:
1. IS TUBE DEFORMATION.
2. IS WOOD CORE COMPRESSION.

WOOD AND STEEL COMPRESSION SEPARATELY.

WOOD ONLY COMPRESSION.
Test on Taper Steel Tubes.

The following results were obtained by tests of short lengths of high tensile weldless tubes having one end tapered. No filling was used and the ends were uncapped.

Total length of each tube - 24".

Thickness of metal of each tube - $\frac{1}{2}"$.

The loads were applied gradually by hydraulic pump, the props being held in a level horizontal position.

Care was taken to apply the load axially as far as possible, but during test 4, after the application of about 50 tons, and in test 12 where the tapered end was not cut quite at right angles, there were deviations from this.

<table>
<thead>
<tr>
<th>No.</th>
<th>Outside Diam.</th>
<th>Length of Taper</th>
<th>Amount of Taper</th>
<th>Max. Load applied Tons</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5&quot;</td>
<td>2&quot;</td>
<td>$\frac{11}{2}$&quot;</td>
<td>65</td>
<td>Shoulder failing. Diam. 5\ 1/8&quot;.</td>
</tr>
<tr>
<td>2</td>
<td>5&quot;</td>
<td>2&quot;</td>
<td>$\frac{11}{2}$&quot;</td>
<td>70</td>
<td>Failing at taper end.</td>
</tr>
<tr>
<td>3</td>
<td>5&quot;</td>
<td>$\frac{3}{2}$&quot;</td>
<td>$\frac{11}{2}$&quot;</td>
<td>72</td>
<td>Shoulder failing. Diam. 5\ 3/32</td>
</tr>
<tr>
<td>4</td>
<td>5&quot;</td>
<td>$\frac{3}{2}$&quot;</td>
<td>1&quot;</td>
<td>67</td>
<td>Shoulder failing. Load not direct.</td>
</tr>
<tr>
<td>5</td>
<td>5&quot;</td>
<td>4&quot;</td>
<td>$\frac{11}{2}$&quot;</td>
<td>78</td>
<td>Failing at shoulder and taper end.</td>
</tr>
<tr>
<td>6</td>
<td>5&quot;</td>
<td>4&quot;</td>
<td>$\frac{11}{2}$&quot;</td>
<td>87</td>
<td>Prop expanding at middle. Max. dia. 5\ 3/32&quot;.</td>
</tr>
<tr>
<td>7</td>
<td>5&quot;</td>
<td>5&quot;</td>
<td>Nil.</td>
<td>84</td>
<td>Large diameter end failing. Prop expanding at middle. Max. dia. 5\ 3/8&quot;.</td>
</tr>
<tr>
<td>8</td>
<td>5&quot;</td>
<td>Nil.</td>
<td>Nil.</td>
<td>84</td>
<td>Failing at taper end. Shoulder failing. Diam. 4\ 9/16&quot;.</td>
</tr>
<tr>
<td>9</td>
<td>4\ 1/2&quot;</td>
<td>2\ 1/2&quot;</td>
<td>$\frac{11}{2}$&quot;</td>
<td>62\ 1/2&quot;</td>
<td>Shoulder failing. Diam. 4\ 9/16&quot;. Shoulder failing. Also at taper end.</td>
</tr>
<tr>
<td>10</td>
<td>4\ 1/2&quot;</td>
<td>2\ 1/2&quot;</td>
<td>$\frac{11}{2}$&quot;</td>
<td>67</td>
<td>Shoulder failing. Diam. 4\ 9/16&quot;. Shoulder failing. Also at taper end.</td>
</tr>
<tr>
<td>11</td>
<td>4\ 1/2&quot;</td>
<td>3\ 1/2&quot;</td>
<td>$\frac{11}{2}$&quot;</td>
<td>70</td>
<td>Large diam. end failing.</td>
</tr>
<tr>
<td>12</td>
<td>4\ 1/2&quot;</td>
<td>3\ 1/2&quot;</td>
<td>$\frac{11}{2}$&quot;</td>
<td>62\ 1/2&quot;</td>
<td>Large diam. end failing. Prop expanding at middle. Max. diam. 4\ 9/16&quot;.</td>
</tr>
<tr>
<td>13</td>
<td>4\ 1/2&quot;</td>
<td>3\ 1/2&quot;</td>
<td>1&quot;</td>
<td>78</td>
<td>Failing at taper end. Bad tapering.</td>
</tr>
<tr>
<td>14</td>
<td>4\ 1/2&quot;</td>
<td>3\ 1/2&quot;</td>
<td>1&quot;</td>
<td>75</td>
<td>Shoulder failure. Diam. 4,3/16&quot;.</td>
</tr>
<tr>
<td>15</td>
<td>4\ 1/2&quot;</td>
<td>Nil.</td>
<td>Nil.</td>
<td>80</td>
<td>Shoulder failure. Diam. 4,3/16&quot;. Failing at shoulder end and at taper end.</td>
</tr>
<tr>
<td>16</td>
<td>4&quot;</td>
<td>2&quot;</td>
<td>$\frac{11}{2}$&quot;</td>
<td>57</td>
<td>Large diam. end failing and prop expanding at middle. Prop expanding at middle. Max. 4,3/16&quot;.</td>
</tr>
<tr>
<td>17</td>
<td>4&quot;</td>
<td>2\ 1/2&quot;</td>
<td>$\frac{11}{2}$&quot;</td>
<td>62\ 1/2&quot;</td>
<td>Large diam. end failing and prop expanding at middle. Prop expanding at middle. Max. 4,3/16&quot;.</td>
</tr>
<tr>
<td>18</td>
<td>4&quot;</td>
<td>2\ 1/2&quot;</td>
<td>$\frac{11}{2}$&quot;</td>
<td>66</td>
<td>Large diam. end failing and prop expanding at middle. Prop expanding at middle. Max. 4,3/16&quot;.</td>
</tr>
<tr>
<td>19</td>
<td>4&quot;</td>
<td>3&quot;</td>
<td>$\frac{11}{2}$&quot;</td>
<td>65</td>
<td>Large diam. end failing and prop expanding at middle. Prop expanding at middle. Max. 4,3/16&quot;.</td>
</tr>
<tr>
<td>20</td>
<td>4&quot;</td>
<td>3&quot;</td>
<td>1&quot;</td>
<td>70</td>
<td>Large diam. end failing and prop expanding at middle. Prop expanding at middle. Max. 4,3/16&quot;.</td>
</tr>
<tr>
<td>21</td>
<td>4&quot;</td>
<td>4&quot;</td>
<td>$\frac{11}{2}$&quot;</td>
<td>68</td>
<td>Large diam. end failing and prop expanding at middle. Prop expanding at middle. Max. 4,3/16&quot;.</td>
</tr>
<tr>
<td>22</td>
<td>4&quot;</td>
<td>Nil.</td>
<td>Nil.</td>
<td>70</td>
<td>Large diam. end failing and prop expanding at middle. Prop expanding at middle. Max. 4,3/16&quot;.</td>
</tr>
</tbody>
</table>
OBSERVATIONS.

1. Failure at the tapered end was associated with short taper.
2. Failure along taper was associated with larger reductions.
3. Highest loads were obtained where taper was long and area reduction small.
4. Irregularities in results due to lack of uniformity in process of tapering.

CONCLUSIONS.

The length of the taper should not be shorter than 1" less than the diameter of the prop.

The amount of taper should not exceed one third of the length of taper. If this rule is observed, the tapered tube will develop practically the full load of the untapered tube, at least for the diameters and thicknesses of metal under test.
STRAPS.

Using the horizontal hydraulic press two straps of the sections shown in Fig. 25 were tested with ends clamped in a suitable frame (Photo 40) and with the application of centre loads. The results are shown in Fig. 25.

Although the Richards strap weighed 13 lbs. per foot as against 9% lbs. per foot for the circular corrugated strap, the greater strength of the former is due chiefly to the better disposal of the material. This will be seen by comparison of the moments of inertia about the axes through the centroids.

For the Richards strap
\[ I = 0.3 \]

and for the circular corrugated strap
\[ I = 0.15 \]

In using the ordinary design of corrugated strap, 5" broad, 1" deep and of material \( \frac{3}{8} \)" thick, it was noted that in contact with weak roofs, many straps were bent between the props. It was found impossible to obtain broader straps than the ordinary 5" and straps of material \( \frac{1}{2} \)" thick and of 1\( \frac{3}{4} \)" depth were found to be better.

It was noted, however, that, in rolling, the edges were sharp and tended to cut into the roof. This cutting action has been considerably reduced by having the edges rounded.
LOAD TESTS ON STEEL STRAPS

DEFLECTION IN INCHES
(CENTRE DEFLECTION)

RICHARDS STRAP

COMMON CORRUGATED STRAP

Fig. 25.
Conversion from Wood to Steel props.

At Colliery No. 14, Seam R, 3' thick with fireclay floor, and a blaes roof varying in thickness from 3" to 18" with banded sandstone above, wood props 4" diam. and wood straps 4" broad were in use. In accordance with the policy of conversion to steel 4" x 3" section single capped joist props were installed, the plain ends being put to the floor. These props penetrated the floor and the roof condition deteriorated. The packing spaces were reduced from approximately 25 feet to approximately 20 feet to improve the roof condition, but the roof still remained weaker than it had been. The quality of the material for packing was poor, some of it being obtained from the dirt rib in the seam. After the roof at the face had collapsed several times, wood props 4" diam. were re-introduced (see under Penetration Tests.)

There were three rows of straps in use, the coalcutter space being protected. To improve the quality of the packing, better material was got from dummy roads brushed in the sandstone beds above the blaes. This improved the roof condition, but as the waste was already partly filled with the blaes from the roof, and stone from the seam, there was difficulty in getting good foundation for the packing stone.

At this stage, the packs were at a minimum distance of 24 feet from the coal face and by changing the strapping system to two rows, (fig.26a) and then by the introduction of hard wood chocks between the packs, the space between packs and face was reduced to 9 feet. This was an improvement.

To reduce this distance still further, one row of 6' long straps was substituted for two rows of 4½' long straps, the undercut being 4½', fig.26b. Then, by dropping a dummy road at a time and substituting a row of chocks of large section wood, the roof at the face has been so improved that tubular steel props of 4" diam. are being introduced, fig.26c.
REARRANGEMENT OF FACE SUPPORTS.

COLLIERY 14. SEAM R.

A. ELEVATION.

B. ELEVATION.

C. ELEVATION.

FIG. 26.
PROPPING SYSTEMS. A system of face supports should be adopted which is effective where persons are working, and gives support where required, to offer resistance in substitution for that removed by the working of the coal. In these respects, systematic strapping as well as propping has to be considered.

At the place where the coal is being worked, even with a proper system, there is usually need for the use of temporary supports before the permanent supports can be erected.

The coalcutter and the conveyor, if these are used, require to be considered in relation to the system.

Figures 27A - F shew various systems of propping and strapping at the stages when the face has been cleared off and also when it is ready to be cleared off.

There is the disadvantage in the arrangement shewn (Fig. 22A) that the roof under which the machine passes is unprotected and there is a liability to falls of roof in this area.

In an arrangement (Fig. 27B) which is specially suitable where the roof is very weak, the props are set to the face ends of the straps immediately after coal cutting. The end prop in each case is erected before the centre prop, shewn dotted, is withdrawn. There is the disadvantage that the packs cannot be advanced as close to the face as in the other cases described.

Some support is afforded to the roof between the prop line and the coal by the overhanging strap (Fig. 27C) and this support can be increased if the space for the conveyor is reduced in width and the straps are needle into the coal. This necessitates the use of straps at least 6' long irrespective of the depth of undercut, as shewn. Long straps (Fig. 27 C) give added support where the space for the conveyor cannot be reduced.

In systems A, C and D the props are not disturbed after setting by the stripper till they are withdrawn.

Whatever the system of strapping adopted, it is important that the straps should not overhang at the waste side as they are liable to be bent and even to push out the waste side props.

In most cases, with coal cutters and conveyors, maximum
Propping Systems.

Scale: \( \frac{\text{\(\frac{\text{inch}}{\text{foot}}\)}}{\text{\(\frac{\text{inch}}{\text{foot}}\)}} \)

A.

BEFORE CLEARING FACE

COAL FACE

COAL CUTTER SPACE

CONVEYOR SPACE

B.

BEFORE CLEARING FACE

COAL FACE

COAL CUTTER SPACE

CONVEYOR SPACE

C.

AFTER CLEARING FACE

COAL FACE

COAL CUTTER SPACE

CONVEYOR SPACE

Fig. 27.
Propping Systems.

Scale: 1/4 inch to 1 foot.

C.1.

Before Clearing Face

Coal Face

Coal Cutter Space

Conveyor Space

Fig. 27.
Propping Systems

Scale: 1/6 inch to 1 foot

D.

After Clearing Face

D₁.

Before Clearing Face

D₂.

After Clearing Face
PROPPING SYSTEMS.

Scale: 1/6 inch to 1 foot.

E.

Before Clearing Face

Coal

Cutter Space

Conveyor

Space

-Pack

F.

Before Clearing Face

Coal Cutter Space

Conveyor Space

Pack

Fig. 27.
spaces of 4' between props can be adopted. This limitation
is desirable even with sandstone and so called strong roofs.
In standardising the maximum distances between props throughout
a colliery, there is the advantage that the officials and men
will become accustomed to the scheme.

In Fig. 27 a system of cross strapping for use under
weak roofs is illustrated, the arrangement of the propping being
similar to Fig. 27 B. The straps shewn parallel to the face
have the ends shaped so that cross straps pass over them and the
same props support both. Between the props all the straps
are in contact with the roof. On a short face where these have
been tried, little or no trouble in erection has been experienced
since the facemen have learnt how to handle them.

Another method of preventing penetration of a
weak roof is shewn in Fig. 27 P where straps of double the
normal width are used. As it was impossible to obtain an
extra wide strap, pairs of 5" wide straps were welded together.
These straps are heavy and require the use of a light erecting
prop, but they have proved very serviceable.

The use of a strap shorter than the depth of undercut
cannot be recommended from experience, as it leads to lack
of system in setting with all the troubles associated.
CHOCKS.

Chocks are set between face and waste to supplement the propping system.

When any longwall face is set away it is good practice to use a row of chocks to reinforce the last row of props until a sufficient volume of packing has been done.

In some cases, despite efficient packing, it has been found that there is an increase in the rate of convergence over the face when the props are withdrawn from the waste. Chocks systematically applied can reduce this action and continue to give resistance until the packs have taken the load.

There is another use for chocks where roof or floor are weak as in seam E where the roof is of weak bleas and in seam K. where the floor is of fifeclay. They may also be used beneficially where water causes the floor material to offer varying resistances to penetration as in the seam, H. Colliery No. 11. In these cases, the props offer very small resistances. A row of chocks can be set between the conveyor and the coal while leaving room for the passage of the coalcutter as in seam L. Colliery No. 8, where a bed of soft fireclay forms the floor. These give early support and help to prevent excessive swinging of the props which is so liable to occur in these circumstances.

Chocks may also be used in place of props in a thick seam as in seam H. Colliery No. 5, Fig. 28. The coal is 9' high being taken off in two "lifts". Temporary props are set where necessary between the chocks.

Chocks should, in all cases, be erected before the coal is cut. Steel chocks pieces made from scrapped arches and short pieces of angle iron or flat bar (Fig. 29) have proved serviceable. They can be handled in one hand easier than a similar hardwood piece.

The chock piece as shown (Fig. 29) 2' long, weighs 25 lbs. compared with a hardwood piece 2' long and of 5" x 5" section weighing 18 lbs. approximately.
Seam H. Colliery No. 5.

Scale 1" to 12'.

Section on AB.

Seam Q. Colliery No. 15.

Average Thickness of Coal 33'

Girders to have 1" Stilts.
STEEL CHOCK PIECES

Fig. 29.
The contact area of a chock with roof and floor should be such as to avoid penetration of the roof yet allow penetration of the floor before the resistance developed is sufficient to destroy the chock pieces. Where the floor is very hard it may be necessary to use a layer of wood to give the necessary yield. As in seam H. Colliery No. 3 where the amount of convergence between face and waste is relatively large, chock withdrawal devices make the withdrawal expeditious and have proved serviceable.
Packing Systems.

The permanent support upon which depends the general control of the movements of the strata, both in advance and behind the coal face, are the roadside and intermediate packs if any. It has been shewn by Dr. Winstanley "that the magnitude and nature of the movements induced by longwall working depend very much on the positions, sizes, quality and, particularly, the tightness and stability of the packs."

The movements of the beds are greatest immediately in front of and behind the face. It is necessary, therefore, to keep the packs as close to the face as possible, so that they will resist early and reduce the span where the damage is most likely to occur. As the greatest movements occur during undercutting, the packs should be built forward before coal is undercut." (Safety in Longwall working - Pamphlet No. 3 - Mining Institute of Scotland Safety Committee).

Tightness and stability are of great importance, if uniformity of resistance is to be obtained.

Packs of poor quality offer very erratic resistances and may cause rather than prevent fracturing of the beds in the neighbourhood of the face. 

Where there is an adequate supply of (high quality) packing material, it would be best to pack the waste completely and tightly if time were available in the cycle of operations. This is done in a development in Seam Q Colliery No. 15 as illustrated Fig. 28. Rapid advance of the face line, however, renders this improbable if done by hand, and the small material which can be handled by stowing machines is rarely packed effectively.

This later was noted during a three months visit to the Ruhr, Germany.

If the packs are of poor quality, even though continuous from one end of face to the other, they will not become effective until considerable convergence had occurred.

As quality of packing is of paramount importance, it is best to utilise/
utilise the higher quality packing material available to build a lesser total volume of pack. There are various arrangements of strip packing which are effective. The first problem will be to where find the best packing material can be obtained. In some cases, a dirt parting or stone band in the seam may provide sufficient material but generally, most of it is obtained from the roof or floor either by brushing or by arranging the packs so that the roof falls in the waste and is available.

Packing from road brushing (with or without falling wastes).

In this case, roads which may not be necessary for haulage or other purposes are brushed at intervals along the coal face, and the material so got is built in strips either on one or both sides of the brushing face. Fig. (26 3) Brushing may be done either in the roof or floor whichever is more suitable.

In ordinary circumstances where good quality packing material is readily obtainable from the wastes, the dummy road system cannot be recommended as the shotfiring associated, unnecessarily shatters the roof or floor and in a gassy seam shotfiring in a position such as this is to be avoided.

Where it is necessary to avoid damage to other seams above, the roads will require to be spaced so that the roof will not collapse in wastes between the packs. The widths of the wastes will be related to the strength properties of the immediate roof beds. From experience, these widths rarely exceed 20 feet. Fig. 3o.

The seam G, Colliery No. 7, a section of which is shown in Fig. 31, is inclined at 1 in 5, and is at a depth of about 600 feet.

A longwall machine belt conveyor strike face (dip and rise) 330 feet long, had been advanced to its boundary. Throughout, it had been supported by wooden props and bars. Packs, built from the inferior coal roof, and reinforced by filled wooden chocks made from the props withdrawn, were as shown in the plan, fig. 31. In the spaces /
spaces between the packs the inferior coal generally broke down from the Top Coal Seam, and partly filled the spaces. The spaces of 12 feet were arranged because this was the practical limit over which the Top coal would normally span without breaking. It was proposed to break up at the bottom coal face, to the Top coal, and to work back a longwall machine conveyor face over the same area.

The turn over and the advances for the first 50 feet will be abnormal, because the ground is still in motion, and the packs have not fully compressed, but serious difficulties are not expected. Wooden props will be used for the present, but steel may be used later on.

The first step is to level the inferior coal fallen in the spaces between the packs, for about 30 feet back (using safety lamps for preference) and to build wooden chocks in this coal to the top coal at not more than 10 feet intervals, the first chock being at the original pack line faces. The initial breaking up is illustrated in Fig.3/3 which shows the conveyor close in to the stopped bottom coal face, and with the supports still in position. The inferior coal taken away will lie underfoot, and the top coal taken down is to be loaded into the conveyor in this position.

The next step is to move the conveyor up to the position shown in Fig.3/4 and to build chocks about 10 feet apart under the inferior coal along the bottom coal face. Another strip of coal can then be taken off and loaded into the conveyor. The roof, supports being set on wooden blocks. If the coal needs to be undercut over the packs, the fallen dirt will need to be levelled as much as possible between the packs and planks may be required to bridge uneven parts.

The roof should then be brushed opposite the spaces between the packs and new packs about 9 feet wide should be built over the bottom coal packs. Surplus dirt should lie underfoot. The conveyor will have been moved to the new position shown in Fig.3/5 before the brushing.

After this stage the procedure will continue in this way, with /
FACE ARRANGEMENTS
IN SEAM GI. — COLLIERY Z.

FIRST OPERATION SECTION MIDWAY BETWEEN PACKS

SECOND OPERATION

THIRD OPERATION

BOTTOM COAL FACE STOPPED.

PLAN

FIG. 31.
with care to ensure that the packs are kept advanced before drawing off props, and the use of wooden foot pieces under the props and the use of chocks in advance of the face. It may well be that additional chocks will be required at the rear of the conveyor until the settled ground is reached.

This changeover is now proceeding successfully.

In other circumstances, the roof in the wastes may be allowed to collapse as the props are withdrawn.

When the props are withdrawn, convergence usually is more immediately following withdrawal, but decreases afterwards. The total movement between face and waste is less than when the props are not withdrawn.

Packs built from material obtained from the waste.

Where suitable material is obtainable from falling wastes, it may be used for pack building and when intermediate roads are unnecessary for transport or other purposes (as on conveyor faces) they may be dispensed with.

The widths of the packs and the spaces between will depend on the strength properties of the roof and floor and on the inclination.

A typical packing and propping system is shown in Fig. 32.

Changing from road brushing to packing from wastes.

Generally, the roads had packs on both sides. The first step was to concentrate the packing to one side of the road, the other side of the road being supported by chocks which were advanced with the brushing, thus leaving an open end to the waste beds.

Particular attention was paid to ensure that the packs were built as uniformly and tightly as possible.

By slightly changing the direction of the brushing where necessary, the waste spaces were adjusted. After a few days the roof in the wastes collapsed and thus provided accessible material for packing and the brushing-s were discontinued.

In cases where props had not previously been drawn off from the wastes, it was found necessary in one or two cases to use chocks /
SEAM G.  COLLIERY NO.3.

ELEVATION

SCALE 25 TO 1

LENGTH OF FACE 100 YDS.

SCALE 1 TO 40

FIG. 32.
chocks temporarily at the waste edges to prevent surges of pressure at the coal face when the props were drawn off. This precaution was specially important when changes were being made in the positions of the packs.

It has been found that for a blaes roof suitable widths for falling wastes vary from 20 to 35 feet, for fakes and sandstone from 30 to 45 feet.

Where insufficient/packing material is available and only in such circumstances, intermediate packing may be discontinued provided the temporary supports are effective enough to minimise lateral as well as vertical movements. In such cases, chocks have been successfully employed together with effective steel props, straps and sprags. Fig.26C gives the details of a face in Seam R Colliery No. 14 on which movements have been successfully controlled. It is important that an effective form of support be provided at the waste edge so that the regular collapsing of the roof may be induced in the waste, thus keeping the load on the supports to a minimum.

This system may not be adopted where there is another workable seam or a very strong bed in the adjacent roof strata. In the latter case, for example in Seam K Colliery No. 11, it has been found that very heavy "Bumping" in the roof may occur periodically due to separation of the roof beds and supports may penetrate into the roof if it is soft, causing swinging of the supports and a collapse of the roof at the coal face.
FACE LAYOUT.

COLLIERY NO. 5   SEAM A.

COLLIERY NO. XI   SEAM K.

SCALE 1" TO 40'
(5). ROAD SUPPORTS.

(a) GENERAL NOTES.

(b) SHAPES OF SUPPORTS

- Rectangular Supports
- Camber Arch
- Shallow Arch
- Circle Arch
- Curved Splayed Legged Arch
- Inverts
- Struts
- Crown Joints
- Stilts
- Lagging
- Archlagging

(c) TESTS ON ARCHES WITH CORRUGATED STRUT LAGGING.

(d) MEASUREMENTS OF STRATA MOVEMENTS IN ROADS.

- Convergence tests road sides
- Deformation of arches on road

(e) EXAMPLES OF THE APPLICATION OF VARIOUS TYPES OF ROAD SUPPORTS:

- Wood legs and wood bars
- Wood legs and straight girders
- Straight girders with joist legs
- Camber arches
- Shallow arches
- Circle arches
ROAD SUPPORTS.

In considering the design of road supports, both the possibilities of shaping the excavation to suit the supports, and of making the shape of the supports to suit the shape of the road should be considered. This is particularly important in inclined workings.

Road supports are applied to make the excavation permanent, that is, to resist pressures which tend to reduce the area of the excavation. Thus it is necessary to know the nature of these movements so that the supports may be designed to resist and minimise them. It is known that convergence of the roof and floor due to the extraction of the coal cannot be wholly prevented, though it may be controlled by the use of the supports. A further convergence, that of the sides, may be induced in weak strata.

Thus supports may require to offer resistance to both vertical and lateral convergence.

In the design it may be possible to counteract, to some extent, the forces induced by the respective convergences. For instance, in the various forms of arches this is the fundamental principle.

Where the supports do not distribute the pressure over sufficient area of the beds, the beds themselves are disintegrated. This has been sometimes wrongly called weathering. As an example of this, it has been observed in some cases that the supports were left undamaged while the roadway was filled with debris.

In the making and supporting of roadways, it has been found advantageous to think of the extent of roof, side and floor exposed each as a span. Where the materials of any span are weak, more effective support has to be given to that span; hence in the support of roadways both the end and side contact areas have in many cases to be considered. The intervals between supports are also important.

It has seemed best to treat the variety of conditions only from the relative strengths point of view as any cases encountered with other factors prominent have been dealt with by slight modification.
Within certain limits, it is possible to select, as the immediate roof and floor, beds having the greatest and most uniform strength properties, by arrangement of the brushing.

Where the life of any roadway is likely to be short and the necessity for renewal of the supports improbable, then the use of wooden supports may be considered. In other circumstances, steel supports have definite advantages for use both in transport and main ventilation roadways.

**Shapes of Supports.**

**Rectangular Supports.**

Little advantage of the principle of counteracting the forces induced by the respective convergences is taken by the use of straight girders with or without legs. Although they may be useful because they conform to the shape of some roads, the weakness of this type of support is, no doubt, responsible for its less frequent adoption.

More recent development has been in the design of various types of arches.

**The Camber Arch.** A Camber arch support is essentially a curved beam, cut at right angles at its end and notched into the sides of the roadway. Its end contact area can be varied by caps or shoes, so that excessive penetration into the sides is prevented. Various designs of caps are shown in Fig. 34. Where large caps are necessary, the use of the camber arch is not recommended.

Various amounts of rise at the centre of the camber arch have been employed successfully. The graphic system,(Fig 35,) gives the radius of curvature for various widths of curve.

The joist sections employed have been 6" x 5", 5" x 43/4", 4" x 4" and 4" x 3", according to the length of span and to the resistance to lateral movement likely to be required. In this regard, it has been observed that "partings" or bedding planes have a great influence on lateral convergence of the sides of roadways. This matter is having further attention.

Each of the above sections has a large side contact area relative/
FLANGES TURNED OVER

CHANNEL CAP RIVETED

PUNCH AND TURNED OVER

CUT AND TURNED OVER

CAMBER ARCH END FITTINGS

SCALE 3/4" TO 1"
relative to its depth.

The cambered arch may be employed with girder legs as a support if the sides are very weak. This is done by having short, horizontal portions at the ends of the curve. The short radius required to make these, however, weakens the support, particularly if they are much more than 6" long and this design cannot be recommended from experience.

Struts between camber arches should not be placed too close to the road sides, as it has been noticed in several cases, particularly where wood struts were in use, that the struts were broken or displaced as the ends of the arch penetrated slightly into the sides.

In several instances where the necessary height of brushing exposed a weak bed in the roof, steel lagging has been applied both behind and between camber arches.

One great advantage that this form of support has over the circle arch is that no stilting or other form of protection is necessary to prevent damage in the area near the face where convergence of roof and floor is largest.

The Shallow Arch. Where any of the immediate roof beds over a seam are weak, camber arch road support is unreliable because this form of support is set between roof and sides and the camber transmits the load to the sides. To obviate the use of circle arches in such cases, the shallow arch was designed, so that the downward pressure of the roof was transmitted by end contact surfaces to the roadside packs or in a narrow road (Fig. 36) on to the solid coal. A shallow arch is a curved beam cut horizontally at its ends, and is generally curved to a smaller radius than the camber arch (Fig. 35).

It has been successfully employed where the camber arch was not successful, and is particularly suited for use in inclined workings, but gives no support to the lower portion of the road sides, and therefore cannot be recommended for important roadwork, except where erected on a brick or concrete wall.

The length of curve is generally 18" to 2' greater than
the road width.

In circle arched roads in inclined workings, it obviates the rise side shoulder gap which is difficult to fill. The rise side of the roadway should be sloped as shewn (Fig. 36).

The shallow circle has its uses in support to the full height of the roof brushing. For convenience this support can be made in halves as is the circle arch. A further design of the shallow arch type is the combination of the curve with short straight splayed legs, the feet of the arch being cut horizontally as before.

These have been used where the immediate roof bed was strong and is being further tested. It is more easily shaped than the ordinary shallow arch.

The Circle Arch. The standard circle arch is formed of a semi-circle with straight, splayed, or curved legs.

Circle arches with curved legs (horse shoe shape) offered small resistances to lateral movements near the floor particularly if a floor brushing was taken in a weak bed. They also accentuated floor heave and their use was discontinued.

Circle arches with straight legs offer resistance to vertical forces but small resistance to lateral convergence near the floor.

A further development to increase the resistance to lateral movement is found in the splay legged circle arch where the legs are splayed to the extent of about 6". The splaying of the legs however reduces the vertical resistance, a factor which has led to the evolution of the curved splay legged arch wherein horizontal resistance is obtained without appreciably impairing the vertical resistance.

The Curved Splay Legged Arch. Curved Leg Arch. The splay legged circle arch has the serious defect that wood stilts break when applied to the legs and steel stilts often bend. The distance between the feet of the arch is shorter than the distance between the feet of the stilts when applied ( ), and the stilt feet are forced to slide inwards as the stilt extension decreases.
Narrow Road
showing
Comparison Between Camber,
Shallow and Circle Arch Supports.

Camber Arch

Roof Brushing Area = 40 sq. ft.
Floor = 12 sq. ft.

Shallow Arch

Roof Brushing Area = 33 sq. ft.
Floor = 12 sq. ft.

Circle Arch

Roof Brushing Area = 33 sq. ft.
Floor = 12 sq. ft.

FIG. 36.
decreases in length. This is improbable, and may only take place in favourable conditions where the floor is extremely hard.

To surmount this difficulty a circle arch was designed with curved legs.

Then stilting accommodation was considered. When adequate steps are taken to prevent the arch feet penetrating into the floor the height of circle arch to be used is directly related to the thickness of the seam.

Fig. 37 gives dimensions of suitable arches for varying thicknesses of seams. It should be noted that the figures given in Fig. 37 are only a guide as practical considerations such as the relative height from the coal to a hard bed, etc., but as a guide they have proved valuable.

A limitation in width of roadway in relation to height can also be seen. For instance, in a 3' seam where a 12' wide roadway is required, 8' is about the minimum height possible. It may not be advisable to make the road so high as weak beds may be exposed.

It will also be seen that there are considerable limitations to be considered if adequate protection is to be given to the arches. For instance, in a 5' thick seam circle arches 12' wide and 8' high (internal dimensions) have insufficient stilting accommodation and if a 12' wide road is required a minimum thickness of brushing of 5' has to be taken, and a 12' x 9' circle arch employed.

To ensure that the distance between the feet of the circle arch and the feet of the stilts did not vary more than 1", a stilt extension line was assumed 3' below the feet of the arch and the centre of curvature of the legs was on a line 18" below the feet also.

Two sizes of arch 10' x 7' and 10' x 6' acted as basis for the redesign, and the leg curvature radii employed (previously found to be nearly what was required) were 14' and 16'.

The centres of curvature lines were drawn and with the semi-circle/
<table>
<thead>
<tr>
<th>Size of Circle Arch</th>
<th>Length of Arch Leg</th>
<th>Total Length of Steel Stilt Used</th>
<th>Maximum Stilt Extension over Girder</th>
<th>Height of SAME - Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 ft x 6 ft</td>
<td>21° 6&quot;</td>
<td>21° 9&quot;</td>
<td>21° 6&quot;</td>
<td>5' 0&quot;</td>
</tr>
<tr>
<td>8 ft x 6 ft</td>
<td>21° 0&quot;</td>
<td>21° 3&quot;</td>
<td>21° 0&quot;</td>
<td>4' 10&quot;</td>
</tr>
<tr>
<td>8 ft x 7 ft</td>
<td>21° 0&quot;</td>
<td>21° 3&quot;</td>
<td>21° 0&quot;</td>
<td>4' 10&quot;</td>
</tr>
<tr>
<td>10 ft x 8 ft</td>
<td>21° 0&quot;</td>
<td>21° 3&quot;</td>
<td>21° 0&quot;</td>
<td>4' 10&quot;</td>
</tr>
<tr>
<td>12 ft x 9 ft</td>
<td>21° 0&quot;</td>
<td>21° 3&quot;</td>
<td>21° 0&quot;</td>
<td>4' 10&quot;</td>
</tr>
</tbody>
</table>

NOTE - Standard distance apart - 4 ft

Fig. 37.
<table>
<thead>
<tr>
<th>Thickness of Seam (in)</th>
<th>Length of Stilt Extension Required (in)</th>
<th>Road 7' wide</th>
<th>Road 8' wide</th>
<th>Road 10' wide</th>
<th>Road 12' wide</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 1/2</td>
<td>1 1/2</td>
<td>Circle 4 1/2</td>
<td>Circle 4 1/2</td>
<td>Circle 5 1/2</td>
<td>Circle 6 1/2</td>
</tr>
<tr>
<td>2 1/2</td>
<td>1 1/2</td>
<td>1 1/2</td>
<td>Arch 4 1/2</td>
<td>Arch 4 1/2</td>
<td>Arch 5 1/2</td>
</tr>
<tr>
<td>3 1/2</td>
<td>1 1/2</td>
<td>Arch 4 1/2</td>
<td>size 4 1/2</td>
<td>size 4 1/2</td>
<td>size 5 1/2</td>
</tr>
<tr>
<td>3 1/2</td>
<td>1 1/2</td>
<td>1 1/2</td>
<td>7' x 6' 1/2</td>
<td>8' x 6' 1/2</td>
<td>10' x 7' 1/2</td>
</tr>
<tr>
<td>4 1/2</td>
<td>1 1/2</td>
<td>1 1/2</td>
<td>Circle 4 1/2</td>
<td>Circle 4 1/2</td>
<td>Circle 5 1/2</td>
</tr>
<tr>
<td>4 1/2</td>
<td>1 1/2</td>
<td>1 1/2</td>
<td>size 4 1/2</td>
<td>size 4 1/2</td>
<td>size 5 1/2</td>
</tr>
<tr>
<td>4 1/2</td>
<td>1 1/2</td>
<td>1 1/2</td>
<td>7' x 6' 1/2</td>
<td>8' x 6' 1/2</td>
<td>10' x 7' 1/2</td>
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<tr>
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<td>2 1/2</td>
<td>-</td>
<td>Circle 4 1/2</td>
<td>Circle 4 1/2</td>
<td>Circle 5 1/2</td>
</tr>
<tr>
<td>4 1/2</td>
<td>2 1/2</td>
<td>-</td>
<td>Arch 4 1/2</td>
<td>Arch 4 1/2</td>
<td>Arch 5 1/2</td>
</tr>
<tr>
<td>4 1/2</td>
<td>2 1/2</td>
<td>-</td>
<td>size 4 1/2</td>
<td>size 4 1/2</td>
<td>size 5 1/2</td>
</tr>
<tr>
<td>4 1/2</td>
<td>2 1/2</td>
<td>-</td>
<td>8' x 7' 1/2</td>
<td>10' x 8' 1/2</td>
<td>12' x 9' 1/2</td>
</tr>
</tbody>
</table>

**NOTE** - The stilt extension is calculated as 40% of the thickness of coal extracted.

The total length of stilt piece used is 9" longer than the stilt extension to allow of clamping to the leg of the circle arch. An extra height of 3" has also been added to let the arch into position.

The steel stilt is now shaped so that an extra extension of 3" is obtained.

An arch with 2'6" straight legs gives a possible extension of 1'9" using 9" to clamp the stilt.

No allowance is made for probable floor penetration.
semi-circle centre, arcs were described with radii 9' & 11',
long these being the differences between the radii of the legs
chosen and the radius of the semi-circle, cutting the curvature
centre lines as shown. With the four points so established
the curved legs of the arches were drawn in and the points of
change of curve established.

It can be seen that the curving of the legs does not
materially change the circle arch. By trial it was found
that with radii over 16' the splay and the stilting accommodation
were too small and with less than 16' the splay was unduly large
and the stilting accommodation more than sufficient for most
widths of arch.

It had been observed in over one hundred roads examined
that, apart from other failures due to lack of stilting and
strutting, the two commonest failures of circle arches were
by depression or elevation of the crown; with strong or
weak roof beds respectively in contact at the crown. This was
accompanied by buckling at the shoulder especially where there
was lack of contact as in Fig. 40.

The Curved Splay Legged Arch. To counteract the depression
of the crown, an arch was designed with a slightly elevated crown,
with a shorter radius at the shoulder, both to give greater
contact at the shoulders and to strengthen them, and with curved
splayed legs.

Elevation at the crown has been successfully counteracted,
and greater area of contact round the shoulder has been provided
by an arch designed with a larger radius or flatter crown, a
short radiaused or elevated shoulder, and the same curved splay legs.

In the latter case, it was found that a universal crown
radius of 10' suited all the arch widths required and at the same
time was not too flat.

The length of 10' radius curve influences the width of the
arch considerably and also the resistance of the arch to crown load.
This length was kept as short as possible but in relation to the
width required. For instance, Fig. 41 shows the four standard
Circle Arch Outline
Heights 7' and 8'
Leg Radii 14' and 16'
To Suit 3' Stilt

Standard
10' x 7'
Widths

Base for 7' Arch

Base for 8' Arch

3' Stilt Extension
Base for Stilt for 7' Girder

1' Base for Stilt for 8' Girder
DISTORTION WITH SIDE PRESSURE.

FISHPLATE NEARLY FLAT.

DISTORTION WITH CROWN AND SIDE PRESSURE.

Fig. 39.
Arches Lacking Shoulder Contact Area.

Strong Bed Unbroken

Possible Fracture Small Contact

Strong Bed Broken and Weakened
INTERNAL AREAS

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12′6″</td>
<td>8′0″</td>
<td>4′0″</td>
<td>4′0″</td>
</tr>
<tr>
<td>2</td>
<td>11′0″</td>
<td>7′0″</td>
<td>3′6″</td>
<td>3′6″</td>
</tr>
<tr>
<td>3</td>
<td>9′4″</td>
<td>6′0″</td>
<td>3′0″</td>
<td>3′0″</td>
</tr>
<tr>
<td>4</td>
<td>8′3″</td>
<td>6′0″</td>
<td>1′6″</td>
<td>3′0″</td>
</tr>
</tbody>
</table>
arches in use and the maximum length of crown curve is 4'.

In order to improve shoulder contact, the radius had to be kept as small as practicable.

With the two sections of joist in common use for arches 5" x 4½" and 5" x 3", it was considered that to bend these sections to a radius of less than 3' would overstrain the metal.

(Note - all joists in use are of mild steel).

As the shoulder radius also influences the width considerably, its size is related to the width required. For instance, in the design of an arch 7' high, a shoulder radius of 4' gives a width of 12'3" while a radius of 3½' gives a width of 11'3".

It was found that variations in width could be obtained by:

1. Varying the crown radius;
2. Varying the length of crown curve; and
3. Varying the shoulder radius.

(1) With a radius greater than 10' it was not difficult to reduce the width to correspond to a height of 6'.

(2) A maximum length of 4' of curve was taken so that the new arch form had a similar relation of width to height, and so that the widths at the level of the top of the tubs on the roadway were about the same.

(3) A maximum shoulder radius of 4' was taken for a width of 12½', so that the shoulder contact was as large as possible at that width without lengthening the crown span over much.

The sizes of circle arches in common use and having suitable widths were 12' x 8', 10' x 7', 8' x 7' and 7' x 6'.

The new arches substituted were 12½' x 8', 11' x 7', 9'4" x 6' and 8'3" x 6', all having flattened crowns.

(Fig. 44) shows a comparison of the new and the old types of arches.

To suit the curved legs a curved steel stilt was designed with a corresponding radius.

A similar procedure was carried out with reference to the elevated crown type.

Elevation was obtained as in Fig. 48.
OUTLINE OF FLATTENED CROWN ARCH
RADIUS OF SHOULDER 4'

WIDTH FOR 7' ARCH FOR 16' RADIUS 11.5'
WIDTH FOR 8' ARCH FOR 16' RADIUS 12.8'

BASE FOR 7' ARCH
BASE FOR 8' ARCH
BASE FOR STILT FOR 7' GIRDER
BASE FOR STILT FOR 8' GIRDER

STANDARD 10' x 7' WIDTHS
Outline of Flattened Crown Arch

Radius of Shoulder 5½

Width for 7' Arch for 16' Radius 11½

Width for 8' Arch for 16' Radius 12½

Crown Arch 3721

1½ for 7' Arch

3½ for 8' Arch

8½ for 8' Groove

10 for 8' Groove

8 Stilt Extension

8 Stilt for Stilt for 8' Groove

Fig 43.
Curved Splay Leg Arch 11' x 7' F.

Flattened Crown.

STANDARD CIRCLE ARCH. 10' x 7'

16' Rad. 16' Rad.

STILT EXTENSION 2' 6''

Fig. 44
OUTLINE OF ELEVATED CROWN ARCH

RADIUS OF SHOULDER 3.6

WIDTH FOR T-ARCH FOR 6 RADIUS = 11'
The same radii were employed but the widths of the arches were slightly less than those of the flattened crown type for the corresponding heights.

It is to be noted that with both the above designs a load applied at any position on the arch causes a butting action of the two halves at the crown. This point led to the design of a suitable butt joint in which the use of bolts could be obviated.

Also for each of the two designs the crown radius and leg radius is standard so that end fittings are interchangeable.
Inverts. Where the floor material is very weak it may be necessary to apply support by using straight girder or inverted camber or other arches. Added resistance of side supports may be obtained by the use of such floor supports. It has been found, however, that where resistance is given to roof and floor convergence by effective supports between them, the necessity for such inverts is considerably reduced.

Fig. 46 shows a shoe to facilitate the attachment of arches to straight inverts.

Struts. Because of its shape the joist section gives greater contact area than the tubular section, and the width of the flange can be selected in relation to the strata where the road supports are used. To give equivalent resistance to distortion in planes other than that of the web, it is imperative that struts be used to reinforce joist supports, although some increase in resistance to buckling has been obtained by increasing the thickness of the web.

To be effective, struts should interact directly on one another as they do when erected in parallel lines. There should be a sufficient number, not less than 5, distributed uniformly.

At refuge holes, struts should be of tie bar form to prevent buckling, and special arches are desirable to frame the refuge hole and prevent distortion of the adjacent arches.

Joint. The original joint for arches consisted of a pair of common fish plates attached by four bolts. With this type there was difficulty in keeping the ends of the arches abutting, and consequently a small amount of depression at the crown resulted in bending of the bolts or tearing of the girder flanges or web. To give greater rigidity to the joint various designs of channel fish plates were evolved, but these did not assure that the girder ends were abutting. Moreover, they merely transferred the locus of failure to the girders near the ends of the fish plates.
**Straight Invert**

*For Floor Support*

- 6' width
- 10'-0" length
- 6' length
- 10'-0" width
- 2 x 4½ R.S.J.
- 1½ holes for ¾ bolts

---

**Fig. 46**
The next stage of evolutions were Sleeve and Clamp joints. With the former there were difficulties in withdrawal, while the latter was too rigid.

The next development consisted of various shapes of butt joints, and in one of these (fig. 47), arrangements were made so that the separate girders were interchangeable as half the butt face on one girder was the reciprocal of the other which ensured that relative lateral movements at the joint were avoided. In conjunction with arches of the shapes described, with flattened or elevated crowns, these joints are shewing better results than the standard fishplated circle arches which were used previously under similar conditions.

As a result of careful observation of the behaviour of the rigid butt joints, and considering the principle of distribution of the girder resistances with a view to avoiding local damage to the girders, a pin joint has been evolved (fig. 48). In this case also, the two halves of the girder are interchangeable. This joint is intended to facilitate distribution of the forces and to avoid local rigidity.

STILTS. In the moving ground, extending for some distance back from the face, provision requires to be made to enable the supports to accommodate themselves to the convergence which takes place while still offering the highest possible resistance.

In the case of road supports, penetration of the floor should not take place as this increases the liability to floor heave. The usual means to provide for accommodation to vertical convergence is by stilts, and it should be noted that the slipping resistances of the stilts determine the resistance of the supports. As the stilts must not penetrate the floor, their end contact areas must be sufficient to prevent this.

In some instances the slipping resistances of the stilts are much too small, and from lack of sufficient support in the early stages the rate of convergence is not controlled. The
Butt Joint

Pin Joint for Arches

Figs. 47 and 48.
strata are damaged and the supports suffer excessively at a later stage.

Wood stilts with clamps have been used but they are liable to break and their slipping resistance is very variable.

A steel stilt has been evolved to provide a slipping resistance of 10 to 12 tons per stilt (fig. 49). The feet can be made to suit the nature of the floor although it should be noted that, to some extent, standardisation is possible. With very weak floors it is necessary to increase the area of contact by plates beneath the stilts.

There are no difficulties in applying stilts to straight legged joists but the range of slipping accommodation is related to the length of straight leg.

When stilts are used on splayed legged supports, the base of the stilt must move inwards as slipping of the stilts proceeds, otherwise the stilts will bend. Difficulties have arisen because the stilts were not free to move laterally. Moreover, unaxial loading of the stilts makes them more liable to buckle by vertical load.

A factor in the development of the curved splay legged arch was the possibility of surmounting difficulties by a curved stilt of the design shown in fig. 49. These stilts are curved to suit the curvature of the joist legs to which they are fitted.

Each roadway using circle arches is supplied with arches complete with stilts attached until there is a sufficient number to serve the length of roadway under subsidence. The roadway is then completely supplied with stilts as the last set is removed and placed on the arch to be erected at the face.

LAGGING. To distribute the resistance of road supports and to prevent material from falling out between the supports, lagging is used.

Wood lagging placed either between the webs of adjacent joist or rail section supports or behind them, has the disadvantage of...
Fig. 49.

Straight Leg of Arch.

Pressed Steel Stilt.
of shrinking, and rotting, and of having little strength.

Various forms of corrugated steel lagging have been tried. At first corrugated steel sheeting of various gauges was placed behind the supports, one corrugation of one sheet overlapping another of the next sheet. A heavier section sheet is necessary as the span of unsupported strata is increased.

Lagging, by this method, entails the use of struts between the supports to reinforce them, and pressure on the supports is applied through the lagging. It is to be remembered that lagging is applied to straight and camber girders, shallow and circle arches, and the like, which are all of Joist section.

To reduce excavation and to obviate strutting, corrugated plates were produced so that when erected each plate butted to its neighbour, and filled the space between the flanges to prevent the plates slipping, one over another. The plates act also between the supports, thereby preventing any tendency of the support to buckle. By packing or stowing, small stones behind the plates, the pressure of the strata is distributed over the supports and liability to local damage is reduced. This type of lagging has been successfully applied to circle arches of 6" x 4½" and 5" x 3" section, and is 18" broad with 4" deep corrugations.

It is erected as shewn in fig. 50

An erecting strip is clamped as shewn on to an arch clamped at a distance equal to 2" more than the length of plate in use, from the already erected girder. The plates are pushed into the web of the new arch and can easily be slipped behind the flange of the previous arch as shewn. The top plate is put in last. The clamps are then screwed tight, drawing the new arch against the plate ends. The clamps used in the erection of the previous bay of lagging are then withdrawn for use in the next bay.

In this way each bay of lagging is erected and held tightly till another is erected.

At/
Fig. 50. Arrangements for Erecting

Strutlagging

Details:
- Curved lagging plate
- Circle arch being erected
- Curved angles
- Strutlagging

Dimensions:
- 5x3

Notes:
- Curved lagging is used for assembling lagging
- Detail of bolt for fixing curved lagging to arch
At manholes, 3' long strut lagging plates can be erected to the level required and angle iron cleats attached to the arches at that level to prevent the plates from slipping down. Wood wedges have been found to be satisfactory for this purpose.

Two thicknesses of plates are in use, 1/16" and 1/8" and plates up to 4' long have given satisfaction.

**Archlagging:** A further development has been made in mine supports by the introduction of archlagging as shown in fig. 51.

This consists of the same section of mild steel plates as in strut lagging, but having the corrugations running longitudinally instead of horizontally, and being curved on their length. Archlagging is intended to obviate the use of joists or rail section supports.

At present it is being made of 3/16" and 1/4" thick mild steel to form circle arches and its weight is respectively 16½ lbs. per ft. and 22 lbs. per ft. Various types of crown joints are being tried, e.g. the butt type. Archlagging is easy to erect and gives a continuous road lining of the simplest possible kind, and it can be protected in moving ground by stilting.

Each bay is a separate entity as it is shaped at present, but the section of metal can be arched in the reverse direction and clamps or bolts can be used to make the bays of archlagging inter-dependent.

Archlagging is thought to have possibilities for roadways, etc. of reasonably long life, but its further trial only will make this certain.

Where contact area is important, as in soft ground, lagging in some form is a necessity.
Test on Arches with Corrugated Strut Lagging.

Professor S.M. Dixon of the Safety in Mines Research Board kindly arranged this test at the City & Guilds Engineering College, London.

Report on a Test of Steel Arches with corrugated Steel Lagging supplied by Messrs. The Fife Coal Co., Ltd.

The arches were of 5" x 3" joist section (11.38 lb./ft. run) 8 ft. dia. and 7 ft. high with straight sides. They were provided with four bolt channel type fishplates, and with special corrugated steel lagging. The test was carried out in order to investigate the behaviour of the lagging. The lagging sheets were 4 ft. long by 1 ft. 3 ins. wide except in the case of the special crown sheets which are 3 ft. 9 ins. long and 2 ft. wide. They were supplied in two thicknesses 0.111 and 0.055 in. thick respectively, in both cases the corrugations were 3 ins. deep. The sheets were placed between the arches and acted as distance pieces between the webs. Four tie rods 5/8" dia. were provided to draw each pair of adjacent arches together. The laggings are supported on angle cleats on the legs of the arches 1 ft. 10 2/3 in. above the feet, the lower portion remaining unlagged.

Although the sheets of lagging supplied were 4 ft. long corresponding to a 4 ft. spacing of the arches, the test was carried out with the arches 3 ft. apart and the laggings were cut to this length. It was necessary to do this in order to get three arches conveniently into the testing machine. As a test on the lagging a 3 ft. spacing is obviously less severe than a 4 ft. spacing. The arches were tested under a combination of vertical and horizontal loads applied through the medium of sand which was placed outside the laggings. The heavier section laggings were used.

The arches deflected gradually as the vertical load was increased, as shown in Fig. M. 416. The side load was maintained at about one-fifth the vertical load in order to afford suitable support to the haunches of the roadway arch.
Failure took place when the total load was 198 tons, or 66 tons per arch. At this point some of the lagging near the springing of the arch failed in bending and ceased to support the centre arch with the result that it buckled sideways. The tie rods were overstrained and the outer arches buckled outwards at the crown. The maximum deflection of the crown of the centre arch was 3.37 inches.

Unfortunately, we have not tested any 5'' x 3'' section arches without lining and so it is not possible to make a direct comparison to shew the effect of the corrugated lagging. It appears, however, that the arches tested must have been considerably stronger than similar arches unlined, because when the lagging ceased to afford lateral support to the centre arch failure was instantaneous. It must be noted that in this method of test the lagging was subjected to a more or less uniformly distributed external load from the sand and thus was caused to bend. Underground it may happen that most of the load comes directly on the arches and that the lagging has little to do but act as a stretcher, in this case it might give even better results than in the test. On the other hand should a concentrated load be imposed on the middle of a sheet of lagging in the pit there would appear to be serious danger of its being bent inwards sufficiently to slip off the flange of the arch. This danger of slipping inwards would appear to be the greatest potential drawback of this method of roadway lining because a local failure not only involves that portion of the lagging but my removing the longitudinal support may lead to the failure of the adjoining arches.

(sgd.) S.M. DIXON.
April 24th, 1933.
Fig M416.

Test on 5 x 3 ins. section 8' wide 7' high arches with 1/8" strut lagging.
STRUT LAGGING TEST RESULTS.

The results of tests on similar arches without lagging are not available, but the 6th Annual Report of the S.M.R.B. contains the following abstracts of results of tests on other sizes of arches.

"The tests were carried out with vertical loads applied at four points on the arch; four stretchers were used and the feet of the arches were free to move outwards during the test.

The 4" x 2" straight sided B.S.S. Type A, (11.13 lbs.) buckled under a load of 27.1 tons per arch.

The 4" x 2" horse-shoe B.S.S. Type A (11.48 lbs.) buckled under a load of 22.5 tons per arch.

The 4" x 1 1/4" section straight sided (9.08 lbs.) buckled at 15.8 tons per arch.

The 5" x 4 1/2" straight sided, B.S.S. Type B, (17.2 lbs) buckled under a load of 56.2 tons per arch."

Even by comparison with the 5" x 4 1/2" straight sided arches (of 17.2 lbs) the results obtained shew that the buckling load was considerably increased by the lagging.

In actual use with proper packing of small stones behind the lagging and arches the load is distributed more uniformly over the arches, than would be obtained in the testing machine where the pressure was applied at four points through intervening sand packing. Also in practice, each bay of lagging is tending to compress against the adjacent one and the strength of tie rods is not involved as it is in this test.
MEASUREMENTS OF STRATA MOVEMENTS ON ROADS.

CONVERGENCE TESTS AT COLLIERY No. 10, SEAM H.

Two records were made to ascertain the convergence of both roof and floor back from a strike longwall face, and to compare this convergence in the packs at the higher and lower sides at one of the roads for this face, which had an inclination of 1 in 5.

No. 1 record, which started 3' from the face and continued back for 140' in a recess in the higher side pack, shows convergence of 3.3" for the first two face advances of 4 1/8' each with a Sunday intervening. At this stage the recorder was at the side of the brushing. Thereafter the magnitude of the convergence gradually decreased and was still going on slowly when the instrument was removed at a position 143' back from the face. The total convergence recorded was 15.6 inches, being the height reduction of 35% of the original height of the seam as exposed.

No. 2 recorder was erected 3' from the face opposite the lower side pack of the same road. In this case there was a convergence of 4.5 ins. for the first two face advances, the movements corresponding to the coal cutting period being exceptionally rapid. Afterwards convergence gradually diminished, but not so rapidly as on the higher side of the road. At 143' back from the face the total convergence was 19.4 ins. or 3.8 ins. more than on the higher side.

This would indicate the need for additional stilting accommodation for supports on the dip side of roads in an inclined working.

It was noted that during the tests the recorder on the higher side pack, swung at the head 2 3/4° towards the centre of the road, and 2 3/4° away from the face. The lower side instrument swung only 1 1/2° towards the centre of the road.
CONVERGENCE TEST IN ROAD FROM FACE

COLLIERY No. 10  SEAM H.

PLAN

ROAD ACROSS

POISE.

SEAM EACH UNDERCUT 1\(1/2\) DEEP

RECORDERS SET 30\(1/2\) FROM FACE.

Fig. 52.
DEFORMATION OF ARCHES ON ROAD.

Fig. 53 refers to measurements taken in Seam P. Colliery 14 of the lateral movement of the legs of arches. The height of the crown of each arch from rail level was also measured.

The 12 x 8 arches were set at the face and were provided with 18" of stilting accommodation. Fig. shews measurements taken on arches at 30 feet intervals.

It will be seen from the diagram that the stilt length was taken up at about 100 feet from the face, only slight inward movement having taken place during this period.

From (b) the arches used were 10' x 8'. At (c) a widening between the legs of the arch occurred due to side pressure being reduced by the presence of a side road. On other arches from (c) outwards the movement of legs was towards the centre of roadway and was accompanied by rising of the crown. Most of the girders failed by tearing of girder web due to crown of girder rising.
PLAN

Measurements on Plan are from foot of Arches.

Measurements on Section are from rail level to Crown of Arch.

Fig. 53.
Examples of the Applications of various Types of Road Supports.

Wood Legs and Wood Bars:

In seam A Colliery 5 a conveyor face was being advanced to a fault. The life of the main level did not warrant the use of steel supports; the roof was of soft blaes and the floor hard sandstone. Wooden props 7' long x 5" dia. and bars 10' long x 7" dia. were erected at 4' intervals (No notching was done). It was observed that between the face and a point on the level 60 yds. behind, 63 legs and 32 bars were broken and had to be replaced, out of 90 legs and 45 bars erected during the 7 weeks taken to advance the face. During this period there were 15 small falls of roof and 9 falls of side on this part of the road.

The wood legs were unable to penetrate the hard floor and were either broken or the bars they supported penetrated into the roof.

Four bars slipped off the supporting legs at one end. This was due to the small contact area between prop and bar. Where the props were not broken, the bars were pressed into the soft roof. This was due to lack of contact area between supports and strata, causing intense pressure on the small contact area offered by the round supports.

Circle arches of 5" x 3" section 10' wide and 8' high are now in use in this seam at 4' intervals as before and no indication of crush around the arches can be seen.
Wood Legs and Straight Girders:

In Colliery 11 in Seam N with a fireclay floor and a hard fake roof, 5" x 4\(\frac{1}{2}\)" joists 18' long were erected on 7" x 5" wood legs in the road ways. The seam was 4\(\frac{1}{2}\)" thick and about 3' of brushing was taken to a good parting in the fake beds. The wood legs were rarely broken and no roof breaks were visible. It was decided to use legs of 5" x 4\(\frac{1}{2}\)" joist section without end caps. Very soon after their adoption rapid vertical convergence of the roof and floor was noticeable, and a centre roof break appeared parallel to the road. The straight horizontal girders were distorted and in a short time the road required rebrushing. Wood legs were reinstalled and the roof condition improved again. Wood legs were employed until the district was abandoned.

In the above case, the resistance offered by the road supports and the rate of vertical convergence were the varying factors. It is known that the resistance offered by a support does not depend on the collapsing load of that support only, but also on its contact area. In this case the wood legs offered greater resistance than the joist legs with ends as cut.
Straight Girders with Joist Legs:

In Colliery 14 Seam G, the roof is of fairly strong banded blaes and the floor is of blaes and coal bands of varying strength. The road brushing is in the floor only. Straight girders on short wood legs were employed, the legs being set in recesses in the road-side buildings on the bench formed by floor brushing. The legs penetrated into the floor blaes to an irregular depth and were sometimes broken. Joist legs 6' long with steel stilts attached were substituted, the stilts having enough contact area with the brushing floor to prevent penetration. These are very successful, particularly when steel cleats between the legs and the girders are used together, with sufficient struts between the legs.

This type of support is being adopted where a strong flat roof bed is exposed, and by its use better contact with the roof is obtained than is likely if circle arches were substituted for the straight girder.

At some back brushings in similar conditions where lateral convergence is evident, the joist legs are splayed and the top end is cut at an angle of 5° off the perpendicular to give 6" splay in a 6' length. This is proving successful in giving added resistance to lateral movement.
Joint for Straight Joist and Leg Supports.

Horizontal Joist

Joist Leg

Pressed Steel Cleat

Fig. 54.
CAMBER ARCHES:

Straight joists in seam C Colliery No. 11 had been severely deflected at the middle and breaks were formed in the roof beds. It was the practice to re-use the bent joists with the curve to the roof. These proved more satisfactory and thereafter curved or camber arches with a radius of curvature of 20' were installed with excellent results.

In Seam G in Colliery No. 11 10' x 8' circle arches were in use but sufficient stilting accommodation was difficult to obtain, as the convenient brushing thickness was only 5½' and the seam was 3½' high. The roof beds were strong and the roadside packs showed no signs of lateral movement. Camber arches were therefore installed satisfactorily, the camber being of a 20' radius.

In Seam E Colliery 5, camber arches were substituted for circle arches in a road at a longwall inclined at about 1 in 3. The roof brushing was in weak blaes which crumbled badly when wet. The camber arches were not successful and half arches with extension pieces were substituted with success.
**SHALLOW ARCHES:**

In Seam R Colliery No. 14, the 12' long camber arches installed in the main coal were continually requiring to have legs set to them at the ends to prevent them falling out. They were set to a strong sandstone roof with blaes sides on which water had a serious weakening effect. Shallow arches 13' long and with a 4' rise were substituted and were set on hard wood blocks with about 2 sq. ft. contact area on the road-side packs. This has solved the road support difficulty in this seam.

In seam F Colliery No. 10, shallow arches 12' long with a $3\frac{3}{4}'$ rise have been substituted for 10' x 8' circle arches without apparent bad effect. The roof is of banded sandstone and the floor is of fireclay. The packing system is very effective.

It has to be borne in mind, when the installation of the shallow arches is considered, that they do not give direct support between roof and floor and where there is a weak floor brushing, their use cannot be recommended.
Circle Arches:

In seam L Colliery No. 7, circle arches were installed where the roof was of massive sandstone and the floor was of sandstone bands. Considerable difficulty was encountered in shaping roadways to suit circle arches and where sufficient protection was afforded by effective stilting, it was noted that the arches were seldom damaged. Even lack of struts between arches did not seem to matter. For a period no arches were installed and the result was carefully noted. There was no increase in the rate of roof and floor convergence and lateral movements were small. The roads in this seam are still unsupported except in faulted ground where circle arches are employed. The important factor in this seam, apart from the natural strength properties of the beds, is the effectiveness of the packs and props. No roof fractures are visible at the face, and the wastes collapse very regularly.

In several seams where circle arches were used, considerable lateral movements were noticeable and the arch legs were bent inwards. For instance, in colliery No. 9 seam J, in the Main level for a longwall face, it was found that in a distance of 100 yds. from the face 52 of the 75 circle arches erected, were distorted in this way. Curved splay legged arches are now employed, and little indication of lateral movement can be measured.

Curved splay legged arches together with curved steel stilts have been installed on over 30 roadways where circle arches were not successful and excellent results are being obtained.

In Seam E Colliery 5 half arches are used with extension pieces, as shown in Fig. 55.
Use of Half Arch with Extension in Inclined Workings.
APPENDIX. SECTIONS OF SEAMS AND STRATA.
SEAMS AND ADJACENT STRATA.

Fig. 57.
SEAMS AND ADJACENT STRATA

H

SEAM 12.0
SANDSTONE

G5.0
SANDSTONE

H1

SEAM 12.0
SANDSTONE

J

LIMESTONE
CLAY, SHALE

J1

LIMESTONE
CLAY, SHALE

FIG. 58.
SEAMS AND ADJACENT STRATA.

Fig. 59.
SEAMS AND ADJACENT STRATA.

Fig. 60.
(6). CONCLUSIONS.
RESUME AND GENERAL CONCLUSIONS.

Although it is not possible to measure the magnitude of the pressures caused by mining operations, the effects are related to the movements induced, and they can be controlled by the supports applied in relation to the supports removed in the process of working.

(a) Removal of Coal:
The greatest movements of the strata occur during this operation and extend for considerable distances from the origin. The movements are directly related to the rate of undercutting.

(b) Application of Support:
Sprags should have large contact areas, be driven well and tightly under the coal as close as possible to the actual point where holing is being done. Designs of sprags are given.

Props are used at working faces to keep the roof in good condition. Tests described in the paper have shown that they are subjected to uniaxial loading due to relative lateral movements of roof and floor, and to slipping during penetration of the floor. The resistances developed are related to the nature of the roof and floor, the areas and nature of contact, rate of convergence and characteristics of the props themselves. The type and size of props should be selected to suit the nature of the roof and floor and the convergence where they are to be used. Various designs of props, some of which have been evolved during the investigations, have been dealt with and notes are given regarding their behaviour under different conditions.

Propping systems to suit different circumstances are described.

Chocks are used to supplement the propping systems. They have been found particularly useful at waste edges where the props are withdrawn, and also where the roof or floor is very weak. They have been used successfully as substitutes for props in the working of thick seams.

Steel chock pieces have been designed, and are described in the paper.

Packing/
Packing. It has been confirmed that the quality and arrangement of the packing has very great influence on the magnitude and nature of the strata movements induced, and is the factor exercising the greatest control over these movements.

Various arrangements of packing actually applied are described.

Straps. Two designs of steel straps have been tested under conditions similar to those which they are used underground.

Road supports are applied to resist pressures which tend to reduce the area and shape of the roads necessary for mine working.

The best results have been obtained when the shape of the road is made to suit the shape of the supports or vice-versa. Failures of supports when the pressure has been insufficiently distributed over them are described.

Strata movements and also deformation of road supports have been observed and measured.

Various designs of supports have been evolved in the course of the investigations, and particulars of the designs are given. The results of the actual application of the various types of supports are described and illustrated in photographs.

In particular, excellent results have been obtained from curved splayed legged arches, with or without inverts.

Strut lagging, designed to distribute the pressure as uniformly as possible over the arches, and to prevent buckling of the joists, has given very good results. Over 1,000 yards of roadway are lagged successfully by this means.

Struts between joists and arches are essential.

Steel Stilts have been designed for use on arches, erected in the moving ground back from the face.

Archlagging has been erected in several roadways and is giving satisfaction as far as it has been tried.

As far as possible standard shapes have been selected, having regard to the conditions of use.
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ALBUM OF PHOTOGRAPHS.

(SEE SEPARATE FILE)