APPENDICES
APPENDIX I

MAGNITUDE AND POSITION OF SUPPORT THRUST
WITH LEMNISCATE SHIELD SUPPORTS

Provided the friction in the hinge pins can be assumed small, a semi-graphical method can be used to determine the magnitude and position of the support thrust $P$.

A line diagram of the support must be drawn in the attitude corresponding to the height of extraction in question. In this diagram let

- $H$ be the centre of the canopy hinge pin,
- $L$ the intersection of the lines through the lemniscate hinge pins (as shown in Figures 53 to 56),
- $a, b$ the co-ordinates of $L$ with respect to $H$ (as in Figure 53),
- $c, d$ the perpendicular distances of the front legs from $H$ and $L$ respectively, and
- $e, f$ the perpendicular distances of the back legs from $H$ and $L$ respectively.

Let $P$ be the required support thrust acting at an angle $\beta$ to the top of the canopy ($\tan \beta = \text{coefficient of friction}$),

- $q$ the distance from $H$ along the canopy at which $P$ acts, and
- $F$ and $B$ the total thrusts of the front and back legs respectively, acting along their centre lines.
With reference to Figure 53,

\[
\text{moment of } P \text{ about } H = P \cdot n = P \cdot q \cdot \cos \beta \quad \ldots (A.1.1)
\]

\[
\text{moment of } P \text{ about } L = P \cdot m = P \cdot (q + a) \cos \beta + b \sin \beta \quad \ldots (A.1.2)
\]

The angle \( \beta \) will normally vary from \( 0^\circ \) to about \( 15^\circ \) (equivalent to a coefficient of friction of 0.3). Therefore \( \sin \beta \) will be fairly small compared to \( \cos \beta \). If the lemniscate mechanism has been correctly designed, \( L \) will lie close to the canopy centre line throughout the working range of the support. Hence \( b \sin \beta \) will be very small compared to \( \cos \beta \). Also \( \cos \beta \) will lie between 1 and 0.966 \( \approx 1 \).

**2-Leg Lemniscate Caliper Shield**

Figure 54 shows the forces acting on the rear, inclined shield of the support.

In this case the support thrust \( P \) will act through the canopy hinge. Therefore \( q = 0 \). By drawing \( P \) through \( H \) at an angle \( \beta \), \( m \) can be measured on the line diagram.

Taking moments about \( L \),

\[
P \cdot m = B \cdot f
\]

\[
\therefore \quad p = \frac{B \cdot f}{m}
\]

(As the lemniscate hinge loads pass through \( L \), their moments about \( L \) will be zero.)
Moment of P about H = P.qcosβ
Moment of P about L = P.((q + a)cosβ + b sinβ)

FIGURE 53. MOMENTS OF P ABOUT H AND L
FIGURE 54. ANALYSIS OF FORCES. 2-LEG LEMNISCATE CALIPER SHIELD
4-Leg Lemniscate Caliper Shield

In a lemniscate caliper shield, the front legs are attached to the canopy, the back legs to the rear, inclined shield.

Figure 55a shows the forces acting on the canopy. Taking moments about H (and referring to Equation A.1.1)

\[ F_c = F_p q \cos \delta \]  \hspace{1cm} \text{(A.1.3)}

Figure 55b shows the forces acting on the base. Taking moments about L (and referring to Equation A.1.2)

\[ F_d + B_f = P_r [(q+a) \cos \delta + b \sin \delta] \]  \hspace{1cm} \text{(A.1.4)}

Solving Equations A.1.3 and A.1.4 simultaneously gives

\[ p = \frac{F(d-c) + B_f}{a \cos \delta + b \sin \delta} \] \hspace{1cm} \text{and} \hspace{1cm} \frac{F(d-c) + B_f}{a}

\[ q = \frac{F_c}{F(d-c) + B_f} \cdot \frac{a \cos \delta + b \sin \delta}{\cos \delta} \] \hspace{1cm} \text{and} \hspace{1cm} \frac{Fca}{F(d-c) + Bf}

4-Leg Lemniscate Chock Shield

In a lemniscate chock shield, all four legs are attached to the canopy.

Figure 56a shows the forces acting on the canopy. Taking moments about H (and referring to Equation A.1.1)

\[ F_c + B_e = F_p q \cos \delta \]  \hspace{1cm} \text{(A.1.5)}

Figure 56b shows the forces acting on the base. Taking moments about L (and referring to Equation A.1.2)

\[ F_d + B_f = P_r [(q + a) \cos \delta + b \sin \delta] \]  \hspace{1cm} \text{(A.1.6)}
a. Forces on canopy

b. Forces on base

FIGURE 55. ANALYSIS OF FORCES. 4-LEG LEMNISCATE CALIPER SHIELD

- 193 -
a. Forces on canopy

b. Forces on base

FIGURE 56. ANALYSIS OF FORCES. 4-LEG LEMNISCATE CHOCK SHIELD
Solving Equations A.1.5 and A.1.6 simultaneously gives

\[ p = \frac{F (d-c) + B (f-e)}{a \cos \theta + b \sin \theta} = \frac{F (d-c) + B (f-e)}{a} \]

\[ q = \frac{Fc + Be}{F (d-c) + B (f-e)} \cdot \frac{a \cos \theta + b \sin \theta}{\cos \theta} = \frac{a(Fc + Be)}{F(d-c) + B(f-e)} \]

If, in the 4-leg chock shield, all four legs are approximately vertical, then

\[ d - c = f - e = a \]

\[ \therefore \quad P = F + B \]

and \[ Q = \frac{Fc + Be}{F + B} \]
APPENDIX 2

CALCULATIONS OF PRESSURE DIAGRAMS

The pressure across the canopy and base plate will vary. If the pressure on each element of the plate is plotted as an ordinate, then the volume of the three-dimensional figure so constructed will represent the total force on the plate, and the resultant of the force will pass through the centre of volume of the figure. If the plate is fairly rigid and the load is evenly distributed across the width, then the variation of load along its length will be approximately linear. In cross-section the figure will be triangular if the force acts at a point less than 1/3 of the plate length from either end, and trapezoidal if it acts between 1/3 and 2/3 of the length. If the size and position of the resultant force is known, use of the above facts allows the stress variation to be estimated.

In the diagrams below:

- total load = volume of pressure diagram, and
- line of action of load passes through centre of volume.

**Triangular Distribution**

```
\[ P \]
\[ v \]
\[ \text{width of diagram} = s \]
```

```
\[ a \]
\[ x \]
\[ c \text{ of area} \]

\[ m \]
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\[ P_v = \frac{1}{3} (m,a)s \]

\[ x = \frac{m}{3} \mu \]

\[ m = 3x \]

and \[ a = \frac{2P_v}{3xs} \]

Trapezoidal Distribution

\[ P = \frac{a + b}{2} \times s \]

\[ x = \frac{1}{3} \mu \frac{a + 2b}{a + b} \]

\[ a = 2P_v \frac{2l - 3x}{l^2 s} \]

and \[ b = 2P_v \frac{3x - l}{l^2 s} \]
APPENDIX 3

SUMMARY OF THE MORE IMPORTANT FORMULAE DEVELOPED IN CHAPTER THREE

Cover load

\[ q = \gamma H \frac{H}{40} \text{ MPa} \]

Depth below which yield zone exists

\[ H^* = \frac{1}{2\gamma} \left( p + p' \right) (k + 1) + \frac{\sigma}{f} \]  \( \ldots (3.9.1) \)

Minimum vertical support required

\[ P_v = d \frac{\gamma k}{2(k - 1)} \]  \( \ldots (3.7.2) \)

Closure of roadway

\[ c = d \frac{1 + \nu}{E} \left( \frac{(k - 1)q + \sigma}{(k + 1)} \right) \]

\[ \frac{2q - \frac{\sigma}{f}}{(p + p')(k + 1)} \]  \( \ldots (3.6.1) \)

\[ c' = d \frac{4}{c} \left( \frac{(k - 1)q + \sigma}{k + 1} \right) \]

\[ \frac{2q - \frac{\sigma}{f}}{(p + 0.1)(k + 1)} \times 10^{-3} \]  \( \ldots (3.6.2) \)

for average strata.

\[ c' = d \times 0.37 \left( \frac{(k - 1)q + \sigma}{k + 1} \right) \times 2q + \frac{\sigma}{f} \]

\[ (p+0.1)(k+1) \times 10^{-3} \]

for drivages completely surrounded by coal.
where $c$ = diametric closure (m)

d = driven diameter of roadway (m)

$E$ = modulus of elasticity (MPa)

$f$ = ratio of laboratory to in situ strength, varying from 1 to 7 depending on degree of fracturing and strength of rock (see Section 3.5 (b))

$H$ = height of overburden (m)

$H'$ = depth below which yield zone exists (m)

$k$ = triaxial stress factor

$p$ = resistance offered by roadway lining (MPa)

$p_v$ = vertical resistance (MPa)

$p'$ = augmentation to lining resistance resulting from the cohesion of the broken rock (approximately $= 0.1$ MPa)

$q$ = cover load (MPa)

$\gamma_r$ = average density of rock (or body force) $= 0.025$ MN/m$^3$

$\xi$ = expansion factor relative to yield zone (approximately $= 0.2$)

$\nu$ = Poisson's ratio

$\sigma$ = unconfined compressive strength of rock as measured in the laboratory (MPa)
APPENDIX 4

SUMMARY OF THE MORE IMPORTANT FORMULAE DEVELOPED IN CHAPTER FOUR

Cover load remote from excavation, \( q = 0.025 \, H \)

Width of caved area required to restore cover load = 0.3 \( H \)

Peak abutment stress,

\[ \sigma = kq + \sigma_o \]  \( \ldots (4.3.3) \)

Yield occurring in roof, floor and seam,

width of yield zone,

\[ x_r = \frac{w}{2} \left\{ \left( \frac{q}{p - p'} \right)^{\frac{1}{k-1}} - 1 \right\} \]  \( \ldots (4.3.7) \)

exponential decay factor,

\[ w > 0.6 \, H, \, C = \frac{0.15 \, H - \frac{M}{2}}{(k-1) + 40 \, \frac{\sigma_o}{H}} \]  \( \ldots (4.4.6) \)

\[ w \leq 0.6 \, H, \, C = \frac{w}{2} \left( 1 - \frac{w}{1.2 \, H} \right) - \frac{M}{2} \]  \( \ldots (4.4.7) \)

stress in yield zone,

\[ \sigma_r = x (p - p') \left\{ \frac{x + \frac{1}{2} \frac{M}{\sigma_o}}{\frac{1}{2} \frac{M}{\sigma_o}} \right\}^{k-1} \]  \( \ldots (4.3.2) \)

Yield occurring in seam only,

width of yield zone,

\[ x_b = \frac{M}{F} \ln \left( \frac{q}{p - p'} \right) \]  \( \ldots (4.3.5) \)

exponential decay factor,

\[ w > 0.6 \, H, \, C = \frac{0.15 \, H + x - \frac{M}{k}}{(k-1) + 40 \, \frac{\sigma_o}{H}} \]  \( \ldots (4.4.4) \)

- 200 -
\[ W < 0.6 \, H, \, C = \frac{W}{2} \left(1 - \frac{W}{1.2 \, H}\right) + x_b - \frac{M}{F} \frac{k}{\sigma} \]

\[ (k-1) + 40 \frac{\sigma}{H} \]

stress in yield zone,

\[ \sigma_y = (p + p') \frac{x_b}{H} \]

\[ \ldots (4.4.1) \]

**Stress in elastic zone**

\[ \frac{x_b - x}{C} \]

\[ \sigma = (\sigma - q) \frac{e}{C} + q \]

\[ \ldots (4.4.1) \]

**Minimum width of stable continuous pillar,**

\[ Q = 2 \left(C + x_b\right) \]

\[ \ldots (4.5.1) \]
Nomenclature

C  constant controlling rate of exponential decay (m)
e  base of Napierian logarithm = 2.718
F  dimensionless function \( \frac{k-1}{\sqrt{k}} + \left( \frac{k-1}{\sqrt{k}} \right)^2 \tan^{-1} \frac{1}{\sqrt{k}} \)
  \((\tan^{-1} \text{ in radians})\)
H  depth of overburden (m)
k  triaxial stress factor (dimensionless)
ln  Napierian logarithm
M  height of extraction (m)
p  resistance offered by supports (MPa)
p' augmentation to support resistance resulting from 'cohesion'
  of broken strata \( \leq 0.1 \text{ MPa} \) (see Section 3.5)
q  cover load or stress field remote from excavation (MPa)
Q  minimum required pillar width (m)
W  width of excavation between ribsides (m)
x  distance from ribside (m)
x_b  width of yield zone (m)
\sigma  stress in elastic zone (MPa)
\sigma_0  unconfined compressive strength of strata in situ (MPa)
  (see Section 3.5)
\sigma_y  maximum stress in abutment zone (MPa)
\sigma_y  stress in yield zone (MPa)
APPENDIX 5

SUMMARY OF THE MORE IMPORTANT FORMULAE DEVELOPED IN CHAPTER FIVE

Closure back from the face

Convergence = 10 M + 30 mm/m \hspace{1cm} (5.2.1)

Downward force of roof block

\[ W = 2 \cdot M \cdot l \cdot s \cdot \gamma \cdot M N \] \hspace{1cm} (5.4.1)

through c. of g. at \( w' = \frac{1}{2} l + M \cdot \cot \alpha \) \hspace{1cm} (5.4.2)

Required support thrust (level seams)

\[ P = W \cdot \frac{r'}{r} - \frac{w'}{p} \cdot \gamma \cdot M N \] \hspace{1cm} (5.4.5)

Equation to replace prop-free-front limitation

\[ M \cdot \gamma^2 = K \cdot m^3 \] \hspace{1cm} (5.7.1)

General equation for required support thrust

\[ P' = 0.06 \cdot M \cdot F \cdot (2 \cdot \cos \delta - \sin \delta \cdot (1 - \gamma) + \mu \cdot \gamma \cdot \cos \delta + \sin \delta) \cdot M N / m. \] \hspace{1cm} (5.11.5)

Minimum values for \( P \)

\[ P = W \cdot (2.5 \cdot \sin \delta + \cos \delta) \cdot M N \hspace{1cm} \text{if reaction slopes towards waste} \hspace{1cm} (5.11.6) \]

\[ P = W \cdot \frac{\cos \delta}{\cos \delta} \cdot M N \hspace{1cm} \text{if reaction slopes towards face} \hspace{1cm} (5.11.7) \]
Nomenclature

F  factor of safety
K  support characteristic = \( \frac{20 \, \frac{PP}{s}}{} \) at conditions of yield (m^3)
L  distance from face to rear of canopy (m)
M  height of extraction (m)
P  distance of support thrust P from rear of canopy (m)
P' distance of support thrust P from face line (m)
P  thrust of supports (MN)
P'' thrust of supports per m of face length (MN/m)
R  distance of reaction from rear of canopy (m)
R' distance of reaction from face line (m)
S  support spacing along face (m)
W  distance of downward force W of roof block from rear of canopy (m)
W' distance of downward force W of roof block from face line (m)
W  downward force of roof block (MN)
\( \alpha \) angle of caving in the waste (°)
\( \delta \) angle of support thrust P to the normal to the roof (°)
\( \gamma \) average density or body force of strata = 0.025 MN/m^3
\( \phi \) full angle of dip of seam (°)
\( \mu \) coefficient of friction, rock on rock