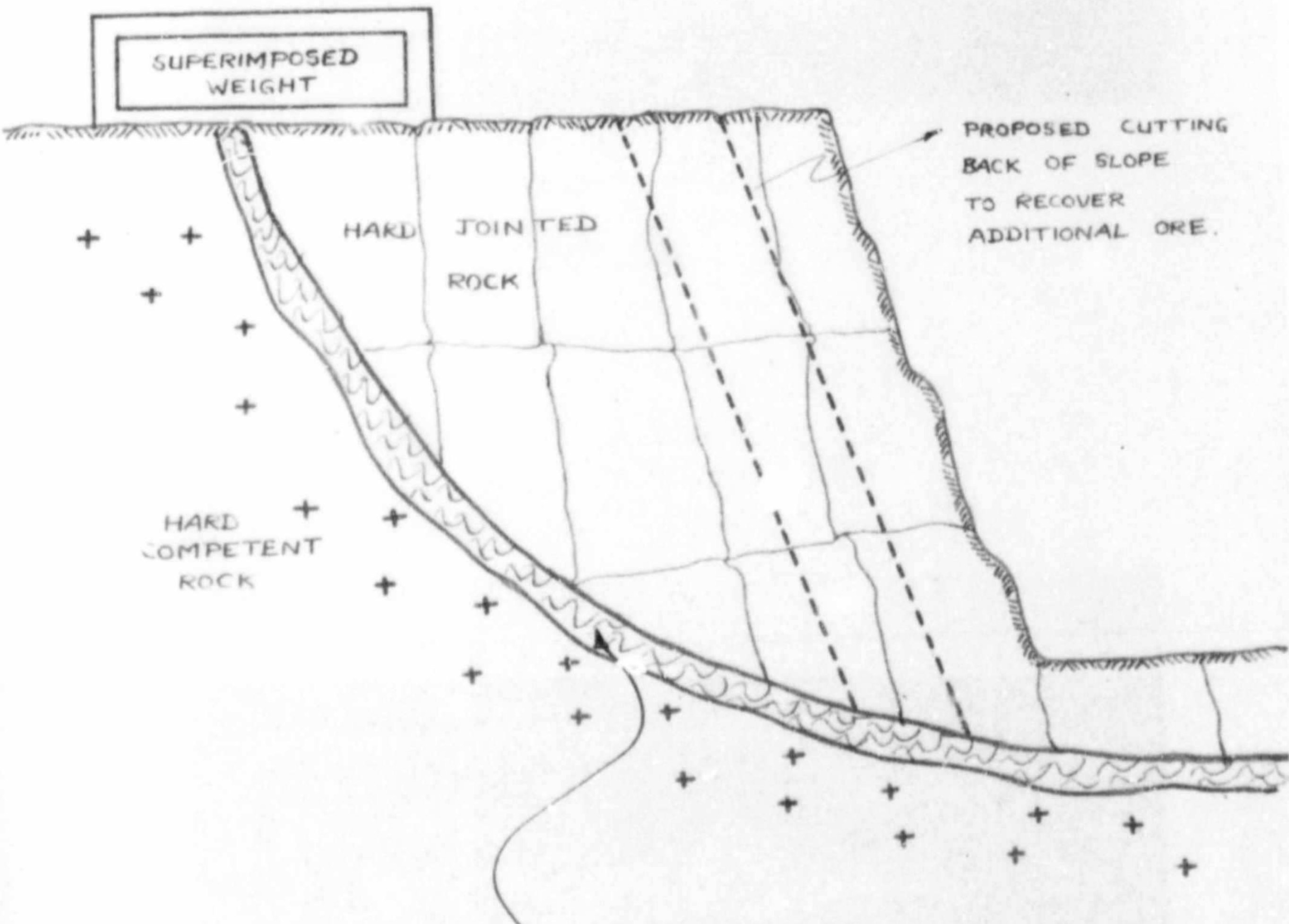

SUPERIMPOSED WEIGHT
PROPOSED CUTTING BACK OF SLOPE TO RECOVER ADDITIONAL ORE.
HARD JOINTED ROCK
HARD COMPETENT ROCK
ZONE OF TALC SCHIST

Fig 30

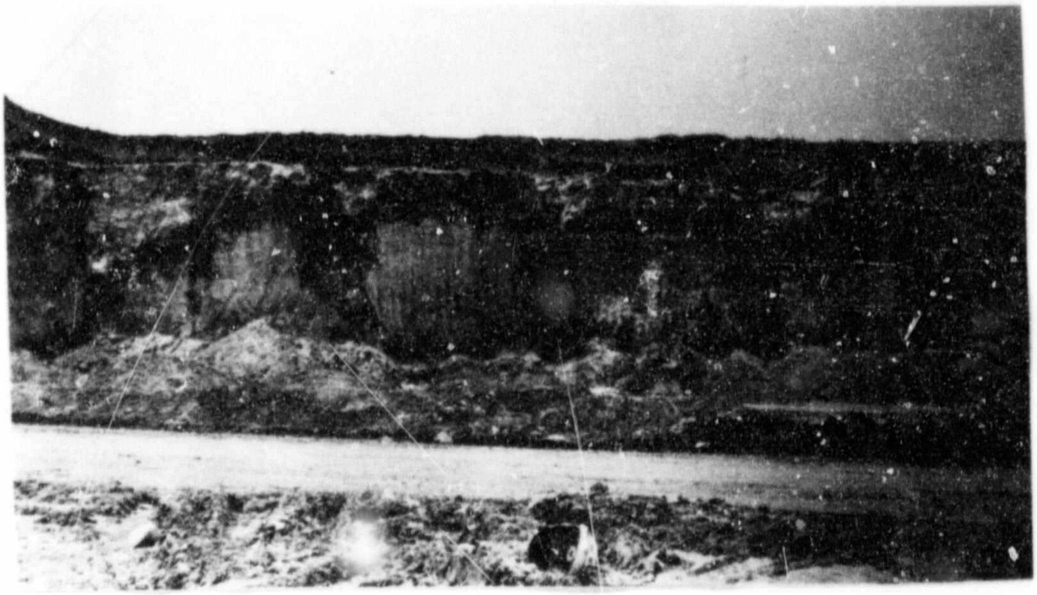


PLATE 1.

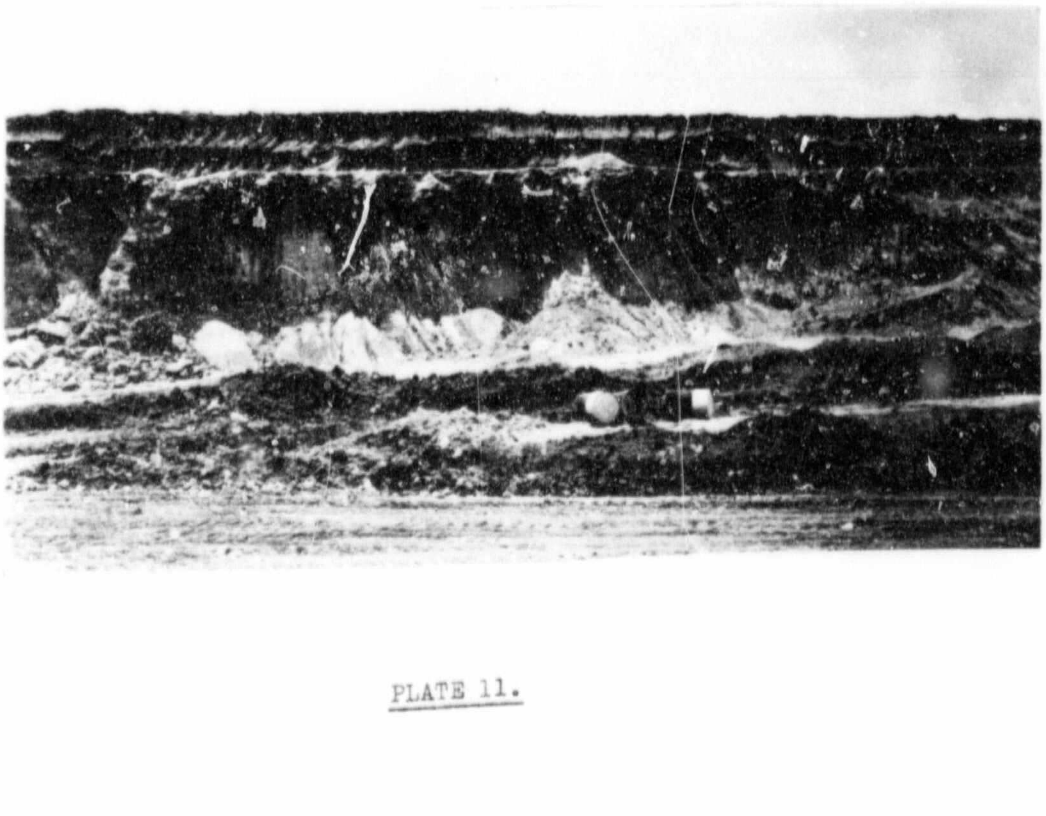


PLATE 11.

APPENDIX I

APPENDIX I

The derivation of general expressions for the Total Volume of excavation and the volume of ore excavated for Pit A.

The shape of the pit and ore body on which the following calculations are based is shown in Fig ______

Calculation of Total Volume of Excavation

Section I : Areas

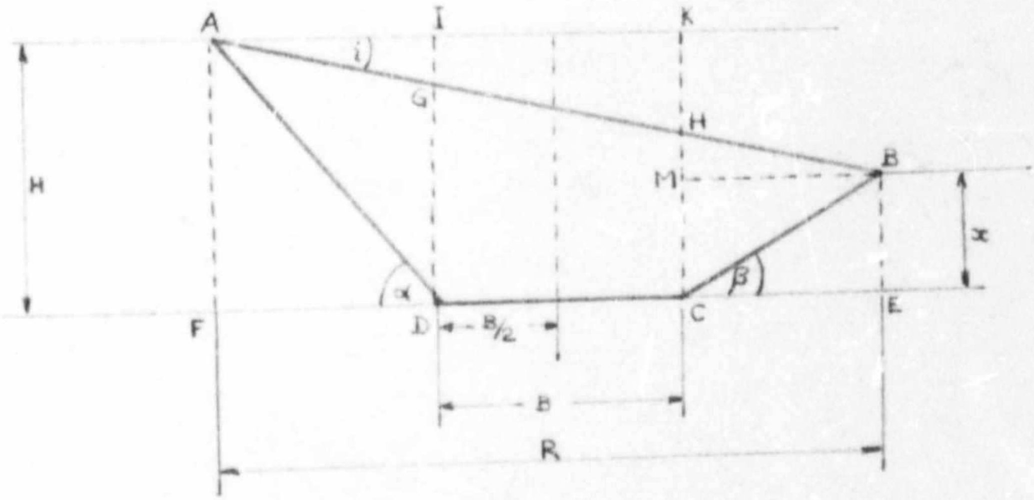


Fig I.1

Cross-section of pit.

From Fig I.1 :- $FD = \frac{H}{\tan\alpha}$, $CE = \frac{x}{\tan\beta}$

$\therefore$ Area ABEF $= \frac{1}{2}(H+x)R$. ——— 1.1.

Area ABCD $= ABEF - (ADF + BEC)$
$= \frac{1}{2}(H+x)R - \frac{1}{2}H.\frac{H}{\tan\alpha} - \frac{1}{2}x.\frac{x}{\tan\beta}$

ie. Area ABCD $= \frac{1}{2}\left\{(H+x)R - \frac{H^2}{\tan\alpha} - \frac{x^2}{\tan\beta}\right\}$ ——— 1.2.

Now $IG = FD\tan i = \dfrac{H\tan i}{\tan\alpha}$

$$\therefore\ GD = H - IG = H\left(1 - \frac{\tan i}{\tan\alpha}\right)$$

$$\begin{aligned}\therefore\ \text{Area } AGD &= \tfrac{1}{2}\, GD.FD \\ &= \tfrac{1}{2} H\left(1 - \frac{\tan i}{\tan\alpha}\right)\cdot\frac{H}{\tan\alpha} \\ &= \tfrac{1}{2}\frac{H^2}{\tan\alpha}\left(1 - \frac{\tan i}{\tan\alpha}\right) \qquad \text{1.3.}\end{aligned}$$

Now $MH = CE\tan i = x.\dfrac{\tan i}{\tan\beta}$

$$\begin{aligned}\text{Area } HBC &= \tfrac{1}{2}\, HC.CE \\ &= \tfrac{1}{2}x\left(1 + \frac{\tan i}{\tan\beta}\right)\frac{x}{\tan\beta} \\ &= \tfrac{1}{2}\frac{x^2}{\tan\beta}\left(1 + \frac{\tan i}{\tan\beta}\right) \qquad \text{1.4.}\end{aligned}$$

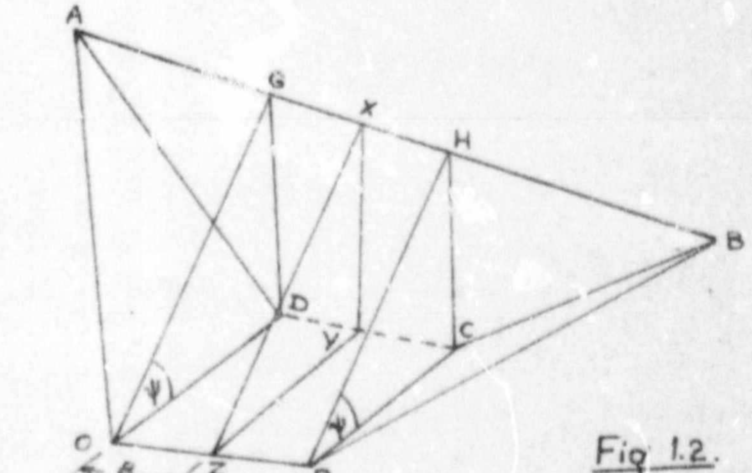


Fig 1.2.

View of Right Hand End of Trench.

Calculation of Area GDO.

$$GD = H\left(1 - \frac{\tan i}{\tan \alpha}\right)$$

$$\therefore OD = \frac{GD}{\tan \psi} = \frac{H}{\tan \psi}\left(1 - \frac{\tan i}{\tan \alpha}\right)$$

$$\therefore \text{Area } GDO = \tfrac{1}{2}\left\{\frac{H}{\tan \psi}\left(1 - \frac{\tan i}{\tan \alpha}\right)\right\} \cdot H\left(1 - \frac{\tan i}{\tan \alpha}\right)$$

$$= \frac{H^2}{2 \tan \psi}\left(1 - \frac{\tan i}{\tan \alpha}\right)^2 \quad \text{———— 1.5.}$$

There will be a similar triangle on the left hand end of the trench whose area will be:-

$$A = \frac{H^2}{2 \tan \theta}\left(1 - \frac{\tan i}{\tan \alpha}\right) \quad \text{———— 1.6.}$$

Calculation of Area HCP

Referring to Fig 1.1

$$HC = H - KH$$
$$= H - (FD + DC) \tan i$$
$$= H - \left(\frac{H}{\tan \alpha} + B\right) \tan i$$

Referring to Fig 1.2.

$$CP = \frac{HC}{\tan \psi} = \frac{H}{\tan \psi}\left(1 - \frac{\tan i}{\tan \alpha} - \frac{B}{H} \tan i\right)$$

$$\therefore \text{Area } HCP = \frac{H^2}{2 \tan \psi}\left(1 - \frac{\tan i}{\tan \alpha} - \frac{B}{H} \tan i\right)^2 \quad \text{———— 1.7.}$$

Similarly, on the left hand side there is an area given by :-

$$A = \frac{H^2}{2 \tan \theta}\left(1 - \frac{\tan i}{\tan \alpha} - \frac{B}{H} \tan i\right)^2 \quad \text{———— 1.8}$$

Calculation of Area XYZ.

The areas of the middle surface, XYZ is given by :-

$$A_m = \frac{H^2}{2\tan\psi}\left(1 - \frac{\tan i}{\tan\alpha} - \frac{B}{2H}\tan i\right)^2 \qquad 1.9.$$

for the right hand side,

and $$A_m = \frac{H^2}{2\tan\theta}\left(1 - \frac{\tan i}{\tan\alpha} - \frac{B}{2H}\tan i\right)^2 \qquad 1.10$$

for the left hand side.

Section II :- Constants.

The following constants will be introduced to simplify the expressions for the volumes.

$$a = \left(\frac{1}{\tan i} - \frac{1}{\tan\alpha}\right) \qquad 2.1$$

$$b = \left(\frac{1}{\tan i} + \frac{1}{\tan\beta}\right) \qquad 2.2.$$

$$c = \left(\frac{1}{\tan\psi} + \frac{1}{\tan\theta}\right) \qquad 2.3$$

From the above equations it will be seen that:

$$\left(1 - \frac{\tan i}{\tan\alpha}\right) = a\tan i \qquad 2.4$$

and $$\left(1 + \frac{\tan i}{\tan\beta}\right) = b\tan i \qquad 2.5$$

Section III Calculation of R and x in terms of H.

Referring to Fig 1.1 we have :-

$$R\tan i = H - x$$

$$\therefore \; R = \frac{H - x}{\tan i} \qquad\text{———} \quad 3.1$$

Also, $$\frac{H}{\tan\alpha} + B + \frac{x}{\tan\beta} = R \qquad\text{———} \quad 3.2.$$

Hence, from 3.1 and 3.2.

$$\frac{H-x}{\tan i} = \frac{H}{\tan\alpha} + B + \frac{x}{\tan\beta}$$

ie. $$x\left(\frac{1}{\tan i} + \frac{1}{\tan\beta}\right) = H\left(\frac{1}{\tan i} - \frac{1}{\tan\alpha}\right) - B.$$

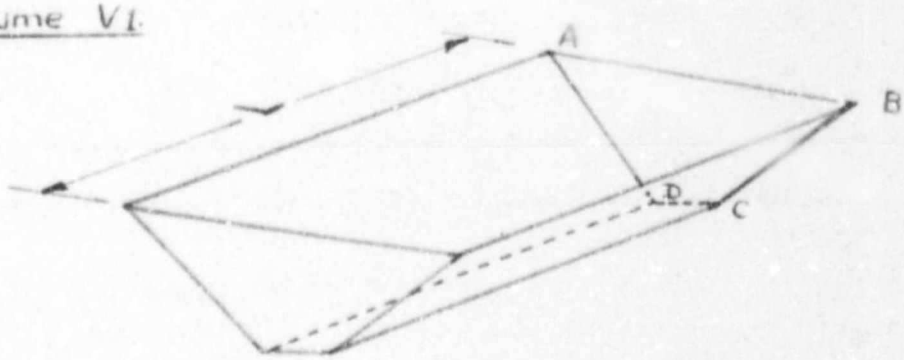
From 2.1 and 2.2 we thus have :

$$bx = aH - B$$

or $$x = \frac{aH - B}{b.} \qquad\text{———} \quad 3.3$$

Section IV :- Volumes.

Volume V1.



$V_1 = L \times (\text{Area ABCD})$

From 1.2

$$V_1 = \frac{L}{2}\left\{(H+x)R - \frac{H^2}{\tan\alpha} - \frac{x^2}{\tan\beta}\right\}$$

From 3.1, substituting for R

$$V_1 = \frac{L}{2}\left\{(H+x)\frac{(H-x)}{\tan i} - \frac{H^2}{\tan\alpha} - \frac{x^2}{\tan\beta}\right\}$$

$$= \frac{L}{2}\left\{H^2\left(\frac{1}{\tan i} - \frac{1}{\tan\alpha}\right) - x^2\left(\frac{1}{\tan i} + \frac{1}{\tan\beta}\right)\right\}$$

From 2.1 and 2.2.

$$V_1 = \frac{L}{2}\left\{aH^2 - bx^2\right\}$$

From 3.3.

$$V_1 = \frac{L}{2}\left\{aH^2 - \frac{(aH-B)^2}{b}\right\} \qquad \text{———— 4.1.}$$

———— " ————

Volume V_2 :

Vol. V_2' is the volume of pyramid AGDO (See Fig 1.2.).

The height of the pyramid is : $h_1 = DO = \frac{GD}{\tan\psi}$.

ie. $h_1 = \frac{H}{\tan\psi}\left(1 - \frac{\tan i}{\tan\alpha}\right)$

Similarly, for the left hand side of the pit the height of the corresponding pyramid is given by :

$$h_2 = \frac{H}{\tan\theta}\left(1 - \frac{\tan i}{\tan\alpha}\right)$$

The total volume of <u>both</u> pyramids is given by:

$$V_2 = \tfrac{1}{3}\,(\text{Area } AGD) \times (h_1 + h_2)$$

From 1.3.

$$V_2 = \tfrac{1}{3}\cdot\tfrac{1}{2}\cdot\frac{H^2}{\tan\alpha}\left(1 - \frac{\tan i}{\tan\alpha}\right) \times H\left(\frac{1}{\tan\theta} + \frac{1}{\tan\psi}\right)\left(1 - \frac{\tan i}{\tan\alpha}\right)$$

$$= \tfrac{1}{6}\,\frac{H^3}{\tan\alpha}\left(\frac{1}{\tan\theta} + \frac{1}{\tan\psi}\right)\left(1 - \frac{\tan i}{\tan\alpha}\right)^2$$

From 2.1 and 2.3, noting that $\left(1 - \frac{\tan i}{\tan\alpha}\right) = a\tan i$

we get :

$$V_2 = \tfrac{1}{6}\,\frac{H^3}{\tan\alpha}\,.\, c.a^2\tan^2 i. \qquad \text{———— 4.2}$$

———— " ————

Volume V_3.

Volume V_3' is the volume of pyramid HBCP (See Fig. 1.2) The height of the pyramid is CP.

ie. $h_1' = CP = \frac{H}{\tan\psi}\left(1 - \frac{\tan i}{\tan\alpha} - \frac{B}{H}\tan i\right)$

Similarly, for the left hand side we have a pyramid of height:

$$h_2' = \frac{H}{\tan\theta}\left(1 - \frac{\tan i}{\tan\alpha} - \frac{B}{H}\tan i\right)$$

The total volume of both pyramids is given by:

$$V_3 = \tfrac{1}{3}\,(\text{Area HBC}) \times (h_1' + h_2')$$

From 1.4. we thus have:

$$V_3 = \tfrac{1}{3}\cdot\frac{x^2}{2\tan\beta}\left(1 + \frac{\tan i}{\tan\beta}\right)\cdot H\left(\frac{1}{\tan\theta} + \frac{1}{\tan\psi}\right)\left(1 - \frac{\tan i}{\tan\alpha} - \frac{B}{H}\tan i\right)$$

From 2.3 to 2.5 we have

$$V_3 = \tfrac{1}{6}\,\frac{Hx^2 cb\tan i}{\tan\beta}\left(a - \frac{B}{H}\right)\tan i.$$

Simplifying, and substituting for x from 3.3.

$$V_3 = c\,\frac{(aH - B)^3\tan^2 i}{6b\tan\beta} \qquad \text{—— 4.3.}$$

Volume V_4

V_4' is the volume of the truncated pyramid GHCDOP (See fig. 1.2.) Applying Newton's formula the volume is given by:

$$V_4' = \tfrac{1}{6}\,h\,(A_1 + 4A_m + A_2)$$

ie $V_4' = \tfrac{1}{6}\,B\,(\text{Area GDO} + 4\times\text{Area XYZ} + \text{Area HCP})$

From 1.5, 1.7 and 1.9 we have:

$$V_4' = \frac{B}{6}\left\{\frac{H^2}{2\tan\psi}\left(1-\frac{\tan i}{\tan\alpha}\right)^2 + 4\cdot\frac{H^2}{2\tan\psi}\left(1-\frac{\tan i}{\tan\alpha}-\frac{B}{2H}\tan i\right)^2\right.$$ I.8.

$$\left. + \frac{H^2}{2\tan\psi}\left(1-\frac{\tan i}{\tan\alpha}-\frac{B}{H}\tan i\right)^2\right\}$$

From 2.4.

$$V_4' = \frac{BH^2}{12\tan\psi}\left\{a^2\tan^2 i + 4\left(a-\frac{B}{2H}\right)^2\tan^2 i + \left(a-\frac{B}{H}\right)^2\tan^2 i\right\}$$

ie. $$V_4' = \frac{BH^2}{12\tan\psi}\left\{a^2 + 4a^2 - \frac{4aB}{H} + \frac{B^2}{H^2} + a^2 - \frac{2aB}{H} + \frac{B^2}{H^2}\right\}\tan^2 i.$$

$$= \frac{B}{12\tan\psi}\left\{6a^2H^2 - 6aBH + 2B^2\right\}\tan^2 i.$$

$$= \frac{B}{6\tan\psi}\left(3a^2H - 3aBH + B^2\right)\tan^2 i$$

Similarly for the left hand side we have a volume V_4'' given by :-

$$V_4'' = \frac{B}{6\tan\theta}\left(3a^2H - 3aBH + B^2\right)\tan^2 i$$

The total volume of the two truncated pyramids is then:

$$V_4 = \frac{B}{6}\left(\frac{1}{\tan\theta} + \frac{1}{\tan\psi}\right)\left(3a^2H - 3aBH + B^2\right)\tan^2 i.$$

From 2.3

$$V_4 = \frac{BC}{6}\left(3a^2H - 3aBH + B^2\right)\tan^2 i \qquad\text{———— 4.4.}$$

———————— 11 ————————

Nett Volume of Excavation

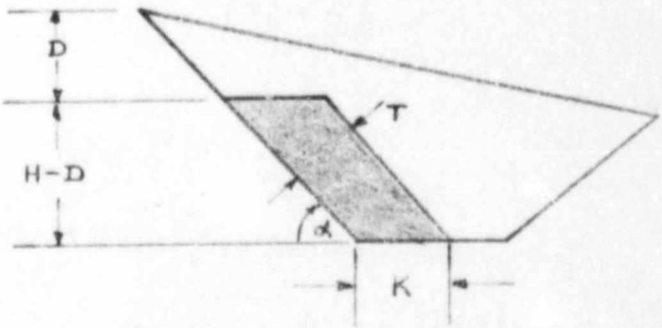
The nett volume of the excavation is given by:

$$V_T = V_1 - \left(V_2 + V_3 + V_4\right)$$

ie $V_T = \frac{1}{2}$ [illegible] H^2 [illegible] $\frac{(aH - \beta)^2}{b} \Big\} - \frac{H^2 \text{[illegible]} \tan^2}{6\,T \sin\alpha}$ [illegible]

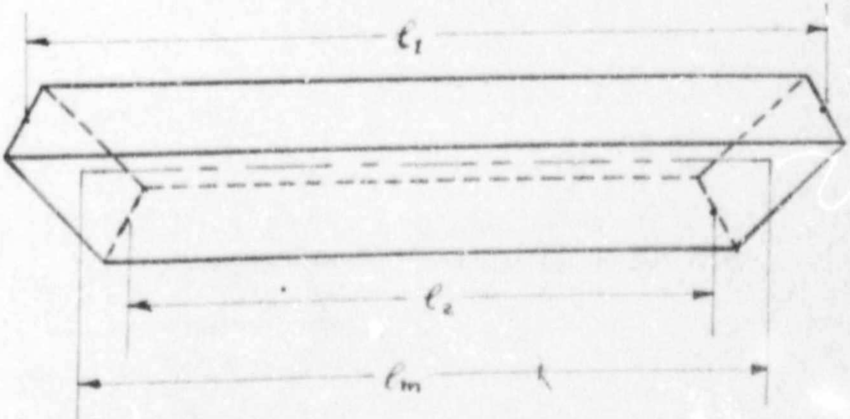
$$- \frac{c(aH-\beta)^3 \tan^2 i}{6\,\text{[illegible]} \tan\beta} - \frac{Bc}{6}\left(3a^2H^2 - 3a\beta H + B^2\right)\tan^2 i \quad \text{—— 4.5}$$

Calculation of Volume of Ore Recovered.



$$K = \frac{T}{\sin\alpha}.$$

Section Showing Ore Body



Ore Body in Plan.

Fig 5.1.

It can easily be shown that the vol. of the ore body is given by :

$$V_o = K(H-D)\,l_m \quad , \quad \text{where } l_m = \frac{l_1 + l_2}{2}$$

<u>Calculation of l_m</u>

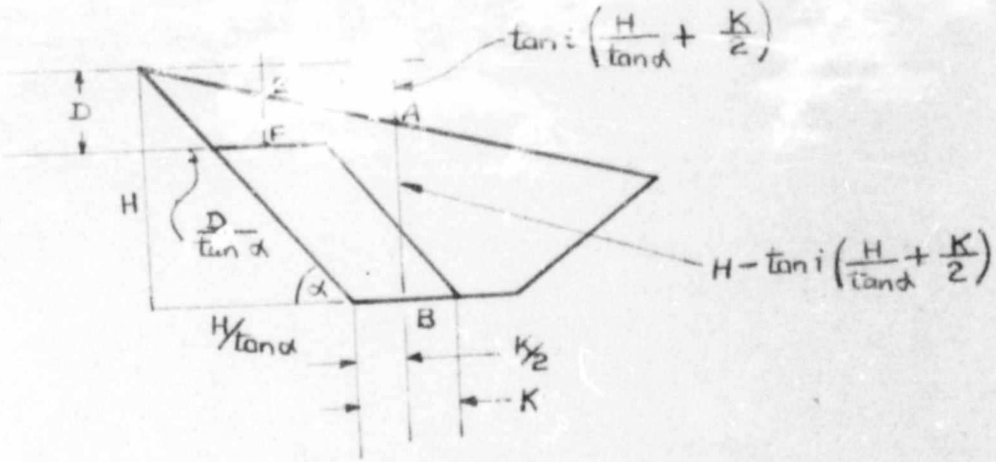


Fig 5.2

From Fig 5.2 we have :

$$AB = H - \tan i\left(\frac{H}{\tan\alpha} + \frac{K}{2}\right)$$

$$= H\left(1 - \frac{\tan i}{\tan\alpha} - \frac{K}{2H}\tan i\right) \qquad 5.1$$

Similarly $$EF = D\left(1 - \frac{\tan i}{\tan\alpha} - \frac{K}{2D}\tan i\right) \qquad 5.2$$

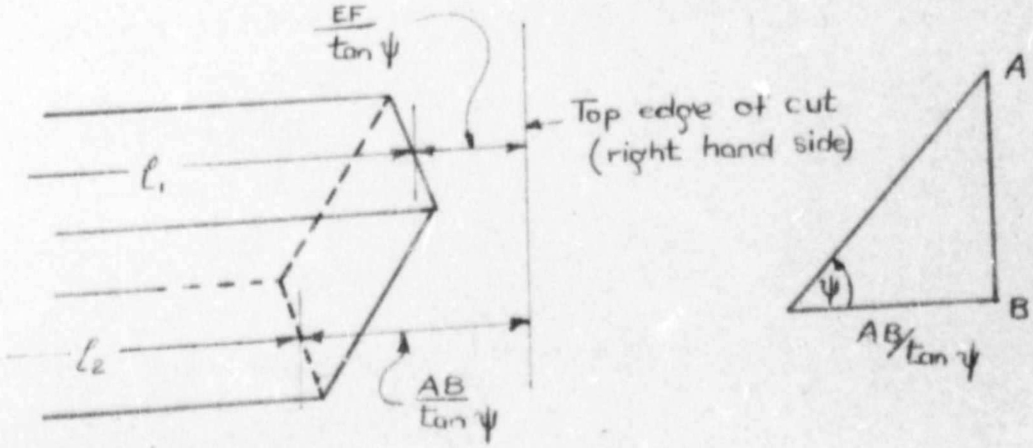


Fig 5.3.

Fig. 5.3 shows the geometry of the right hand end of the ore body. The same formulae apply to the left hand end, with the exception that $\tan\psi$ is replaced by $\tan\theta$.

Hence : $l_1 = L - EF\left(\frac{1}{\tan\theta} + \frac{1}{\tan\psi}\right)$

From 2.3 $l_1 = L - EF.c$ ———————— 5.4

Similarly $l_2 = L - AB.c.$ ———————— 5.5.

$$\therefore\ l_m = \frac{l_1 + l_2}{2} = L - \frac{c(EF + AB)}{2}$$

$$= L - \frac{c}{2}\left\{D\left(1 - \frac{\tan i}{\tan\alpha} - \frac{K}{2D}\tan i + H\left(1 - \frac{\tan i}{\tan\alpha} - \frac{K}{2H}\tan i\right)\right\}\right.$$

From 2.4.

$$l_m = L - \frac{c}{2}\left\{D\left(a - \frac{K}{2D}\right) + H\left(a - \frac{K}{2H}\right)\right\}\tan i$$

$$= L - \frac{c}{2}\left\{a(H-D) - K\right\}\tan i \quad \text{———— 5.6.}$$

Volume of ore Recovered

The volume of ore recovered is given by :

$$V = K(H-D)\, l_m.$$

ie From 5.6.

$$V = K(H-D)\left\{L - \frac{c}{2}\left[a(H+D) - K\right]\tan i\right\} \quad \text{———— 5.7}$$

——— " ———

Expressions For Volumes For Horizontal Ground Surface.

When the ground surface is horizontal the expressions for the total volume of excavation and the volume of ore recovered (Eqns. 4.5 and 5.7) become indeterminate in the form in which they have been given, since when $i = 0$, $\tan i = 0$ and hence the constants a, and $b \rightarrow \infty$.

Four additional results are required in order to evaluate Eqns. 4.5 and 5.7. when $\tan i = 0$.

1. a/b :- From 2.1 and 2.2. we have :

$$a/b = \frac{\left(\frac{1}{\tan i} - \frac{1}{\tan \alpha}\right)}{\left(\frac{1}{\tan i} + \frac{1}{\tan \beta}\right)}$$

$$= \frac{\tan \beta \,(\tan \alpha - \tan i)}{\tan \alpha \,(\tan \beta + \tan i)}.$$

when $\tan i = 0$

$$a/b = \frac{\tan \beta . \tan \alpha}{\tan \alpha . \tan \beta} = 1 \qquad\text{——— 6.1.}$$

2. $\left(a - \frac{a^2}{b}\right)$:-

$$\left(a - \frac{a^2}{b}\right) = \frac{a}{b}\left(b - a\right)$$

From 2.1 and 2.2.

$$= \frac{a}{b}\left(\frac{1}{\tan i} + \frac{1}{\tan \beta} - \frac{1}{\tan i} + \frac{1}{\tan \alpha}\right)$$

$$\text{ie} \quad = \frac{a}{b}\left(\frac{1}{\tan \alpha} + \frac{1}{\tan \beta}\right)$$

From 6.1, when $\tan i = 0$

$$\left(a - \frac{a^2}{b}\right) = \left(\frac{1}{\tan\alpha} + \frac{1}{\tan\beta}\right) \quad \text{——— 6.2.}$$

3. $a\tan i$:- From eqn. 2.4. we have :-

$a\tan i =$ [illegible]

when $\tan i = 0$, $a\tan i = 1$. ——— 6.3.

Hence $a\tan^2 i = 0$ ——— 6.4.

Similar results also hold for $b\tan i$ and $b\tan^2 i$

4. $\frac{1}{a}$:- From 2.1. it follows that

$\frac{1}{a} = 0$ when $\tan i = 0$ ——— 6.5.

Similarly for $\frac{1}{b}$.

Expressions for the total volume of excavation and the volume of Ore recovered can now be derived for the case $\tan i = 0$.

——— " ———

From 4.1. we have :-

$$V_1 = \frac{L}{2}\left\{aH^2 - \frac{(aH-B)^2}{b}\right\}$$

$$= \frac{L}{2}\left\{aH^2 - \frac{a^2H^2}{b} + \frac{2a}{b}H.B. - \frac{B^2}{b}\right\}$$

$$= \frac{L}{2}\left\{H^2\left(a - \frac{a^2}{b}\right) + 2\frac{a}{b}H.B - \frac{B^2}{b}\right\}$$

From 6.1 to 6.5 we have, when $\tan i = 0$

$$V_1 = \frac{L}{2}\left\{ H^2\left(\frac{1}{\tan\alpha} + \frac{1}{\tan\beta}\right) + 2HB \right\} \qquad \text{--- } 6.6$$

——————— " ———————

From the derivation of V_2 we have :-

$$V_2 = \frac{H^3}{6\tan\alpha}\left(\frac{1}{\tan\theta} + \frac{1}{\tan\psi}\right)\left(1 - \frac{\tan i}{\tan\alpha}\right)$$

If $\tan i = 0$ and using eqn 2.3. we get

$$V_2 = \frac{cH^3}{6\tan\alpha} \qquad \text{--- } 6.7.$$

——————— " ———————

From 4.3 we have:-

$$V_3 = \frac{c}{6b}\left(aH - B\right)^3 \frac{\tan^2 i}{\tan\beta}$$

$$= \frac{c}{6}\left(\frac{a}{b}H - \frac{B}{b}\right)^3 \frac{b^2\tan^2 i}{\tan\beta}$$

From 6.1, 6.3 and 6.5 we get, when $\tan i = 0$

$$V_3 = \frac{cH}{6\tan\beta} \qquad \text{--- } 6.8$$

——————— " ———————

From 4.4. we have :

$$V_4 = \frac{Bc}{6}\left(3a^2H^2 - 3aBH + B^2\right)\tan^2 i.$$

$$= \frac{Bc}{6}\left(3H^2a^2\tan^2 i - 3BHa\tan^2 i + B^2\tan^2 i\right)$$

From 6.3 and 6.4, when $\tan i = 0$

$$V_4 = \frac{Bc}{6}\left(3H^2\right)$$

ie. $$V_4 = \frac{BcH^2}{2} \qquad \text{——— 6.9}$$

——— " ———

Hence the total volume of excavation is

$$V_T = V_1 - \left(V_2 + V_3 + V_4\right)$$

From Eqns. 6.6 to 6.9

$$V_T = \frac{L}{2}\left\{H^2\left(\frac{1}{\tan\alpha} + \frac{1}{\tan\beta}\right) + 2HB\right\} - \frac{CH^3}{6}\left(\frac{1}{\tan\alpha} + \frac{1}{\tan\beta}\right)$$

$$- \frac{BcH^2}{2} \qquad \text{——— 6.10.}$$

——— " ———

The volume of ore is given by eqn 5.7.

$$V_o = K(H-D)\left\{L - \frac{c}{2}\left[a(H+D) - K\right]\tan i\right\}$$

remembering that $a\tan i = 1$ (Eqn. 6.3) we get,

when $\tan i = 0$

$$V_o = K(H-D)\left\{L - \frac{c}{2}(H+D)\right\} \qquad \text{——— 6.11.}$$

——— " ———

The Calculation of overall and Instantaneous Stripping Ratios.

The overall stripping ratio for the pit is given by:-

$$R = \frac{\text{Total volume} - \text{Volume of Ore}}{\text{Volume of Ore.}}$$

ie. $R = \dfrac{V_T - V_o}{V_o} = \dfrac{V_T}{V_o} - 1$ ——— 7.1.

The instantaneous stripping ratio, $\bar{R}$, is given by:-

$$\bar{R} = \frac{\text{Increase in total volume per unit height} - \text{Increase in volume of ore per unit height}}{\text{Increase in volume of ore per unit height.}}$$

$$\text{ie } \bar{R} = \frac{\dfrac{\partial V_T}{\partial H} - \dfrac{\partial V_o}{\partial H}}{\dfrac{\partial V_o}{\partial H}} \qquad R = \frac{\partial V_T}{\partial H} \Big/ \frac{\partial V_o}{\partial H} - 1 \text{ ——— 7.2.}$$

In order to evaluate Eqn. 7.2, the derivatives of V_T and V_o with respect to H are required.

From 6.10, for the case $\tan i = 0$ we have

$$V_T = \frac{L}{2}\left\{H^2\left(\frac{1}{\tan\alpha} + \frac{1}{\tan\beta}\right) + 2HB.\right\}$$

$$- \frac{cH^3}{6}\left(\frac{1}{\tan\alpha} + \frac{1}{\tan\beta}\right) - \frac{BcH^2}{2}$$

Differentiating w.r.t. H we have:

$$\frac{\partial V_T}{\partial H} = L\left\{H\left(\frac{1}{\tan\alpha} + \frac{1}{\tan\beta}\right) + B\right\} - \frac{cH^2}{2}\left(\frac{1}{\tan\alpha} + \frac{1}{\tan\beta}\right) - BcH \text{ ——— 7.3.}$$

From 6.11 we have:

$$V_o = K(H-D)\left\{L - \frac{c}{2}(H+D)\right\}$$

Differentiating w.r.t. H we have

$$\frac{\partial V_o}{\partial H} = K\left\{L - \frac{c}{2}(H+D)\right\} - K(H-D)\cdot\frac{c}{2}$$

$$= KL. - \frac{2cKH}{2}$$

——— 7.4.

$$\text{ie } \frac{\partial V_o}{\partial H} = K(L - Hc)$$

——— " ———

The values of R and $\bar{R}$ have been calculated for different depths of pit; the results of the calculations are given in tables Nos I.1 and I.2.

The following values were assumed f[illegible] variables in the expressio[illegible] [illegible] V_T and V_o.

Length of Pit along strike	=	L	= 4000 ft
Depth of orebody below the surface	=	D	= 60 ft.
Thickness of the orebody	=	T	= 100 ft.
Width of the box-cut	=	B'	= 30 ft
Angle of dip of Ore body	=	α	= 30°
Angle of ground surface	=	i	= 0°

The calculations were done on the assumption that the side slopes of the pit on all sides, except that on which the ore body lies, were equal. The calculations were done for the following range of slopes :-

Angle of side slopes of Pit $\theta = \psi = \beta$

a) $\beta = 15°$

b) $\beta = 25°$

c) $\beta = 35°$

d) $\beta = 45°$

Curves have been plotted from the tabulated values as indicated in the text of Chapter 7.

From these curves the values of H and the corresponding values of β were read off for different stripping ratios. These values are given in table Nº I.3.

TABLE Nº I.1.

Total Volume of Excavation, Volume of Ore and Overall Stripping Ratio For Various Depths of Excavation and Side Slopes.

H ft.	β = 15°			β = 25°			β = 35°			β = 45°			H ft
	V_T ft^3	V_o ft^3	R	V_T ft^3	V_o ft^3	R	V_T ft^3	V_o ft^3	R	V_T ft^3	V_o ft^3	R	
60	—	0	∞	—	0	∞	—	0	∞	—	0	∞	60
75	1.220×10^8	0.105×10^8	10.952	1.084×10^8	0.111×10^8	8.832	1.021×10^8	0.114×10^8	7.949	0.980×10^{8}	0.116×10^8	7.448	75
100	1.848	0.272	5.790	1.618	0.293	4.528	1.504	0.302	3.984	1.434	0.307	[illegible]	100
125	2.568	0.430	4.969	2.231	0.468	3.764	2.058	0.486	3.237	1.950	0.496	[illegible]	125
150	3.392	0.579	4.890	2.920	0.639	3.570	2.677	0.666	3.020	2.526	[illegible]	2.703	150
200	5.279	0.848	5.223	4.522	0.964	3.696	4.117	1.016	3.052	3.861	1.047	2.687	200
300	9.888	1.275	6.755	8.546	[illegible]	4.432	7.746	1.673	3.630	7.225	[illegible]	3.135	300
400	15.26	1.553	[illegible]	[illegible]	2.049	5.599	12.30	2.273	4.413	11.47	[illegible]	3.766	400
500	21.00	1.681	11.492	19.29	2.463	6.830	17.70	2.816	5.285				500
600	Ore body peters out			25.67	2.791	8.196	25.84	3.302	6.220	22.40	3.607	5.209	600
800	at depth of 535.8 ft.			39.64	3.191	11.423	38.01	4.102	8.264	36.20	4.641	6.789	800
1000				Ore body peters out			54.08	4.674	10.569	52.44	5.527	8.487	1000
1200				at depth of 932.6 ft.						70.68	6.247	10.313	1200

TABLE No I.2.

Rates of Change of Total Volume and Volume of Ore with Depth And Instantaneous Stripping Ratio For various depths and Side Slopes.

H	$\beta = 15°$			$\beta = 25°$			$\beta = 35°$			$\beta = 45°$			H
	$\frac{\partial V_T}{\partial H}$	$\frac{\partial V_o}{\partial H}$	$\bar{R}$	$\frac{\partial V_T}{\partial H}$	$\frac{\partial V_o}{\partial H}$	$\bar{R}$	$\frac{\partial V_T}{\partial H}$	$\frac{\partial V_o}{\partial H}$	$\bar{R}$	$\frac{\partial V_T}{\partial H}$	$\frac{\partial V_o}{\partial H}$	$\bar{R}$	
60	2.055×10^6	0.710×10^6	1.893	1.761×10^6	0.749×10^6	1.353	1.623×10^6	0.766×10^6	1.119	1.338×10^6	0.776×10^6	0.725	60
100	2.731	0.651	3.196	2.289	0.714	2.205							100
150	3.482	0.576	5.045	2.920	0.675	3.326							150
200	4.132	0.501	7.242	3.491	0.628	4.556	3.136	0.686	3.573	2.904	[illegible]	3.034	200
250	4.680	0.427	9.965	4.528	0.543	7.343							250
300	5.097	0.352	13.47	5.398	0.457	10.81	4.095	0.629	5.514	3.815	0.680	4.610	300
350	5.471	0.278	18.71	6.102	0.371	15.44							350
400	5.713	0.203	27.17	6.639	0.285	22.27	4.860	0.572	7.503	4.670	0.640	6.297	400
500							5.619	0.514	9.924	5.471	0.600	8.118	500
600							6.289	0.457	12.75	6.218	0.560	10.10	600
700							6.867	0.400	16.16	6.859	0.520	12.13	700
800							7.356	0.343	20.45	7.546	0.480	[illegible]	800
900										8.129	[illegible]	[illegible]	900

TABLE No I.3.

Corresponding Values of Side Slope and Depth For Constant Values of Overall and Instantaneous Stripping Ratios

R = 10.0		R = 7.5		R = 5.0	
β	H	β	H	β	H
15°	444	15°	340	15°	172
25°	718	25°	550	25°	346
35°	954	35°	729	35°	474
45°	1163	45°	883	45°	574

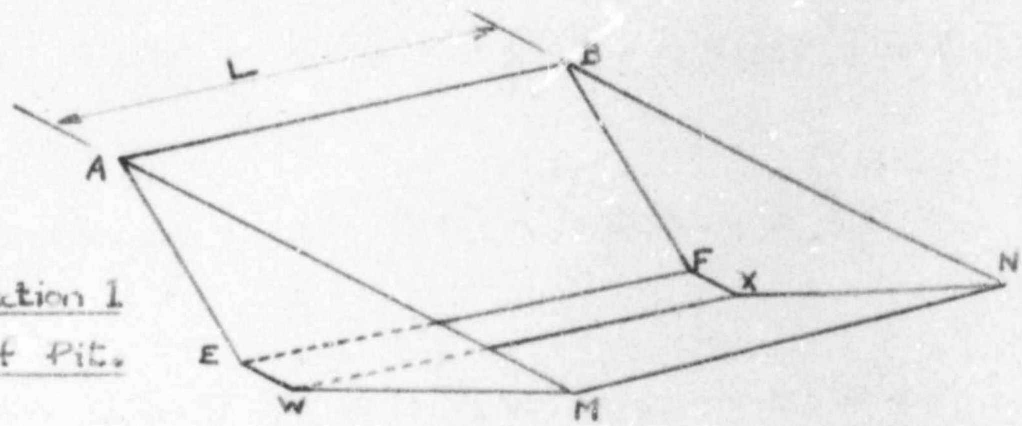
$\bar{R}$ = 20		$\bar{R}$ = 15		$\bar{R}$ = 10	
β	H	β	H	β	H
15°	360	15°	320	15°	255
25°	567	25°	495	25°	380
35°	791	35°	674	35°	505
45°	960	45°	810	45°	595

Note: The above values for H have been read off from curves plotted.

APPENDIX 2

The derivation of general expressions for the total volume of excavation and the volume of ore excavated for Pit B.
[See fig 2 for shape of pit and orebody].

Section 1 of Pit.

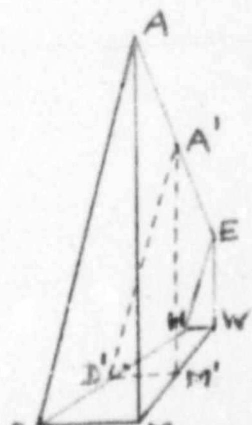


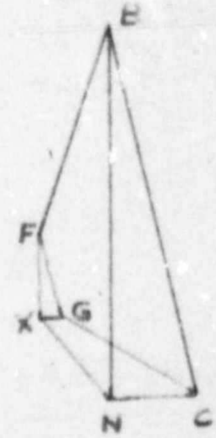
Area of section $AMWE = \frac{1}{2}(AM + EW) \times H$

$= \frac{1}{2} H (W + B)$

Volume of Section 1 $= \underline{\frac{1}{2} L.H.(W+B)}$ - - - - - - - - ①

Section 2 of Pit



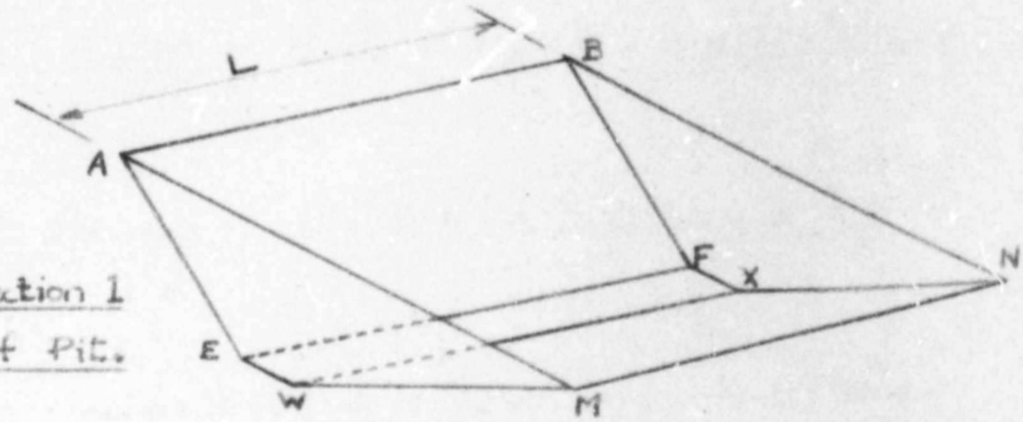


Section 3 of Pit.

APPENDIX II

APPENDIX 2

The derivation of general expressions for the total volume of excavation and the volume of ore excavated for Pit B.
[See fig 2 for shape of pit and orebody].

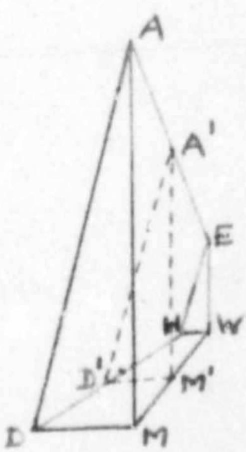


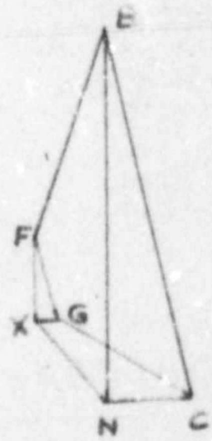
Section 1 of Pit.

Area of section AMWE $= \frac{1}{2}(AM + EW) \times H$
$= \frac{1}{2} H (W+B)$

Volume of Section 1 $= \underline{\frac{1}{2} L.H. (W+B)}$ - - - - - - - - ①

Section 2 of Pit





Section 3 of Pit.

Area of Δ ADM $= \frac{1}{2} AM \times DM$
$= \frac{1}{2} W^2 \tan\phi$

Area of Δ EWH $= \frac{1}{2} B^2 \tan\phi$

Area of Δ A'D'M $= \frac{1}{2}\left(\frac{1}{2}H\cot\alpha + B + \frac{1}{2}H\cot\beta\right)^2 \tan\phi$

[Newton's Formula $V = \frac{1}{6}h\left(A_1 + 4A_m + A_2\right)$]

$\therefore$ Volume of Section 2 $= \frac{1}{6}H\left[\frac{1}{2}W^2\tan\phi + \frac{1}{2}B^2\tan\phi + 2\left(\frac{1}{2}H\cot\alpha + B + \frac{1}{2}H\cot\beta\right)^2\tan\phi\right]$

$$= \frac{1}{6}H\tan\phi\left[\frac{1}{2}W^2 + \frac{1}{2}B^2 + \left(H\cot\alpha + 2B + H\cot\beta\right)^2\right] \cdots (2)$$

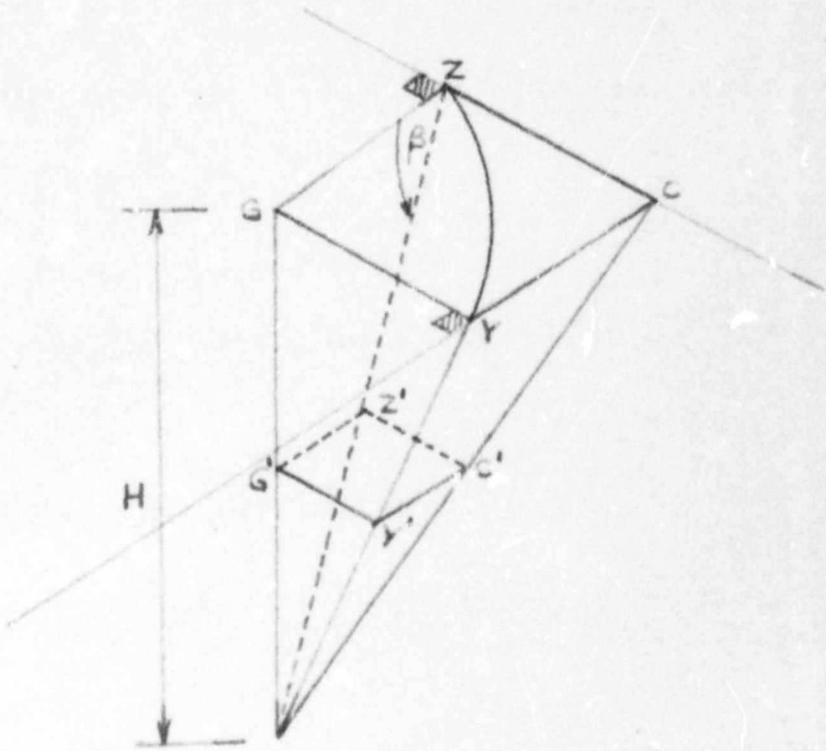
Similarly, Volume of Section 3

$$= \frac{1}{6}H\tan\delta\left[\frac{1}{2}W^2 + \frac{1}{2}B^2 + \left(H\cot\alpha + 2B + H\cot\beta\right)^2\right] \cdots (3)$$

Total Volume, Sections 1 + 2 + 3.

$$= \frac{1}{2}L.H(W+B) + \frac{1}{6}H(\tan\phi + \tan\delta)\left[\frac{1}{2}W^2 + \frac{1}{2}B^2 + \left(H\cot\alpha + 2B + H\cot\beta\right)^2\right]$$

Calculation of volume saved by cutting off the corners.



Area of GZCY $= 2 \times$ Area of Δ GZC

$= GZ \times ZC$

But $GZ = H \cot \beta$

and $ZC = YC$

$= NC - NY$

$= W \tan \delta - B \tan \delta$

$= (W-B) \tan \delta$

$\therefore$ Area of GZCY $= H \cot \beta \, (W-B) \tan \delta$

Similarly —

Area of G'Z'C'Y' $= \frac{1}{4} H \cot \beta \, (W-B) \tan \delta$.

Vol. of pyramid $= \frac{1}{6} H \left(2H \cot\beta \, (W-B) \tan\delta \right)$

$= \underline{\frac{1}{3} H^2 \cot\beta \, (W-B) \tan\delta}$

Vol. of portion of cone $= \underline{\frac{1}{6} \left(\frac{\pi}{2} + \delta \right) \text{ in rads.} \times H \times (H \cot\beta)^2}$

$\therefore$ Vol. of cut-off corner

$= \frac{1}{3} H^2 \cot\beta \, (W-B) \tan\delta - \frac{1}{6} H^3 \cot^2\beta \left(\frac{\pi}{2} + \delta \text{ rads} \right).$

Vol. of both cut-off corners

$= \underline{\frac{1}{3} H^2 \cot\beta \left[2 (W-B) \tan\delta - H \cot\beta \left(\frac{\pi}{2} + \delta \text{ rads} \right) \right]}$

Total Vol. of excavation now becomes :—

$$V_T = \tfrac{1}{2} L.H. (W+B) + \tfrac{1}{6} H (\tan\phi + \tan\delta) \left[\tfrac{1}{2} W^2 + \tfrac{1}{2} B^2 + (H\cot\alpha + 2B + H\cot\beta)^2 \right]$$
$$- \tfrac{1}{3} H^2 \cot\beta \left[2 (W-B) \tan\delta - H \cot\beta \left(\tfrac{\pi}{2} + \delta \text{ rads} \right) \right].$$

Total Vol. of Ore $= (H-D) \operatorname{Cosec}\alpha \times T \left[L + \tfrac{1}{2} T \operatorname{Cosec}\alpha (\tan\phi + \tan\delta) \right]$

$$V_o = \underline{(H-D) T \operatorname{Cosec}\alpha \left[L + T \operatorname{Cosec}\alpha . \tan\phi \right]}$$

The Calculation of Overall and Instantaneous Stripping Ratios

As shown in appendix 1

Overall Stripping Ratio $R = \dfrac{V_T - V_o}{V_o}$.

Instantaneous Stripping Ratio $\bar{R} = \dfrac{\dfrac{\partial V_T}{\partial H} - \dfrac{\partial V_o}{\partial H}}{\dfrac{\partial V_o}{\partial H}}$

In order to evaluate $\bar{R}$, the derivatives of V_T and V_o with respect to H are required.

From above:

$$V_o = (H - D)\, \text{Cosec}\, \alpha . T . \left[L + T\, \text{Cosec}\, \alpha . \tan \phi \right]$$

$$= T.H.\, \text{Cosec}\, \alpha \left[L + T\, \text{Cosec}\, \alpha . \tan \phi \right] - D.T.\, \text{Cosec}\, \alpha \;\ldots$$

$$\ldots \times \left[L + T\, \text{Cosec}\, \alpha . \tan \phi \right]$$

$$\frac{\partial V_o}{\partial H} = T\, \text{Cosec}\, \alpha \left[L + T\, \text{Cosec}\, \alpha . \tan \phi \right]$$

$$= \text{a constant.}$$

From above:

$$V_T = \tfrac{1}{2} L.H.(W+B) + \tfrac{1}{6} H(\tan\phi + \tan\delta)\left[\tfrac{1}{2}W^2 + \tfrac{1}{2}B^2 + (H\cot\alpha + 2B + H\cot\beta)^2\right]$$

$$- \tfrac{1}{3}H^2\cot\beta\left[2(W-B)\tan\delta - H\cot\beta\,(\pi/2 + \delta \text{ rads})\right].$$

$$V_T = \tfrac{1}{2} L.H(H\cot\alpha + 2B + H\cot\beta) + \tfrac{1}{3} H\tan\phi\Big[\tfrac{1}{2}(H\cot\alpha + B + H\cot\beta)^2$$

$$+ \tfrac{1}{2}B^2 + (H\cot\alpha + 2B + H\cot\beta)^2\Big] - \Big[\tfrac{2}{3}H^2\cot\beta(H\cot\alpha + H\cot\beta)\tan\delta$$

$$- \tfrac{1}{3}H^3\cot^2\beta\,(\pi/2 + \delta \text{ rads}).$$

$$V_T = \tfrac{1}{2} L.H^2(\cot\alpha + \cot\beta) + L.H.B + \tfrac{1}{3}H\tan\phi\Big[\tfrac{3}{2}H^2\cot^2\alpha + 5HB\cot\alpha$$

$$+ 3H^2\cot\alpha.\cot\beta + 5B^2 + 5HB\cot\beta + \tfrac{3}{2}H^2\cot^2\beta$$

$$-\left[\tfrac{2}{3}H^3\cot\beta.\cot\alpha.\tan\delta + \tfrac{2}{3}H^3\cot^2\beta.\tan\delta - \tfrac{1}{3}H^3\cot^2\beta\,(\pi/2 + \delta \text{ rads})\right]$$

$$\frac{\partial V_T}{\partial H} = LH(\cot\alpha + \cot\beta) + L.B + \tfrac{1}{3}\tan\phi\Big[\tfrac{9}{2}H^2\cot^2\alpha + 10HB\cot\alpha$$

$$+ 9H^2\cot\alpha.\cot\beta + 5B^2 + 10HB\cot\beta + \tfrac{9}{2}H^2\cot^2\beta\Big]$$

$$-\left[2H^2\cot\beta.\tan\delta(\cot\alpha + \cot\beta) - H^2\cot^2\beta\,(\pi/2 + \delta \text{ rads})\right]$$

$$\frac{\partial V_T}{\partial H} = L.H(\cot\alpha + \cot\beta) + L.B + \tfrac{1}{3}\tan\phi\Big[\tfrac{9}{2}H^2(\cot\alpha + \cot\beta)^2$$

$$+ 10HB(\cot\alpha + \cot\beta) + 5B^2\Big] - H\cot\beta\Big[2(W-B)\tan\delta$$

$$- H\cot\beta\,(\pi/2 + \delta \text{ rads})\Big].$$

The values of R and $\overline{R}$ have been calculated as for Pit A in appendix 1. The results of the calculations are given in tabular form in tables Nº's 2.1 and 2.2.

The same values were used for variables and the same assumptions were made as for the calculations in appendix 1.

Angle of side slopes of Pit $\theta = \psi = \beta$.

The calculations were done for the following side slopes :-

(a) $\beta = 35°$
(b) $\beta = 45°$

Curves have been plotted from the tabulated values as in appendix 1.

From the curves the values of H and the corresponding values of β were read off for different stripping ratios. These values are given in table Nº 2.3.

DETERMINATION OF ϕ IN TERMS OF α AND θ.

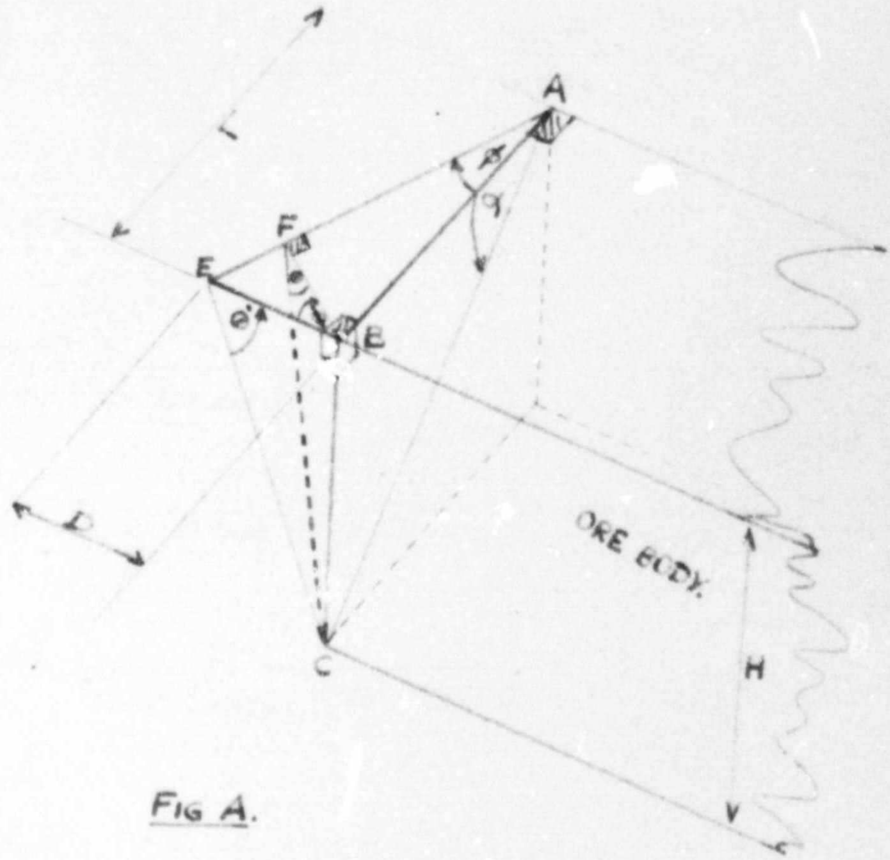


FIG A.

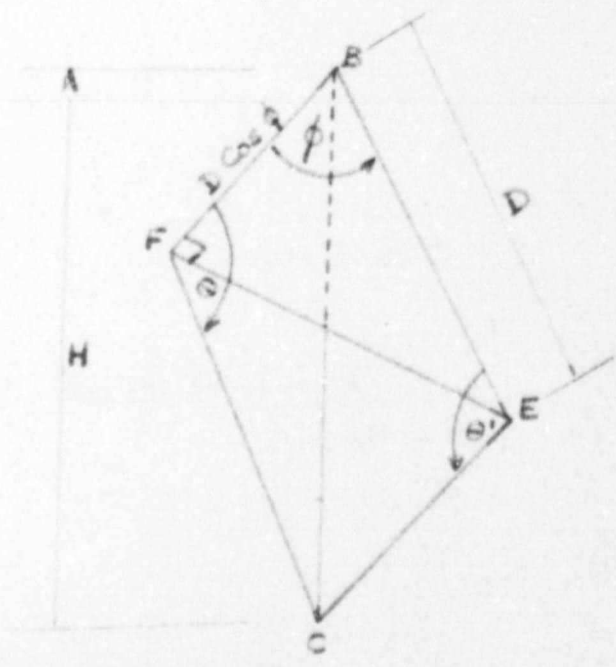


FIG B

From Fig A.

$$L = H \cot \alpha$$
$$D = H \cot \theta'$$

$$\tan \phi = \frac{D}{L} = \frac{H \cot \theta'}{H \cot \alpha} = \frac{\cot \theta'}{\cot \alpha} \quad \text{------------ (1)}$$

From Fig B

$$\tan \theta = \frac{H}{D \cos \phi}$$

but $D = H \cot \theta'$

$$\therefore \tan \phi = \frac{H}{H . \text{Cotangent}\ \theta' \cos \phi}$$

$$\cot \theta' = \frac{1}{\tan \theta . \cos \phi} \quad \text{------------ (2)}$$

Subst. (2) in (1)

$$\tan \phi = \frac{1}{\cot \alpha . \tan \theta . \cos \phi}$$

$$\tan \phi . \cos \phi = \frac{\tan \alpha}{\tan \theta}$$

$$\therefore \quad \sin \phi = \frac{\tan \alpha}{\tan \theta}$$

TABLE Nº 2.1

TOTAL VOLUME OF EXCAVATION, VOLUME OF ORE, AND OVERALL STRIPPING RATIO FOR VARIOUS DEPTHS OF EXCAVATION AND SIDE SLOPES FOR OPEN PIT WHICH HAS A CONSTANT STRIKE LENGTH OF OREBODY WITH INCREASING DEPTH OF PIT.

$\beta = 35°$				
H ft	V_T ft³	V_o ft³	R	H ft
60	—	0	∞	60
75	1·2608×10⁸	0·1287×10⁸	8·796	75
100	1·9030×10⁸	0·3433×10⁸	4·542	100
125	2·6644 "	0·5579 "	3·776	125
150	3·5492 "	0·7725 "	3·580	150
200	5·7022 "	1·2016 "	3·746	200
300	11·6713 "	2·0600 "	4·666	300
400	20·0883 "	2·9183 "	5·884	400
500	31·2744 "	3·7766 "	7·281	500
600	44·3731 "	4·6349 "	8·574	600
800	83·8163 "	6·3516 "	12·196	800
1000	187·5425 "	8·0682 "	16·047	1000
1200	208·4135 "	9·7848 "	20·251	1200

$\beta = 45°$				
H ft	V_T ft³	V_o ft³	R	H ft
60	—	0	∞	60
75	1·1112×10⁸	0·1242×10⁸	7·947	75
100	1·6533×10⁸	0·3313×10⁸	3·990	100
125	2·2862 "	0·5384 "	3·246	125
150	3·0122 "	0·7455 "	3·041	150
200	4·7553 "	1·1596 "	3·101	200
300	9·4824 "	1·4879 "	3·770	300
400	16·0122 "	2·8162 "	4·686	400
500	24·5258 "	3·6444 "	5·780	500
600	34·4496 "	4·4727 "	6·702	600
800	63·9396 "	6·1293 "	9·431	800
1000	103·0041 "	7·7858 "	12·230	1000
1200	154·4920 "	9·4424 "	15·361	1200

TABLE No. 2.2.

RATES OF CHANGE OF TOTAL VOLUME AND VOLUME OF ORE WITH DEPTH AND INSTANTANEOUS STRIPPING RATIO FOR VARIOUS DEPTHS AND SIDE SLOPES.

$\beta = 35°$			
H ft	$\frac{\partial V_T}{\partial H}$	$\frac{\partial V_o}{\partial H}$	$\bar{R}$
75	$2·340 \times 10^6$	$0·858 \times 10^6$	1·727
100	$2·804 \times 10^6$	"	2·268
125	3·287 "	"	2·881
150	3·786 "	"	3·413
200	4·868 "	"	4·639
300	7·143 "	"	7·331
400	9·735 "	"	10·346
500	12·621 "	"	13·710
600	15·742 "	"	17·347
800	22·859 "	"	25·642
1000	31·582 "	"	35·226
1200	41·686 "	"	45·254

$\beta = 45°$			
$\frac{\partial V_T}{\partial H}$	$\frac{\partial V_o}{\partial H}$	$\bar{R}$	H ft
$1·948 \times 10^6$	$0·828 \times 10^6$	1·353	75
$2·285 \times 10^6$	"	1·760	100
2·680 "	"	2·176	125
2·985 "	"	2·66[illegible]	150
3·713 "	"	3·109	200
5·263 "	"	5·2[illegible]1	300
6·989 "	"	7·380	400
8·789 "	"	9·554	500
10·663 "	"	11·878	600
14·964 "	"	17·[illegible]2	800
19·603 "	"	22·675	1000
24·820 "	"	28·976	1200

TABLE Nº 2.3.

CORRESPONDING VALUES OF SIDE SLOPE AND DEPTH FOR CONSTANT VALUES OF OVERALL AND INSTANTANEOUS STRIPPING RATIOS.

$R = 15$		$R = 12.5$		$R = 10$		$R = 7.5$		$R = 5$	
β	H	β	H	β	H	β	H	β	H
35°	950	35°	820	35°	700	35°	520	35°	380
45°	1170	45°	1020	45°	840	45°	680	45°	440

$\bar{R} = 20$		$\bar{R} = 15$		$\bar{R} = 10$		$\bar{R} = 7.5$		$\bar{R} = 5$	
β	H	β	H	β	H	β	H	β	H
35°	650	35°	540	35°	400	35°	300	35°	200
45°	900	45°	720	45°	530	45°	420	45°	300

NOTE: The above values for H have been read off from Figs and

APPENDIX III

APPENDIX Nº III

CALCULATION OF ANGLE OF SHEARING RESISTANCE ϕ FROM INTERSECTION OF CAVING CRACKS.

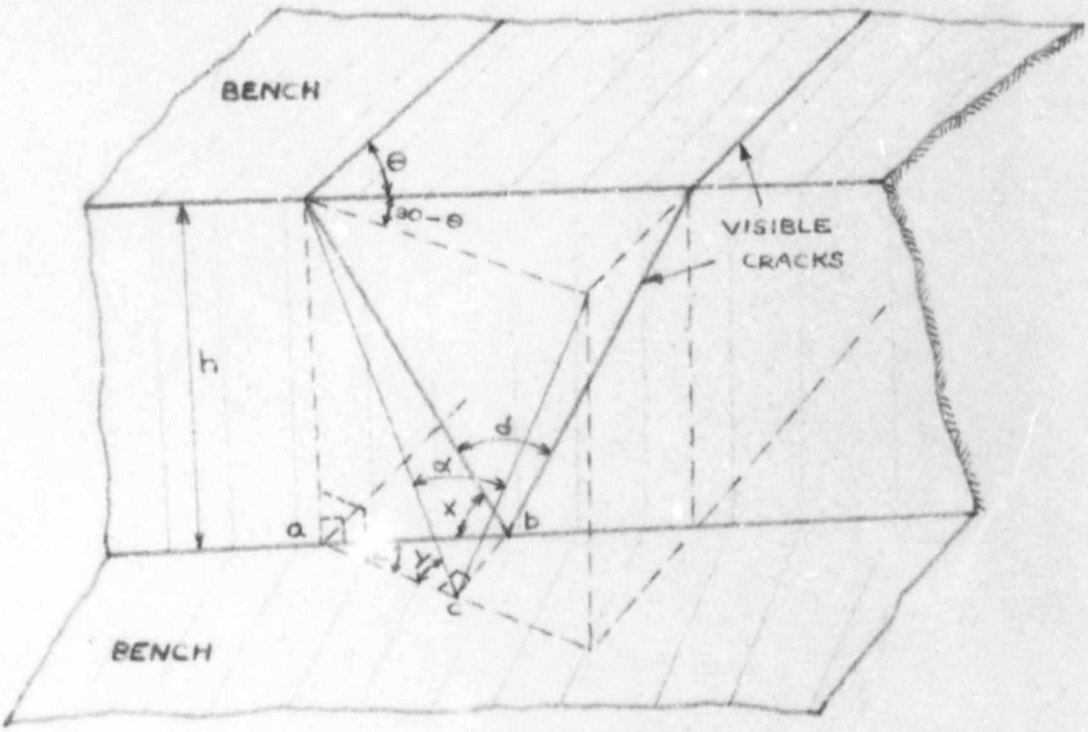


Fig AIII 1

$$X = \frac{180^\circ - \delta}{2} \qquad \tan Y = \frac{h}{ac}$$

$$Y = \frac{180^\circ - \alpha}{2} \qquad ab = h \cot X \qquad ac = ab \cos Z = h \cot X . \cos Z$$

$$Z = 90^\circ - \theta \qquad \underline{\tan Y = \tan X . \sec Z}.$$

$$\phi = 90^\circ - \alpha$$

CALCULATIONS FROM MEASUREMENTS FROM FIG						
δ°	θ°	X°	Z°	Y°	α°	ϕ°
52½	63	63¾	27	66¼	47¼	42¾
51½	66	64½	24	66¼	47½	42½
52½	68	63¾	22	64¾	50¾	39½
50	62½	65	27½	57¼	45¼	44¾
				AVERAGE ϕ		42½.