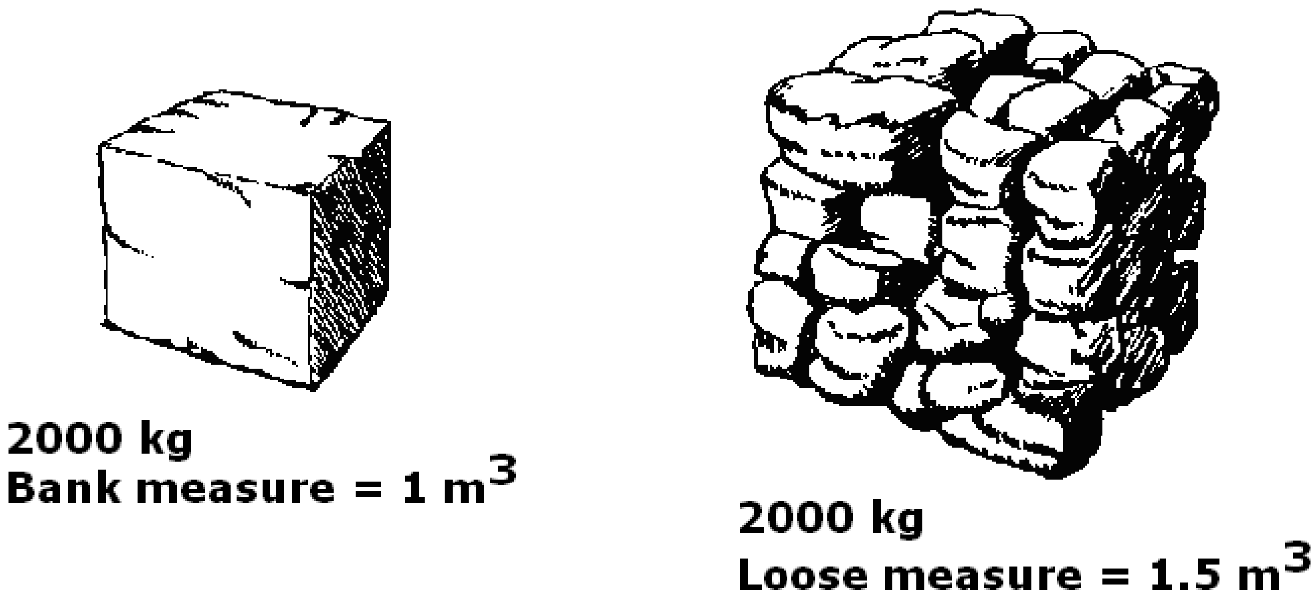
MAD260 - MINING I

UNDERGROUND MINING RELATED PROBLEMS

MATERIALS. On nearly all earthmoving and mining operations, the material requirement is given in terms of bank or in-place cubic meter. The in-place weight of the material is given in terms of specific gravity-kilogram per cubic meter. When the in-place material is dug or blasted from its original position, it breaks up into particles or chunks that lie loosely on each other. This rearrangement creates spaces or voids and adds to its bulk. This change from bank to loose measure is commonly know as swell, and is given in percent of swell. This is best illustrated in the following figure.



Pictorial definition of meaning of material swell.

Swell Factor (SF) = 100 / (100 + % of Swell) …. (1)

% of Swell = (100 – 100*SF) / SF …. (2)

According to this definition SF is always less than 1.0

1) For the same volume (Bank volume = Loose volume) of material

Loose Weight = Bank Weight * SF …. (3)

Thus; Unit weight of loose material = Unit weight of bank material * SF

2) For the same weight (Bank weight = Loose weight) of material

Loose Volume = Bank Volume / SF …. (4)

PROBLEM : Bank specific weight of a material is 3.2 g/cm^3. If 0.75 m^3 of loose material weights 2000 kg, determine both swell factor (SF) and % of swell.

SOLUTION :

Bank measures	Loose measures	
1 m^3 = 3200 kg	*0.75 m^3 = 2000 kg*	*are given.*
0,75 m^3 = 3200 * (3/4) = 2400kg	1 m^3 = 2000 * (4/3) = 2667.67 kg	
2000 kg = 2000 / 3200 = 0.625 m^3	3200 kg = (3200 / 2000) * 0.75 = 1.2 m^3	

If we determine SF on the basis of equal volumes of bank and loose material, we use equation 3;

SF = Loose weight / Bank weight = 2666.67 / 3200 or 2000 / 2400 = 0.8333 is found.

If we determine SF on the basis of equal weights of bank and loose material, we use equation 4;

SF = Bank volume / Loose volume = 0.625 / 0.75 or 1 / 1.2 = 0.8333 is found.

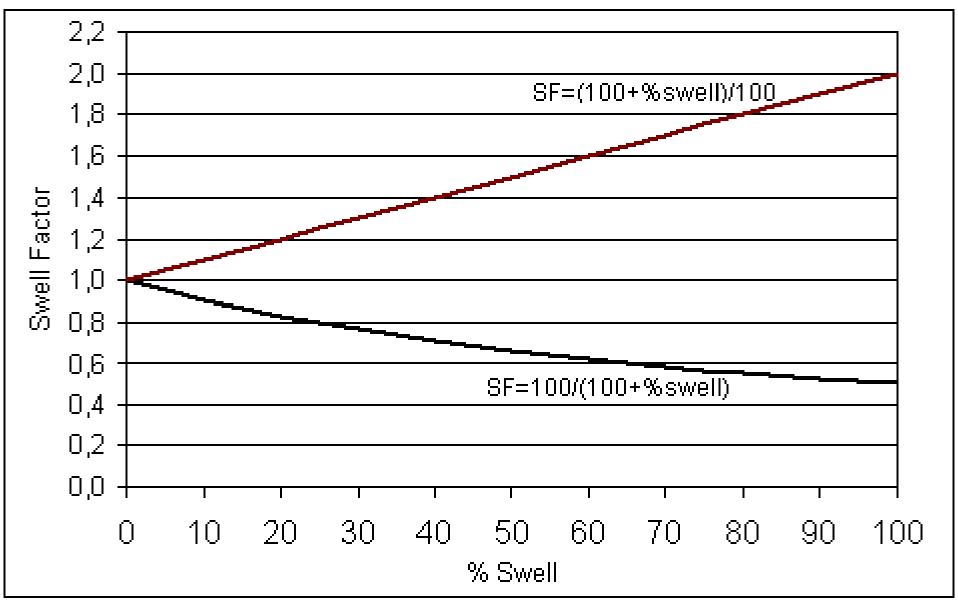
From equation 2,

% of swell = (100 – 100*SF) / SF = (100 – 100*0.833) / 0.833 = 20% is found.

It can also be determined from volume measures for the same weight of material,

% of swell = [(Loose volume – Bank volume) / Bank volume] * 100

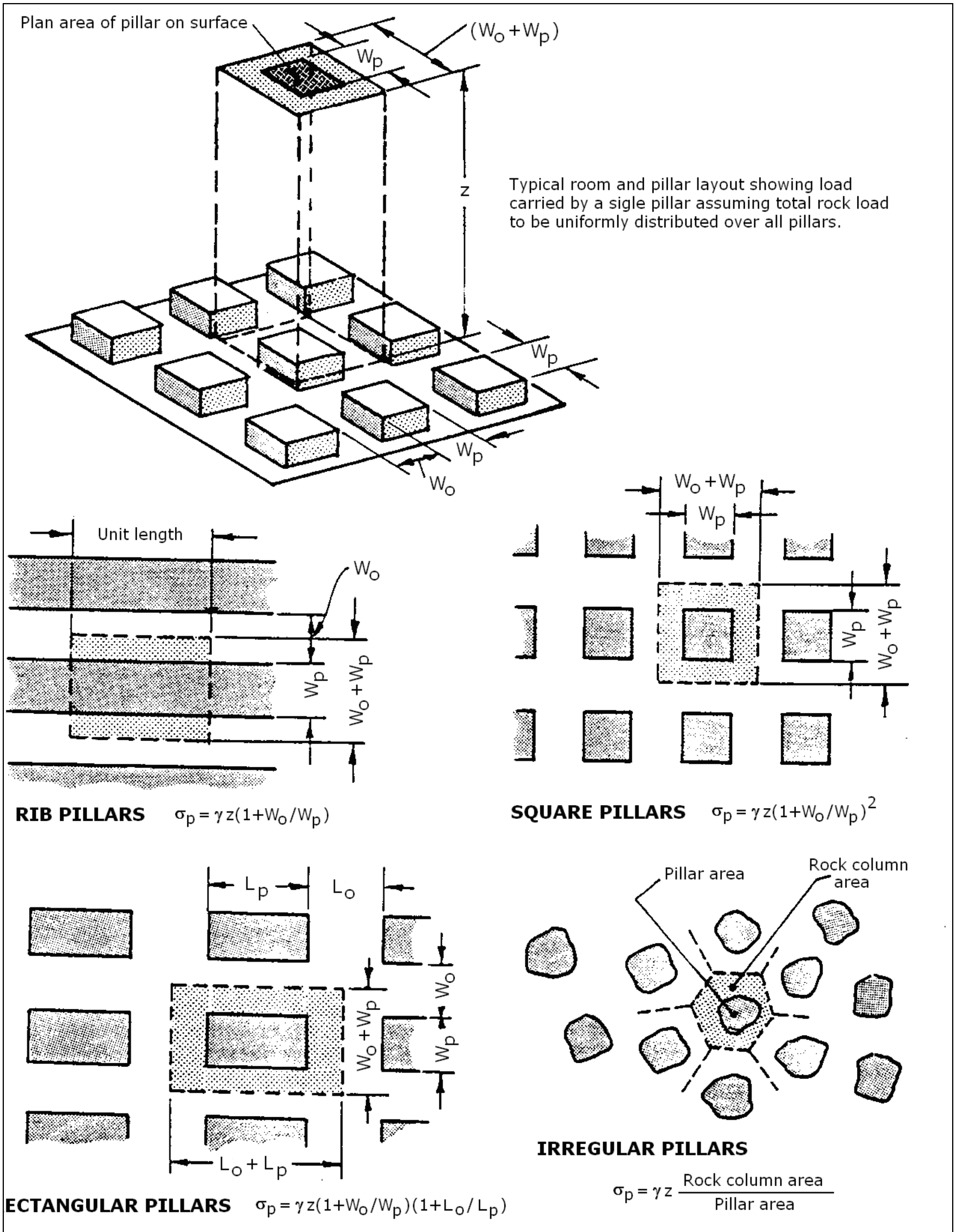
= [(1.2 – 1) / 1] * 100 or = [(0.75 – 0.625) / 0.625] * 100 = 20% is also found.



Above relationship between swell factor and % swell can be defined by the equations;

$$\text{Swell Factor (SF)} = \frac{100 + \%\text{Swell}}{100} = \frac{\text{Bank unit weight}}{\text{Loose unit weight}} \qquad \text{where SF} \geq 1.0$$

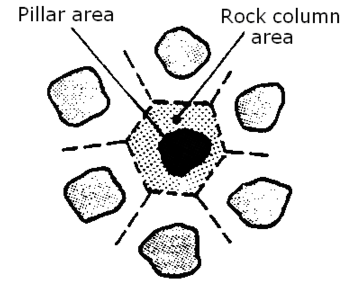
$$\text{Swell Factor (SF)} = \frac{100}{100 + \%\text{Swell}} = \frac{\text{Loose unit weight}}{\text{Bank unit weight}} \qquad \text{where SF} \leq 1.0$$



Average <u>vertical pillar stresses</u> in typical pillar layouts.
Illustrations are all plan views.

PROBLEM:

A horizontal ore seam is extracted by room and pillar. Irregular shaped pillars are left as shown. Average pillar area and rock column area are 20 m^2 and 64 m^2 respectively. The unit weight of overburden strata is 2.5 g/cm^3 and the compressive strength of ore material is 182 kg/cm^2. To maintain a safety factor (SF) of 1.4 for pillar stability, determine the maximum depth of seam.



Average vertical pillar stress,

$$\sigma_p = \gamma z \frac{\text{Rock column area}}{\text{Pillar area}}$$

SOLUTION:

To maintain 1.4 SF

Average vertical pillar stress = 182/1.4 = 130 kg/cm^2 (maximum stress comes from overburden)

130 kg/cm^2 = 1300 $tonnes/m^2$, then

1300 t/m^2 = 2.5 t/m^3*z*(64/20) ➔ z=1300/8 = 162.5 m.

PROBLEM :

A horizontal coal seam with a 2 meter thickness is lying 160 meter below surface. If pillar strength of coal and tonnage factor of overburden material are 320 kg/cm^2 and 0.8 m^3/t respectively, determine the maximum ratio between room width and pillar width.

(Assume square pillar where $\sigma_p = \gamma z\,[1+(W_o/W_p)]^2$)

SOLUTION :

320 kg/cm^2 = (320 kg/cm^2 *10^4 cm^2/m^2) / 10^3 kg/t = 3200 t/m^2

If Tonnage Factor = 0.8 m^3/t then Unit weight, γ = 1/TF = 1/0.8 = 1.25 t/m^3

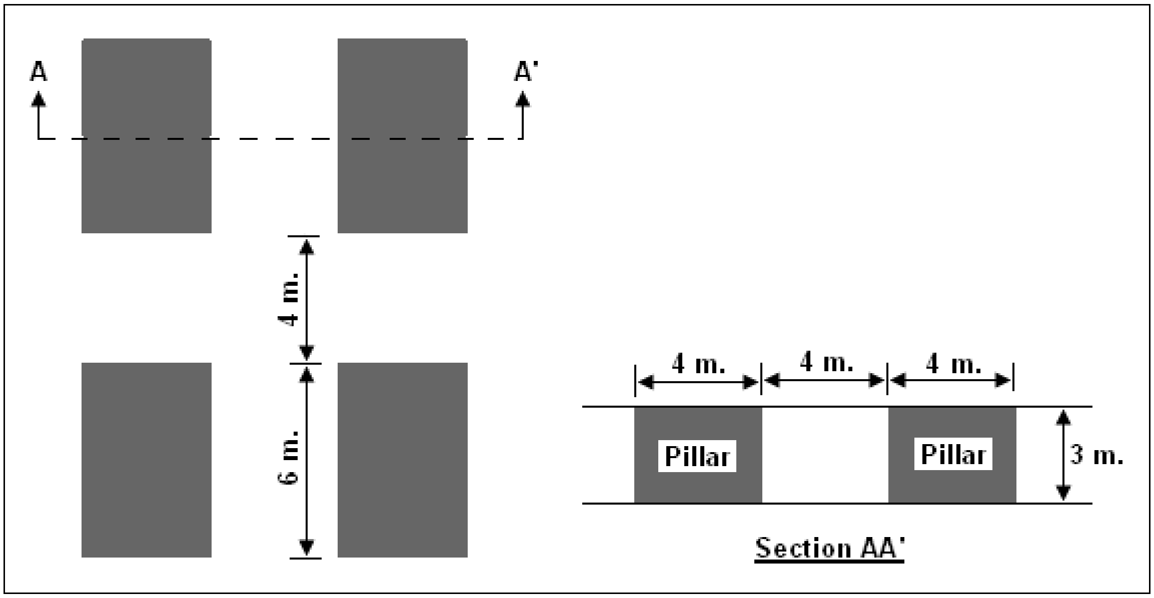
By usin the equation $\sigma_p = \gamma z\,[1+(W_o/W_p)]^2$)

$$3200\ t/m^2 = 1.25\ t/m^3 * 160\ m * [1+(W_o/W_p)]^2 = 200*[1+(W_o/W_p)]^2$$

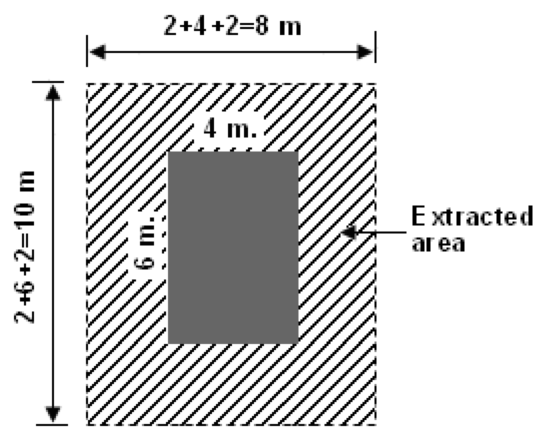
then $[1+(W_o/W_p)]^2 = 3200/200 = 16$

$1+(W_o/W_p) = 16^{1/2} = 4$ so $\mathbf{(W_o/W_p) = 3}$

PROBLEM : A room-and-pillar mining method is applied as shown below. Determine the extraction percentage (ratio).



SOLUTION :



According to influence area of a pillar, the figure can be drawn and sized as shown. Then,

$$\text{Extraction Percentage (Ratio)} = \frac{\text{Extracted area}}{\text{Whole area}} = (10*8-6*4)/(10*8) = 56/80 = 0.7 = 70\%$$

PROBLEM : Determination of critical depth for the application of room-and pillar mining

General view of a room-and-pillar mining method application is given. Drive a general equation to determine critical depth for an extraction ratio of 60% (e).

Compressive strength of coal (in lab on 10 cm cubic sp.), $\sigma_{c,lab}$ = 275 kg/cm^2

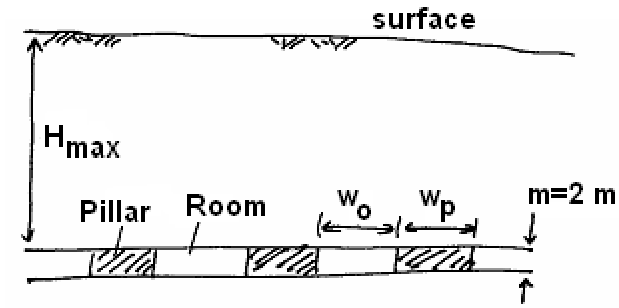
Seam thickness, m = 2 m

Pillar shape : square (top view)

Thickness of immediate roof, t = 1.75 m

Flexural strenth of roof, σ_e = 20 kg/cm^2

Density of overburden, γ = 2.5 t/m^3



SOLUTION :

If pillar stability is considered, safety factor can be defined as;

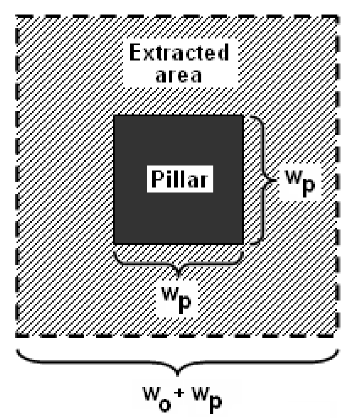
$$F = \frac{\text{Pillar Strength } (\sigma_p)}{\text{Average vertical pressure on pillar } (\sigma_t)} = \frac{\sigma_1 m^{-0.66} w_p^{0.46}}{\frac{0.1\gamma H_{max}}{(1-e)}} \geq 1$$

In this equation;

F : safety factor (for this situation F=1.25 is preferred)
σ_1 : 1*1*1 m*m*m size pillar; its strength in-situ in kg/cm^2
(it can be determined by, $\sigma_1=(\sigma_{c,lab}/n)$ where n is crack frequency in specimen. For densely cracked coal n=4-5. In this problem n=4 is taken.
m : seam thickness w_p : pillar width
γ : average density of overburden, =2.5 t/m^3
H_{max} : critical depth of mine e : extraction ratio

$$H_{max} \leq \frac{10 * \sigma_1 m^{-0.66} w_p^{0.46} (1-e)}{F\gamma}$$ for F=1.25 and γ=2.5 t/m^3

$H_{max} \leq 3{,}2\sigma_1 m^{-0.66} w^{0.46}(1-e)$ to solve this equation for H_{max}, pillar width (w) should be given or determined from "e" value.



From the figure, for square pillar

whole area = $(w_p+w_o)^2$

extracted area = $(w_o+w_p)^2-w_p^2$

then, extraction ratio, e = $[(w_o+w_p)^2-w_p^2]/[(w_p+w_o)^2]$

e = $(w_o^2+2w_ow_p)/(w_p+w_o)^2$ w_o is safe width of room

w_o can be determined from flexural strength test result as

$$w_o \le 4.47\sqrt{t\frac{\sigma_e}{F_a\gamma}}$$ where F_a is safety factor for openings (4 is suitable)

$w_o \le 4{,}47\sqrt{1.75\frac{20}{4*2.5}} \le 8.4$ m is determined. By considering supporting and production conditions w_o is taken as 6 m. Then;

$0.6 = (6^2+2*6*w_p)/(w_p+6)^2 = (36+12w_p)/(w_p^2+12w_p+36)$ ➔

$0.6w_p^2-w_p(12-7.2)-36-21.6 = 0 = 0.6w_p^2-4.8w_p-14.4$ if each divided by 0.6 then

$w_p^2-8w_p-24 = 0$ second order equation is obtained. Then;

$$w_{p,12} = \frac{8\mp\sqrt{64+4*24}}{2} = \frac{8\mp 12.6}{2}$$ from this equation we get two w_p values.

$w_{p,1} = (8+12.6)/2 = 10.3$ m $w_{p,2} = (8-12.6)/2 = -2.3$ m

Thus $w_p = 10.3$ m is found.

$\sigma_1 = \sigma_{c,lab}/n = 275/4 = 68.75$ kg/cm^2

Pillar strength, $\sigma_p = \sigma_1 m^{-0.66} w_p^{0.46} = 68.75*2^{-0.66}*10.3^{0.46} = 127$ kg/cm^2

Critical depth, $H_{max} \le 3.2*68.75*2^{-0.66}*10.3^{0.46}*(1-0.6) \le 162.5$ m

There is a linear relationship between critical depth and laboratory strength. For instance; if only $\sigma_{c,lab}$ is changed to 350 kg/cm^2, then the H_{max} would be determined 200 m.

Under given conditions if the critical depth is asked to increase then the extraction ratio is decreased. If we decrease it to 50% and make the calculations again;

$0.5 = (36+12w_p)/(w_p^2+12w_p+36)$ ➔ $w_p^2-12w_p-36 = 0$ ➔ $w_p = 14.5 \cong 15$ m, then

Pillar strength, $\sigma_p = \sigma_1 m^{-0.66} w_p^{0.46} = 68.75*2^{-0.66}*15^{0.46} = 151$ kg/cm^2

Critical depth, $H_{max} \le 3.2*68.75*2^{-0.66}*15^{0.46}*(1-0.5) \le 240$ m

As it can be concluded, a 17% decrease in extraction ratio (from 60% to 50%), critical depth increases 50% (from 162.5 m to 240 m).

The **tonnage factor** is dependent upon the specific gravity of the ore, and the specific gravity is a function of the mineral composition of the ore. Probably the most accurate method of determining specific gravity of an ore is to calculate an average specific gravity using specific gravities of individual minerals, provided the relative percentages of ore minerals present are accurately known. For example, if a massive sulfide ore is 10% (by volume) galena (sp.gr. is 7.6) 35% sphalerite (sp.gr. is 4.1) and 55% pyrite (sp.gr. is 5.0), the specific gravity of ore would be:

Galena : 7.6 * 0.10 = 0.76

Sphalerite : 4.1 * 0.35 = 1.44

Pyrite : 5.0 * 0.55 = 2.75

Sum = 4.95 ➔ specific gravity of ore

The **specific gravity** of an ore may also be computed by weighing a core or specimen of the ore in air, then weighing the same sample suspended in water. The specific gravity is calculated by the following equation:

$$\text{Sp.gr.} = \frac{W_a}{W_a - W_w}$$

where W_a = weight in air and W_w = weight in water.

In British System

Specific Gravity * 62.5 (lb per cu.ft of water) = lb per cu.ft of ore

Tonnage Factor = (2000 lb/ton) / lb per cu.ft of ore = cu.ft per ton ore (ft^3/ton)

1 m^3 water = 1000 kg

35.314 ft^3 = 2203 lb ➔ 1 ft^3 water = 62.5 lb

For example; if a porphry copper ore has a specific gravity of 2.8, then

2.8 * 62.5 = 175 lb/ft^3 ore

Tonnage Factor = 2000/175 = 11.43 ft^3/ton

1 tonnes (metric) = 2204 lb = 1000 kg

1 tons (also named UK or long) = 2240 lb = 1016 kg

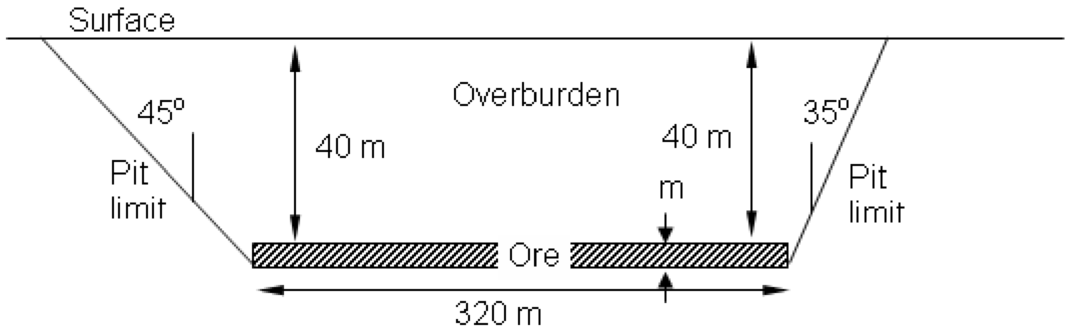
1 tons (also named US or short) = 2000 lb = 907 kg

1 lb = 453.59 gram = 0.454 kg

Specific Gravity	Weight Category	Example Minerals
1-2	Lightweight	Borax (1.7) Ulexite (1.9) Kernite (1.95)
2-4	Average Weight or Medium Weight	Sulfur (2.0-2.1) Halite [salt] (2.16) Gypsum (2.3-2.4) Bauxite (2.4-2.6) Orthoclase (2.5-2.6) Quartz [rock crystal] (2.65) Calcite (2.7) Fluorite (3.0-3.2) Realgar (3.5-3.6)
4-6	Heavyweight	Chalcopyrite (4.1-4.3) Barite (4.3-4.6) Stibnite (4.6) Zircon (4.6-4.7) Marcasite (4.8-4.9) Bornite (4.9-5.1) Pyrite (4.9-5.2) Hematite (4.9-5.3)
Over 6	Very Heavy	Colbaltite (6.3) Wulfenite (6.5-7.0) Vanadinite (6.7-7.2) Cassiterite (6.8-7.1) Galena (7.4-7.6) Cinnabar (8.0-8.2) Native Copper (8.9) Native Gold (19.3)

PROBLEM : A horizontally bedded ore seam with an uniform thickness is lying 40 meters below the surface. The ore will be mined under given conditions. Determine:

a. Critical seam thickness (m) in meter
b. Discuss the result in relation with the stripping ratio (Draw the related figure).



Depth of seam (regular)	: 40 m	Underground mining cost (M_y)	: 36 TL/m^3
Seam length in 3rd direction	: 1200 m	Open pit mining cost (M_a)	: 10 TL/m^3
Tonnage factor of overburden	: 0,75 m^3/t	Stripping cost (M_d)	: 4 TL/t
Unit weight of ore (γ)	: 1,4 gr/cm^3		

SOLUTION :

a. According to given cost parameters, critical stripping ratio is found by;

$K_{critical} = (M_y – M_a) / M_d = (36 - 10) / 4 = 6,5$ tonnes/m^3

Then, volume/weight of overburden material is determined as

Surface length = 320 + 40*tan35^o + 40*tan45^o = 320+28+40 = 388 m

Area of trapezoid = [(320+388)/2]*40 = 14160 m^2

Volume of overburden = 14160*1200 = 16.992.000 m^3

Tonnage of overburden = Volume / T.F. = 16992000/0,75 = 22.656.000 tonnes

Ore volume = 1200*320*m = 384.000*m

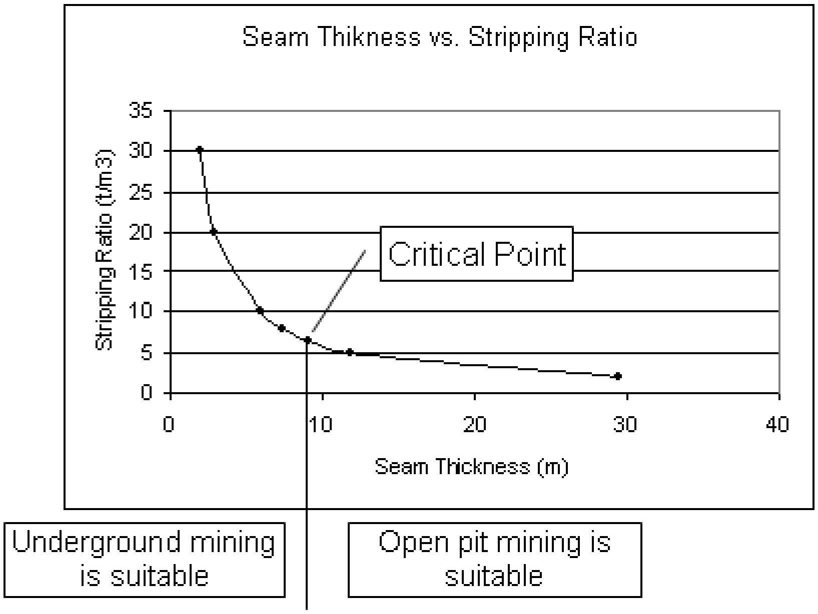
If SR = Amount of stripped material / Amount of ore excavated, then

6,5 = 22.656.000 / 384.000*m

If above equation is solved for “m”, we obtain

m (Critical seam thickness) = 22.656.000 / (384.000*6,5) = **9.08 meters**

b. By using equation m = 22656000/(384000*K), we can obtain different m values for different K values and then, draw the following graph.



K(t/m^3)	m (m)
2	29,50
5	11,80
6,5	9,08
8	7,38
10	5,90
20	2,95
30	1,97

As it is clear from the above figure, open pit mining operation is economically feasible for a seam thicker than the critical value (9,08 meters). Otherwise the reserve must be mined with an underground mining method.

PROBLEM : Determine the daily and yearly production rate in a room and pillar coal mine using conventional equipment under the following conditions.

Working place : 1.83 m * 5.49 m (6 ft * 18 ft)

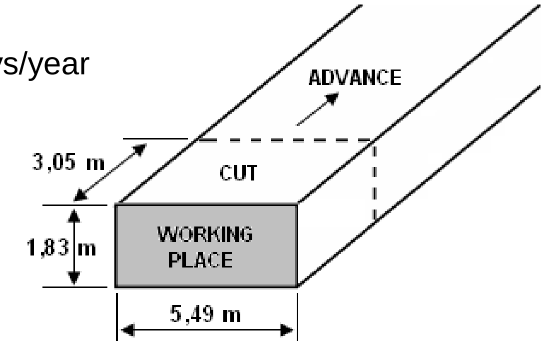
Working time : 7 hrs/shift, 2 shifts/day, 250 days/year

Working sections : 14

Advance per cut : 3.05 m (10 ft)

Number of cuts per shift : 12 cuts/shift

Tonnage factor : 0.75 m^3/tonnes (24 ft^3/ton)



SOLUTION :

Volume of ore per cut, V = 1.83 * 5.49 * 3.05 = 30.64 m^3/cut (=1082 ft^3/cut)

Weight of ore per cut, W = 30.64/0.75 = 40.85 tonnes/cut

Section production per day = 40.85 * 12 cuts/shift * 2 shifts/day = 980.4 tonnes/day/section

Mine production per day = 980.4 * 14 sections = 13 725 tonnes/day

Annual mine production = 13 725 * 250 = 3 431 250 tonnes/year (=2 573 437 m^3/year)

if ore recovery is 100%, then

Surface area exploited per day, A = 5.49*3.05*12*14*2 = 5626.15 m^2/day

" " " " year = 5626.15 * 250 = 1 406 537 m^2/year ≅ 140 hectares/year

OR

3 431 250 tonnes/year = 2 573 437 m^3/year

if seam thickness is 1.83 m., then

Surface area = 2 573 437/1.83 = 1 406 250 m^2/year ≅ 140 hectares/year

In selecting equipment for a mechanized, sequential operation such as modern room and pillar mining, it is necessary to balance each operation within the production cycle. This calls for the estimation of cycle times for each unit operation and the calculation of the required output for each machine.

PROBLEM : Determine the cycle time per working place and the output rating of a gathering-arm loader for a section of the coal mine in the previous problem, given the following additional information.

Place change time : 3.5 min

Car change time : 0.6 min

Delay time/Place : 2.2 min

Shuttle car capacity : 7.3 tonnes (8 tons)

SOLUTION :

Allowable cycle time/working place = (7 hr/sh*60 min/hr) / 12 cuts/sh = 35 mins/cut

Net available loading time = 35 – (3.5+2.2) = 29.3 mins/cut

Number of shuttle car loads/cut = (40.85 tonnes/cut) / 7.3 tonnes/car = 5.6 cars = 6 cars

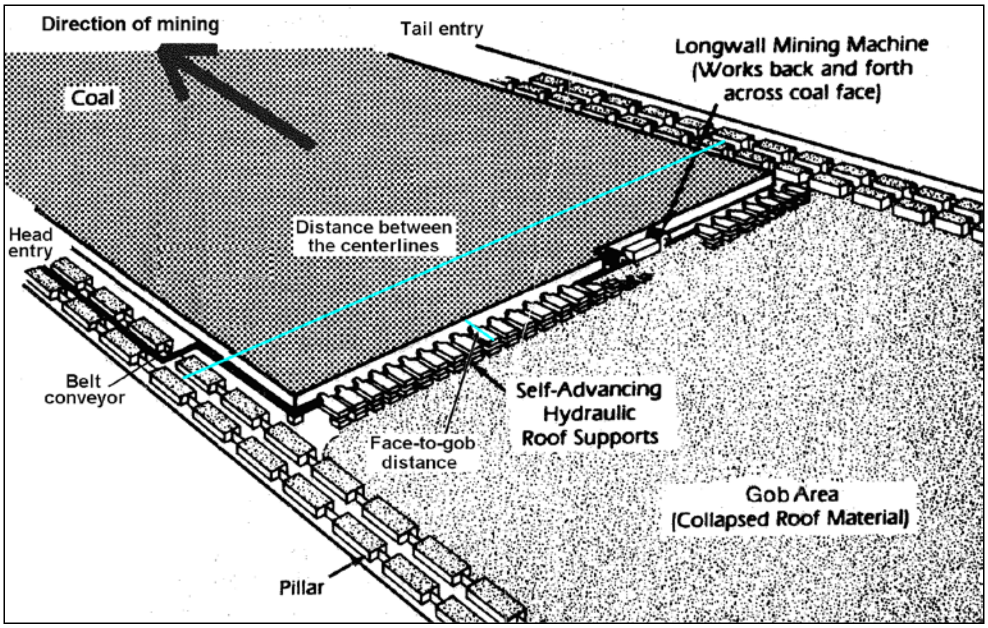
Loading time/Place = 29.3 – (6*0.6) = 25.7 mins

Required loader output = (40.85 tonnes/cut) / (25.7 mins/cut) = 1.59 tonnes/min

Since this is a minimum rating based on average performance, a loader with a somewhat higher output, say, 3 or 4 tonnes/min would be selected to allow for surges and contingencies.

PROBLEM : Calculation of support load density related to longwall mining method.

Support load density is the term used to indicate the average amount of support provided for the entire face are expressed in load per area (e.g., ton/ft^2, t/m^2, etc.). The support area is defined by the face-to-gob distance and distance between the centerlines of head and tail entries.



Assuming an average face-to-gob distance of 4191 mm and a centerline distance of 182,88 m, the total area to be supported is then;

$$4{,}191 \text{ m} * 182{,}88 \text{ m} = 766{,}45 \text{ m}^2$$

The amount of resistance provided by each support is determined by the design yeld pressure of the hydraulic legs. Therefore, for 2 legged shields with 158,8 t/leg capacity on 1371,6 mm centers along the face, the total amount of support is;

$$2 \text{ legs/shield} * 158{,}8 \text{ t/leg} * (182{,}88 \text{ m}/1{,}3716 \text{ m/shield}) = 42558{,}5 \text{ tonnes}$$

The support load density expressed in tonnes per square meter is the total amount of support divided by the total area;

$$42558{,}5 \text{ tonnes}/766{,}45 \text{ m}^2 = 55{,}53 \text{ tonnes/m}^2$$

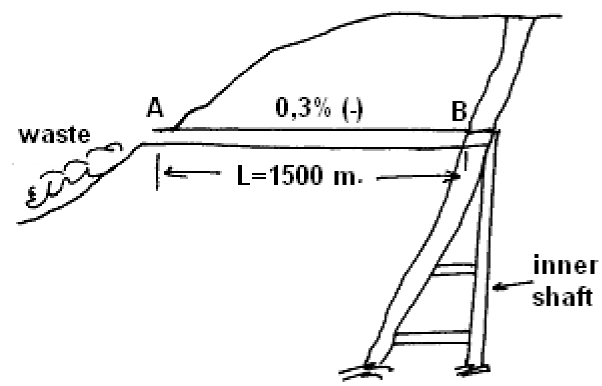
As the distance between the face and the hanging gob increase, the cantilever effect of the unbroken roof becomes greater and loading increases. In order to maintain a minimum cantilever length the face-to-gob distance should be kept to a minimum. A short face-to-gob distance will also maximize the load density of the supports since there will be a smaller area to support. Too little support or to great a distance from the face to the tip of the roof canopies of the supports will allow excessive fracturing and roof falls in front of supports, especially when mining under massive strata.

PROBLEM : Calculation of locomotive power.

A diesel locomotive is scheduled to transport waste material (broken) of an interior shaft sinking in a mine. Related parameters are given as follows. By assuming that this operation should have been done in 35 minutes, determine locomotive power needed.

Given parameters :

Shaft dimension, F : 2*2,5 m*m
Advance per shift, l_i : 1,5 m/shift
Broken rock density, γ : 1,8 t/m^3
% swell : 30 %
Car weight, W_v : 750 kg
Car capacity, W_f : 2000 kg
Locomotive weight, W_g : 2200 kg
Motor efficiency,η : 70%
Road grade, i : 0,3% (-)
Friction coefficient, μ : 0,01
Loading+Damping+Maneouvre time, t : 25 mins



SOLUTION :

First, the velocity of train should be determined. Thus, time required for a cycle of transport

$t_{cycle} = t_{loaded} + t_{empty} + t_{maneouvre}$ ➔ assume $t_{loaded} = t_{empty}$ then $t_{cycle} = 2*t_{loaded} + t_{maneouvre}$

$t_{loaded} = L/V$ then 2100 sec = 2*(1500 m/V) + 25*60 from this

V = 3000/(2100-1500) = 5 m/sec ➔ 5*3600/1000 = 18 km/hr is determined

To determine number of cars needed to transport the waste;

waste volume/shift = 2*2,5*1,5 = 7,5 m^3/shift

loosened waste volume = [(100+30)/100]*7,5 = 9,75 m^3/shift

loosened waste weight = 1,8*9,75 = 17,55 t/shift

number of cars, n = 17,55/2 = 8,8 ≅ 9 cars needed

Total friction force is calculated by

$\Sigma F = (\mu - i)[W_g + n(W_w + W_f)] = (0,01-0,003)[2200+9(750+2000)] = 188,6$ kg

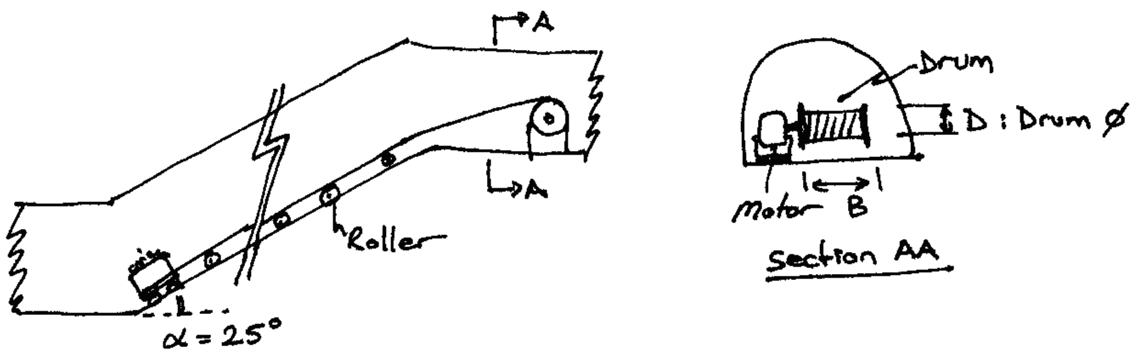
Motor power, $N = (\Sigma F * V)/(75*\eta)$ in HP where η is efficiency (%)

V is velocity in m/sec

N = (188,6*5)/(75*0,70) = 18 HP ≅ 20 HP

PROBLEM : Determination of hoist motor power

A hoist motor is mounted on a decline as shown to remove waste material. Determine hoist motor power and drum dimensions (diameter and width) if the parameters are given as follows;



Given parameters :

Car capacity : 1000 liter
Car empty weight, W_b : 720 kg
Waste weight, W_t : 1800 kg
Slope, α : 25^o
Distance (road), S : 80 m

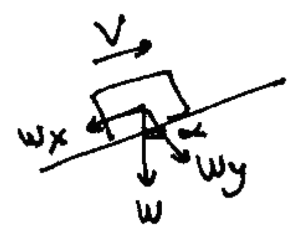
Traction coefficient, T : 10 kg/t
Motor efficiency, η : 70%
Friction on rollers, μ : 0,3
Speed, v : 1 m/s

SOLUTION :

First of all required rope characteristics (diameter, weight, etc.) should be determined.

Static weight, $W = W_b+W_t = 1800+720 = 2520$ kg

Components of this weight,



$W_x = W\sin\alpha = 2520*\sin25^o = 1065$ kg

$W_y = W\cos\alpha = 2520*\cos25^o = 2280$ kg

Traction (friction) force, $F_s=T*W_y = 10*2,28 = 23$ kg

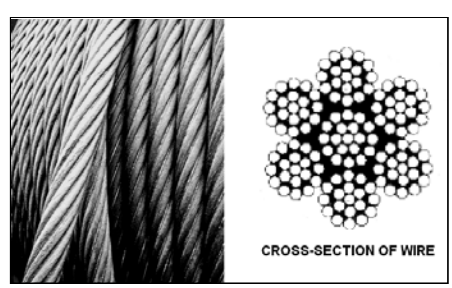
Total force on rope, $F_r = W_x+F_s = 1065+23 = 1090$ kg

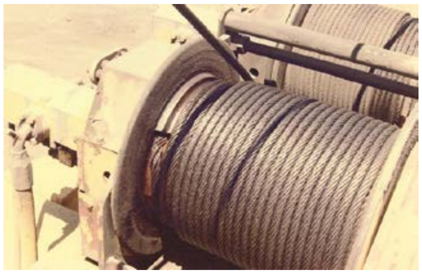
If a Safety Factor (SF) = 5 is taken for rope break, then;

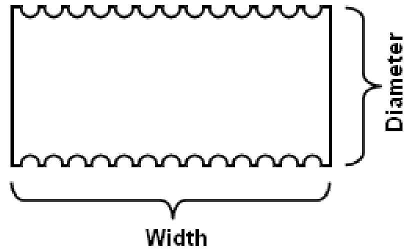
Breaking force, $F_k = SF*F_r = 5*1090 = 5540$ kg

According to international standards (eg., DIN-655), rope is choosen;

Break force = 5700 kg
Wire diameter = 0,7 mm
Rope diameter = 11 mm
Rope section = 43,9 mm^2
Rope weight, q = 0,41 kg/m
Break strength = 130 kg/cm^2







Drum diameter, D = 600*Wire diameter = 600*0,7 = 420 mm = 0,42 m

To determine drum width, first the rope length is found

Road distance (length), S = 80 m
Distance to hoist motor = 7,5 m (application)
Lower end distance = 7,5 m (application)
Extra length on drum = 20 m (for safety)

Then, rope length, L = 80+7,5+7,5+20 = 115 m

Number of windings on drum, $z = L/\pi D$ = 115/(3,14*0,42) = 87

If 2 mm gaps are left between the windings, then;

Drum width, B = z(d+2)/1000 = 87(11+2)/1000 = 1,15 m d:rope diameter in mm

Motor power, $N=(\Sigma F.V)/(75\eta)$

ΣF = Forces on rope (due to full car + rope weight + Friction on rollers)

$\Sigma F = F_r + q.S.\sin\alpha + q.S.\cos\alpha.\mu = 1090+0,41*80*\sin 25^o+0,41*80*\cos 25^o*0,3$

ΣF = 1113 kg

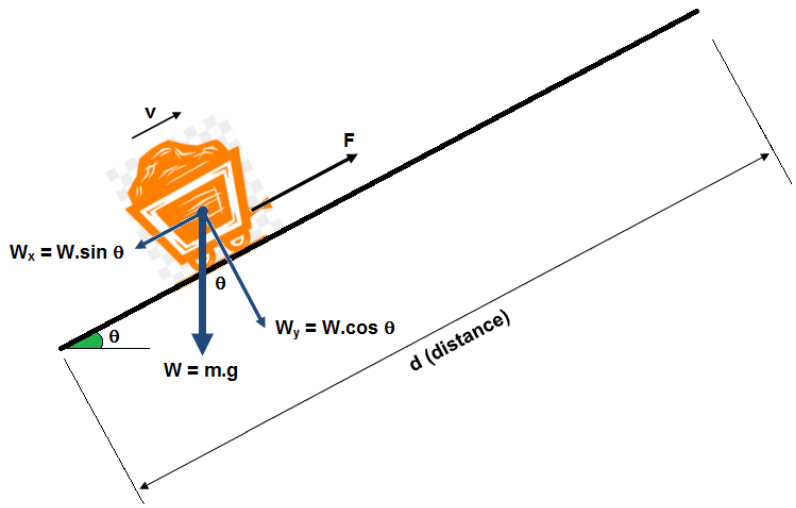
Motor power, N=(1113*1)/(75*0,7) = 21,2 HP or 15,8 kW 1 kW=1,34 HP

.... CHOOSE MOTOR WITH 25 HP

PROBLEM : A loaded ore car has a mass of 870 kg and rolls on rails with negligible friction. It starts from rest and is pulled up an inclined shaft by a cable connected to a winch. The shaft is inclined at 28.5° above the horizontal. The car accelerates uniformly to a speed of 2.20 m/s in 10.5 s and then continues at constant speed.

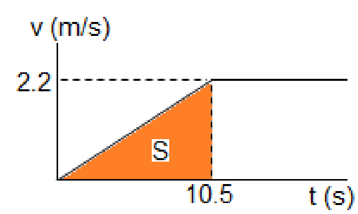
(a) What power (W) must the winch motor provide when the car is moving at constant speed?
(b) What maximum power (W) must the winch motor provide?
(c) What total energy (J) transfers out of the motor by work by the time the car moves off the end of the track, which is of length 1500 m?

SOLUTION :



a) Force required to move the car up the rails is it's weight times sin of the angle
F = m*g*sin28.5 = 870*9.8*0.4772 = 4068 Newtons
once it reaches constant speed, in one second, it moves 2.2 meters, so
Work = 4068*2.2 = 8950 Joules
since this is one second, that is a rate of 8950 Watts

$$\mathrm{W} = \frac{\mathrm{J}}{\mathrm{s}} = \frac{\mathrm{N \cdot m}}{\mathrm{s}} = \frac{\mathrm{kg \cdot m^2}}{\mathrm{s^3}}$$



b) While accelerating, it must provide additional work.
average acceleration is 2.2/10.5 = 0.21 m/s²
distance (S) is 2.2 m/s*(1/2)*10.5s = 11.6 m
F = ma = 870*0.21 = 182 Newtons
182 newtons over a distance of 11.6 m is 2111 joules.
The power to do this is 2111/10.5 = 201 watts
total power = 8950+201 = 9151 Watts

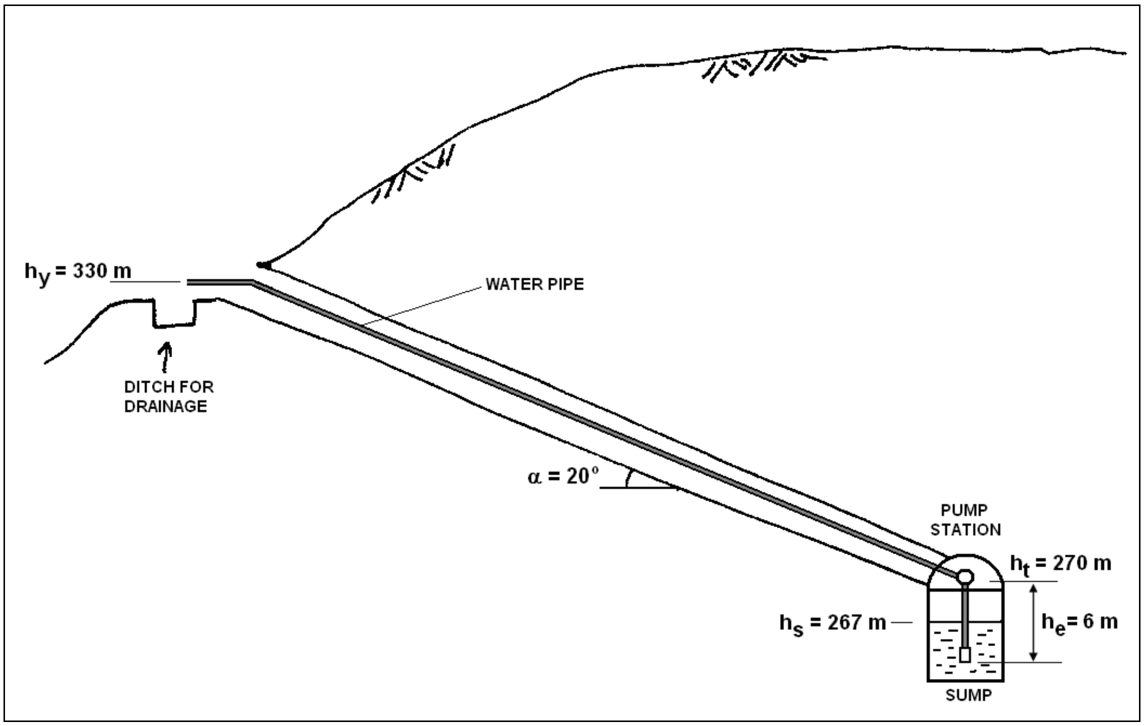
c) 1500m x 4068 N = 6,102,000 N.m = 6.1 MJ
add to that the energy need for acceleration, 2101 J (=0.002 MJ), and we still get 6.1 MJ

PROBLEM : Determination of motor power of a pump to discharge underground water

A submerged pump is located on a sump in underground to pump incoming mine water (see figure below). Determine pump motor power according to given parameters.

Given parameters :

Water flow rate : 1,5 liter/sec	Pipe diameter, D : 0,025 m
Discharge elevation, h_y : 330 m	Water elevation, h_s : 267 m
Pump elevation, h_t : 270 m	Pipe slope, α : 20^o
Motor efficiency, η : 0,7	Submerged end pipe, h_e : 6 m
Friction factor of pipe, λ : 0,03	



SOLUTION :

Motor power, $N=(\Sigma H.Q)\gamma/(75\eta)$ where Q : water flow rate, m^3/sec
ΣH : total head, m
γ : water density, kg/m^3

$\Sigma H = \Delta h+\Sigma[(\lambda.v^2.L)/(2.g.D)]+\Sigma[(\xi.v^2)/(2.g)]$ where λ : friction factor of pipe
v : water speed in pipe, m/sec
L : pipe length, m
g : gravitational acceleration, m/sec^2

$\Delta h = h_y - h_s = 330-267 = 63$ m

$Q = F.v = 0{,}785.D^2.v$ for laminar flow

$v = 1{,}27.Q/D^2 = 1{,}27*0{,}0015/0{,}025^2 = 3$ m/s

Water speed in a pipe should not exceed v_{max}=2 m/sec. In our case, pipe diameter can be increased to decrease the speed. If we choose D=0,05 m, then;

$v = 1,27*0,0015/0,05^2 = 0,76$ m/s

$v_{min}=0,5$ m/sec < $v=0,76$ m/sec < $v_{max}=2$ m/sec.

Water speed shouldn't be less than 0,5 m/sec to prevent particle sedimentation in pipe.

Total pipe length, $L =(h_y-h_t)/\sin\alpha + h_e = (330-270)/\sin 20^o + 6 = 175+6 = 181$ m

Total friction loss in pipe, $h_s = [(\lambda.v^2.L)/(2.g.D)] = [(0,03*0,76^2*181)/(2*9,81*0,05)] = 3,2$ m

$\Sigma H = \Delta h+h_s+\Sigma[(\xi.v^2)/(2.g)]$ head loss because of fittings. For simple straight lines this parameter can be neglected.

Then, $\Sigma H = \Delta h+h_s = 63+3,2 = 66,2$ m

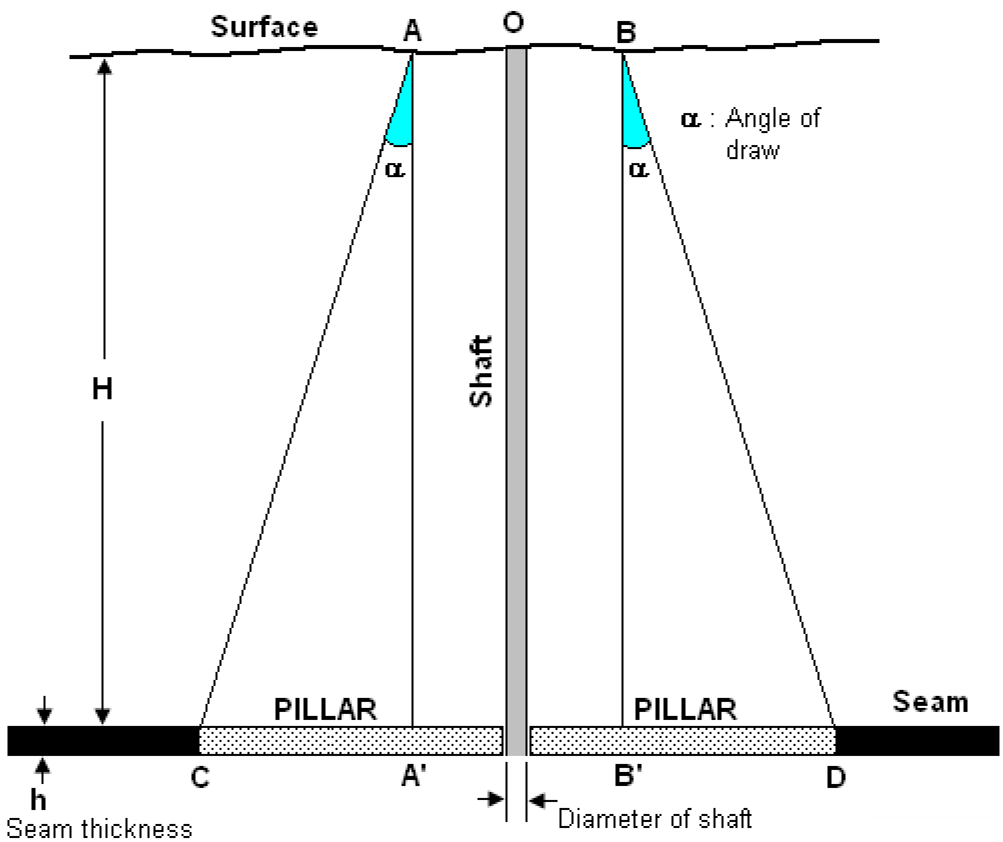
Motor power, $N=(\Sigma H.Q)\gamma/(75\eta) = (66,2*0,0015*1000)/(75*0,7) = 1,89$ HP $\cong$ 2 HP

1,5 lt/sec = 0,0015 m^3/sec

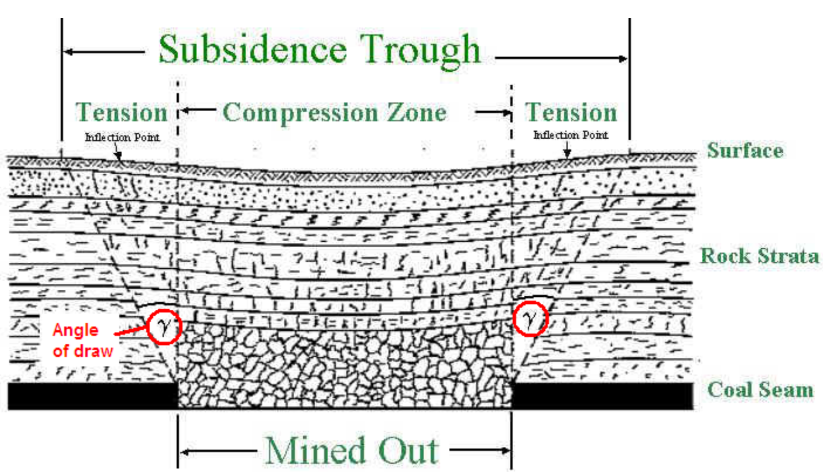
PILLAR CALCULATIONS FOR SHAFTS OR SURFACE STRUCTURES

The form of a shaft pillar is determined by the shape of the surface area to be protected. The first essential, therefore, is to decide upon the area of surface to be protected around the shaft. Pillar size can be determined by graphically or calculation.

Pillar shape, therefore the pillar size change according to seam inclination. Calcuations and drawings in the following pages are done for horizontal and inclined ore seams.



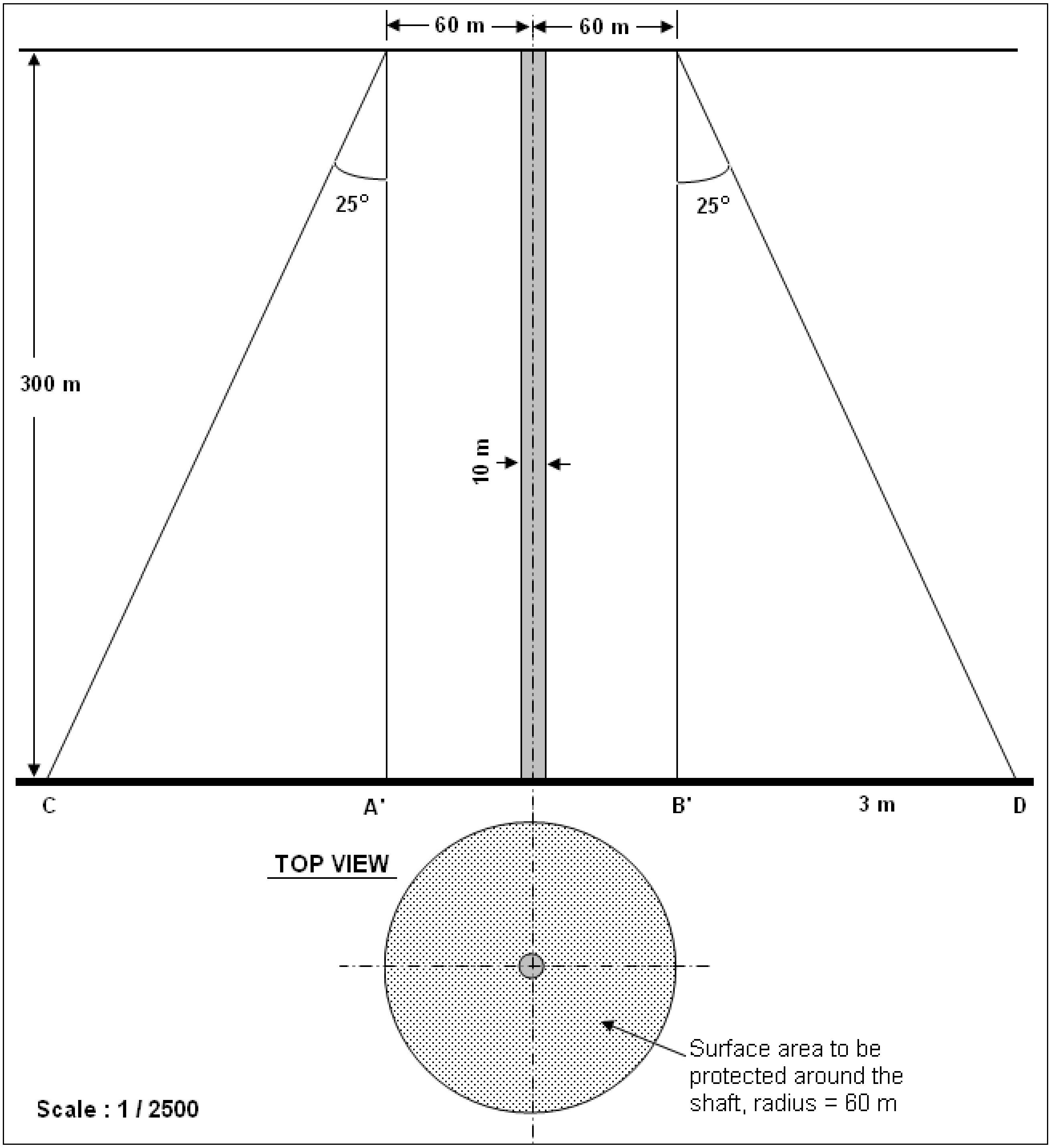
angle of draw : In coal mine subsidence, this angle is assumed to bisect the angle between the vertical and the angle of repose of the material and is 20-25 degrees for flat seams. For dipping seams, the angle of break increases, being 35.8 degrees from the vertical for a 40 degrees dip. The main break occurs over the seam at an angle from the vertical equal to half the dip.



A. HORIZONTAL SRATA (Seam)

1) Single Shaft

Example : Suppose that a shaft 10 m in diameter and an area around shaft 60 m (AO) from the shaft center is to be protected. Determine the size of the pillar graphically and by calculation if the coal seam is at 300 m depth (H) and 3 m thick (h). Assume an angle of draw 25^o for horizontal strata.



CD = 16 cm (on scale)*25 m/1 cm = 400 m. (Graphical solution)

By calculation :

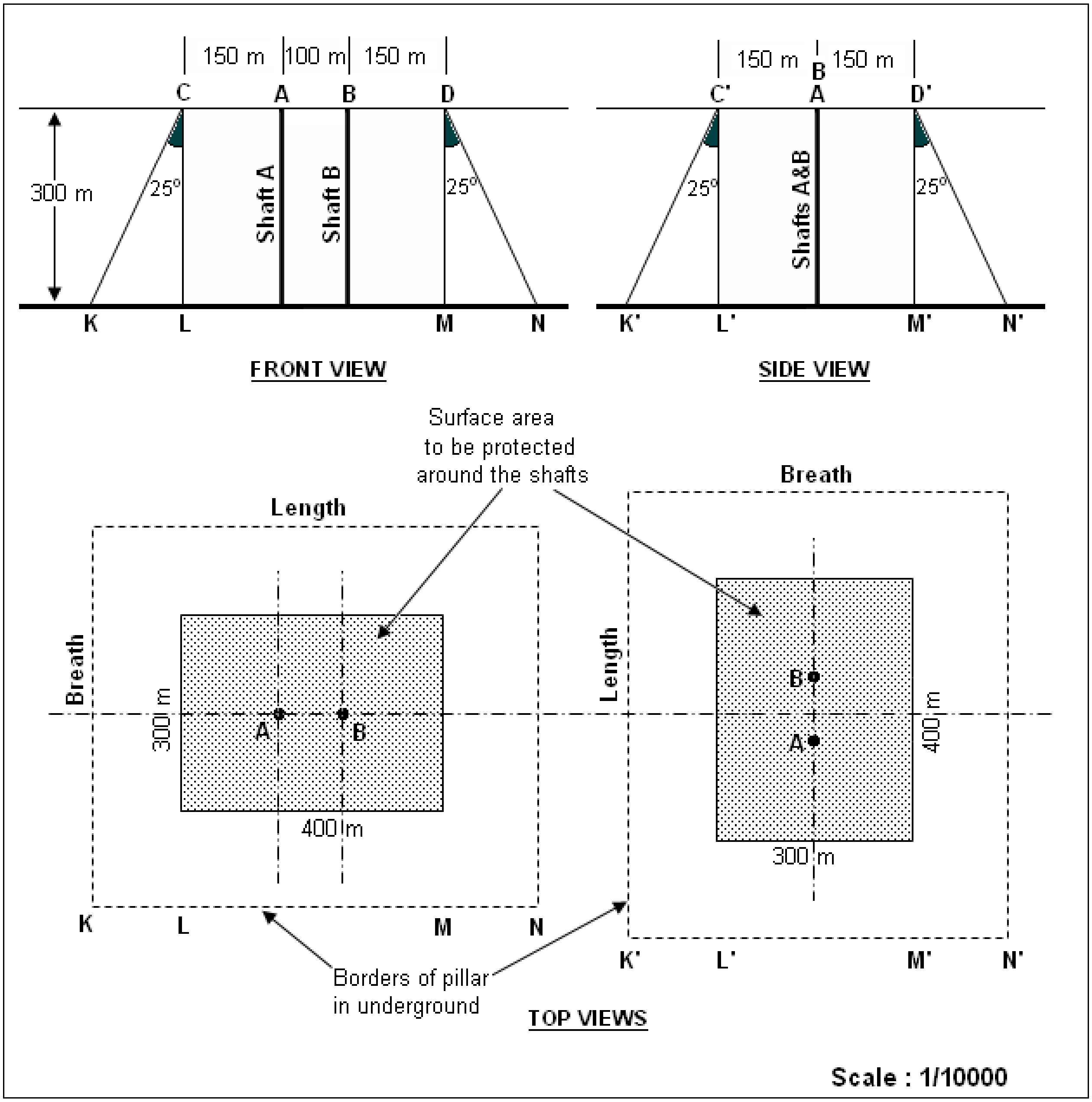
CD = CA'+A'B'+B'D where CA' = B'D = 300*tan25^o = 140 m. then

CD = 140+120+140 = 400 m.

A circular pillar with 400 m in diameter should be left in underground to protect a circular surface area of 60 m in radius from the center of the shaft.

2) Two Shafts

Example : If we have two shafts A and B are in 10 m diameter and situated at 100 m apart. CD is the length of the surface to be protected that in line with the shafts. C'D' is the length of the surface to be protected at right angles to the line of the shafts. Find the size of the pillar graphically and by calculation if the coal seam is at 300 m depth. Angle of draw is 25^o.



From drawing,

Length = 6,8 cm*100 m/cm = 680 m. Breath = 5,8 cm*100 m/cm = 580 m.

Size of surface are to be protected;

Length, CD = CA+AB+BD = 150+100+150 = 400 m.

Breath, C'D' = C'A+AD' = 150+150 = 300 m.

Size of pillar to be left in underground;

Length, KN = KL+LM+MN = $400+2(300*\tan 25^o) = 680$ m.

Breath, K'N' = KL'+L'M'+M'N' = $300+2(300*\tan 25^o) = 580$ m.

Area of pillar = $680*580 = 394400$ m^2

B. INCLINED SRATA (Seam)

Angle of draw depends on the inclination of seam. For seams inclined up to 24^o, the size of shaft pillar can be obtained by calculating angle of draw on the rise and dip side of the shaft using Statham's equations;

Angle of draw on the rise side = α + d*[(24-α)/24]

Angle of draw on the dip side = α - (d*α/24)

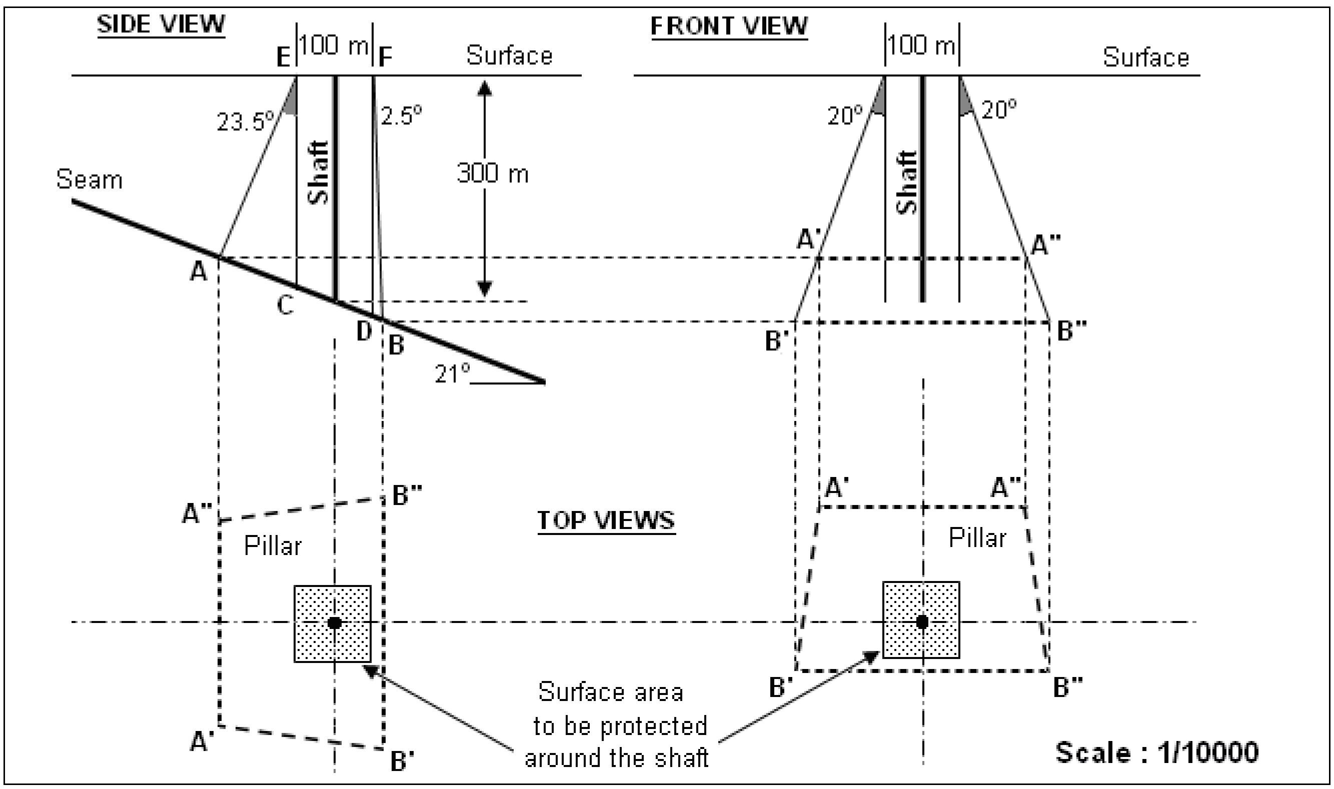
where α : angle of draw for horizontal strata d : inclination of seam

1) Single Shaft

Example : A 10 m diameter and 300 m deep shaft and a square around the shaft at the given dimension is to be protected. Find the size of the pillar graphically and calculation, if the coal seam has an inclination of 21^o. Assume that the angle of draw is 20^o for horizontal strata. Square area to be protected is 100*100 m^2.

Angle of draw on the rise side = 20^o + 21^o*[(24-20^o)/24] = 23.5^o

Angle of draw on the dip side = 20^o - (21^o*20^o/24) = 2.5^o



On the rise side ➔ Depth of point C is 300-(50*tan 21) = 280.8 m then

Considering ACE triangle, Angle EAC = (90-23.5)+21 = 87.5^o and Angle ACE = (90-21) = 69^o

According to Sine rule, [AE/sin 69^o]=280.8/sin 87.5^o ➔ AE = 262.4 m.

Vertical depth to point A = 262.4*cos 23.5^o = 240.64 m.

On the dip side ➔ Depth of point D is 300+(50*tan 21) = 319.2 m

Considering BDF triangle, Angle FDB = 90+21 = 111^o and Angle DBF = (180-111-2.5) = 66.5^o

According to Sine rule, [BF/sin 111^o)]=319.2/sin 66.5^o ➔ BF = 324.95 m.

Vertical depth to point B = 324.95*cos 2.5^o = 324.64 m.

From front view, A'A'' = 2*(240.64*tan 20^o) + 100 = 275.17 m (on draw 2.75 cm)

B'B'' = 2*(324.64*tan 20^o) + 100 = 336.32 m (on draw 3.36 cm)

Horizontal distance between the points A&B is the height of trapezoid,

h = 240.64*tan 23.5^o + 100 + 324.64*tan 2.5^o = 218.8 m (on draw 2.2 cm)

or h = (324.64-240.64)/tan21^o = 84/tan21^o = 218.8 m

Area of pillar (trapezoidal shape) = [(275.17+336.32)/2]*218.8 = 66897 m^2

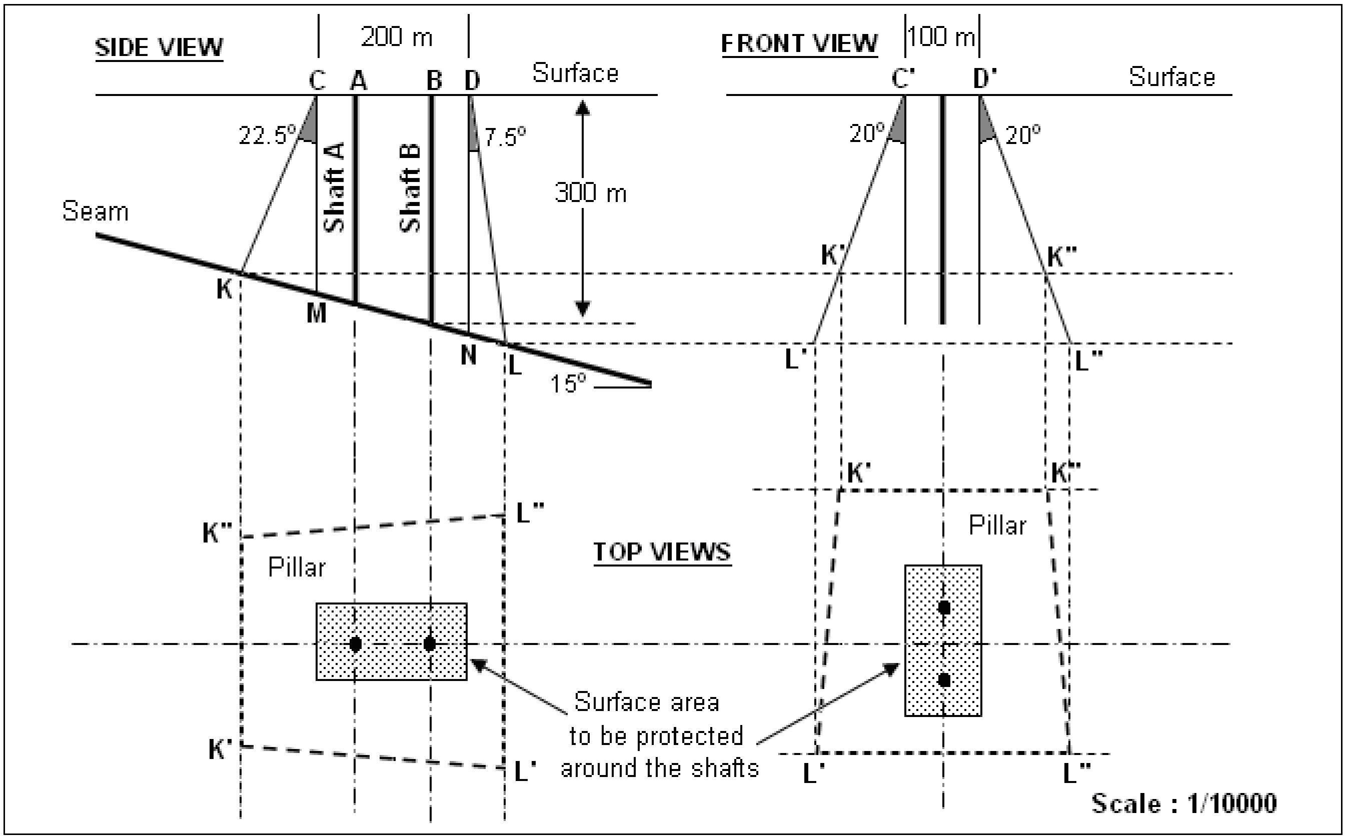
This is the area projected on the horizontal plane. To find the true (inclined) area of the pillar;

True area of the pillar = 66897/cos 21^o = 71656 m^2

2) Two Shafts

Example : Shafts A and B are situated at 100 m apart. CD (200 m) is the length of the surface to be protected in line with the shafts and C'D' (100 m) is the length of the surface to be protected at right angles to the line of the shafts. If the depth of the shaft at the dip side is 300 m and the inclination of the seam is 15°. Assume that the angle of draw is 20° for horizontal strata. Find the size of the pillar.

Angle of draw on the rise side = $20^o + 15^o*[(24-20^o)/24] = 22.5^o$
Angle of draw on the dip side = $20^o - (15^o*20^o/24) = 7.5^o$



On the rise side ➔ Depth of point M is 300-(150*tan 15) = 259.8 m then
Applying sine rule on CKM triangle, [CK/sin(90-15)]=259.8/sin 82.5 ➔ CK = 253.11 m.
Vertical depth to point K = 253.11*cos 22.5 = 233.85 m.

On the dip side ➔ Depth of point N is 300+(50*tan 15) = 313.4 m
Applying sine rule on DNL triangle, [DL/sin(90+15)]=313.4/sin 67.5 ➔ DL = 327.66 m.
Vertical depth to point L = 327.66*cos 7.5 = 324.86 m.

From front view, K'K'' = 2*(233.85*tan 20) + 100 = 270.23 m (on draw 2.70 cm)
L'L'' = 2*(324.86*tan 20) + 100 = 336.48 m (on draw 3.36 cm)

Horizontal distance between the points K&L is the height of trapezoid,
h = 233.85*tan 22.5 + 200 + 324.86*tan 7.5 = 339.63 m (on draw 3.40 cm)
or h = $(324.86-233.85)/\tan 21^o = 91/\tan 15^o = 339.63$ m

Area of pillar (trapezoidal shape) = $[(270.23+336.48)/2]*339.63 = 103028\ m^2$
This is the area projected on the horizontal plane. To find the true (nclined) area of the pillar;
True area of the pillar = $103028/\cos 15^o = 106662\ m^2$