1899

Design of a mining plant

George C. Clark

Follow this and additional works at: http://scholarsmine.mst.edu/bachelors_theses

Part of the Mining Engineering Commons
Department: Mining and Nuclear Engineering

Recommended Citation
THEESIS

FOR THE

Degree of Bachelor of Science

IN

Mining Engineering.

SUBJECT:
Design of a Mining Plant.

CEO. C. CLARK.
DESIGN OF A PLANT TO OPERATE THE ISABELLA PROPERTY AT
LEADVILLE, COLORADO.

It is to be hoped that in the perusal of this short discussion, the idea will not be lost sight of that the work has been done by a novice—probably a needless caution as the fact is patent at every step—. Again, while the work is supposed to be laid along practical lines, no attempt has been made to abbreviate and show merely what is absolutely necessary.

As the subject is treated as a thesis and not as a proposition to contractors, the attempt has been made to show the method of arriving at conclusions, and when necessary to use formulae, their derivation is shown unless entirely empirical in their nature.

Departures from good practice will undoubtedly occur frequently but as before stated this paper was not gotten up by one who imagines himself an "expert" in any sense of the word.

These errors could have easily been rectified by application to the competent men at hand but as this work is done by a student and not by the Faculty, their assistance has been asked only in a few instances when experience was absolutely necessary to intelligent treatment.

When a new mine is to be equipped, it is desirable to place on the property machinery suitable for the purpose of development and to block out the ground as expeditiously as possible.

There is much diversity of opinion among mining people as to what comprises a proper equipment, and the modes of operating in the West (as far as the plant proper is concerned) are about as numerous as there are mine managers.
As all undeveloped mines are uncertain as to size of ore deposits, value of ore, water that may be encountered, and character of ground, it is wise to anticipate difficulties; it would be however reckless to put up an expensive hoisting plant until it has been determined that such a plant is necessary.

When a depth of five hundred to one thousand feet has been reached however, levels run along the ore body or vein, cross cuts made and raises put through, the manager has a definite idea of the quantity of material exposed possessing a net value and can then put in a plant suitable to the requirements of the mine and these are the conditions under which we are supposed to work.

In the upper workings not much ore was found and these have been worked out and abandoned.

At the sixth level, which as it is the first now working, we will in future speak of it as such; and at a depth of eleven hundred (1100) feet, large ore bodies were struck which increased in size through the second and to the third levels, at twelve hundred (1200) and thirteen hundred (1300) respectively.

Drifts, cross cuts and berrings showed the ore in sight to warrant the expenditure of capital necessary to increase the output of the mine to six hundred (600) tons of smelting ore.

A very large winding drum has been put in, for the reason that should the output still further increase, no other change will be necessary than the substitution of a large motor for hoisting, which change can be made without other alteration in the hoisting machinery.

The power house is situated on the railroad at a distance of 2 miles, to save the haulage of coal, which in this case would cost for transportation along $1.00 per ton.
(3)

The contour of the ground renders the installation of a gravity tram impracticable.

Hoisting Plant.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Present Output</td>
<td>300.00 T</td>
</tr>
<tr>
<td>Proposed increase</td>
<td>300.00 &quot;</td>
</tr>
<tr>
<td>Waste 33 1/2%</td>
<td>300.00 &quot;</td>
</tr>
<tr>
<td>Total Hoist</td>
<td>900.00 T</td>
</tr>
</tbody>
</table>

Weight of ore per car
3000.00 #

Weight of waste per car
1500.00 #

Therefore the number of trips necessary to hoist the waste and ore are the same since

\[
\frac{1,200,000}{3,000} = 400 \text{ cars of ore}
\]

\[
\frac{600,000}{1,500} = 400 \text{ cars of waste}
\]

As near as possible the following are the hours actually put in by the men:

Day shift
10 hours.

Night shift
9 hours.

Less one hour for meals
8 hours.

Actual work of two shifts
18 hours.

Therefore it will be necessary to hoist at the rate of

\[
\frac{18 \times 60}{3000} = 1.36 \text{ minutes per car}
\]
As we use a double deck cage this decreases the time of a single hoist to 2.7 minutes, so that the cage will have to move with a velocity of

\[
\frac{1200}{1.8} = 720 \text{ feet per minute or 12 feet per second.}
\]

Thus allowing 2.7 - 1.8 .9 minutes or 54 seconds for handling the cars at surface and bottom.

If \( s \) = space traversed by cage.
\( v \) = velocity in feet per second
\( a \) = acceleration per second per sec.

and if the cage gains its constant speed of 12 feet per second in passing over the space of 25 feet, then since \( s = \frac{v^2}{2a} \) we have

\[
\frac{144}{50} = 2.88 \text{ feet per second per sec.}
\]

If \( t \) = time required to traverse the space \( s \)

\[
t = \sqrt{\frac{2s}{a}} = \sqrt{\frac{50}{2.88}} = 4.22 \text{ seconds.}
\]

and since the cage consumes an equal amount of time in slowing up at the top the time spent in passing the 25 feet at top and bottom is 8.44 second, therefore

\[
\frac{1150}{\text{min}} = 96 \text{ seconds at constant velocity of 12 feet per second}
\]

96+8.5 = 105 seconds at time for one trip.

108 - 105 = 3 seconds, which we may add to the time already allowed for handling cars, thus allowing 57 seconds.

This should allow sufficient time to handle timbers and men, for if it is found to require more time to handle cars at surface, another man can be added here. As for the station men at the levels, they have their cars brought to them and can handle them in one-fourth the time required on top.
\[
\frac{57 \times 400}{3600} = \frac{6}{1/2} \text{ hours daily consumed of which } 1/2 \text{ hours is in hoisting men, so that the engine works actual time } 18-6 \text{ 12 hours through an average distance of twelve hundred (1200) feet.}
\]

Taking up next the acting forces we have

- Weight of cage \(1400.00\) lbs
- Weight of cars \(1400.00\) lbs
- Weight of ore \(6000.00\) lbs
- Weight of rope (crucible steel flat) \(2800.00\) lbs

Total dead load \(11300.00\) lbs

If \(S\) = the pull in the shaft
\(W\) = the dead load

Then the force \(F\), necessary to overcome the inertia of \(W\) will be since \(F = Mass \times Acceleration\)

\[
F = \frac{\text{11300} \times 2.83}{32} = 982, \text{ and the pull}
\]

\[
S = 11300 + 982 = 12282 \text{ pounds.}
\]

Friction in the Sheave.

Taking a split wood filled sheave 72 inches in diameter and weighing 1400 lbs, we will consider the pull exerted by the motor as acting parallel with that of the dead load, since it will make no appreciable difference and also as we do not know \(P\) (the pull of motor) exactly until we know the value of the friction. Further, the friction of the guides, the degree of lubrication and consequently the coefficient of friction itself being an uncertain quantity renders this calculation not by any means exact. Luckily however, it is only a small item and a few pounds more or less can make but little difference in the final result.
Let \( f \) coefficient of friction .08

\( L' \) force of friction.

\( N \) normal pressure.

then

\[
L' = fN \cdot 0.08 \cdot 2(12280) \cdot 1400 = 14000 \cdot 2028^g
\]

If \( R \) radius of sheave 72 inches

\( r \) radius of sheave axle 3

\( L \) force applied at sheave circumference to overcome friction.

then

\[
L = \frac{L'R}{r} = \frac{2000 \times 1/8}{3} = 86^g
\]

Therefore to overcome friction a force of \( 86^g \) applied at the circumference of the sheave is necessary.

The motor will have to supply still another force to overcome the inertia of the sheave and impart to it a certain angular acceleration.

If

Weight of axle 70^g
Weight of rim 930^g
Weight of spokes 400^g

\( I \) moment of inertia of parts.

\( R \) radius of sheave 3 feet

\( r \) radius of axle .25

\( r_1 \) outer radius of sheave 3 feet

\( r_2 \) inner radius of sheave 2.42

\( a \) acceleration per second per second 2.88

\( \phi \) angular acceleration per sec. per sec.
Taking the moment of inertia of the part we have

First for the axle

\[ I_0 = I_x + I_y \]
\[ I_x = \int y^2 \, dm \]
\[ dm = \frac{r^2}{q} \, d\theta = \frac{r^3}{q} \, \rho \, d\rho \, d\phi \]

In which \( T \) = thickness and \( y \) = heaviness

From the figure \( y^2 = r^2 \sin^2 \theta \)

\[ I_x = \frac{r^3}{q} \int_0^{2\pi} r^2 \sin^2 \theta \, d\theta = \frac{1}{4} \pi r^2 \]

From this \( I_y = I_y \) and hence \( I_0 = \frac{1}{2} M r^2 \)

2nd. For the rim we obtain the same form of integral between the limits \( r_1 \) and \( r_2 \) giving \( I_{rim} = \frac{1}{2} M (r_2^2 - r_1^2) \)

3rd for the spokes

\[ I_y = \frac{1}{q} \int_{-\frac{1}{2}l}^{\frac{1}{2}l} \int_{-\frac{1}{2}h}^{\frac{1}{2}h} \frac{z^2}{r^2} \, dz \, dr \]
\[ = \frac{2}{3} \frac{b^2 l^2}{a^2} \]
\[ = \frac{1}{12} M (r_2^2 - r_1^2)^3 \]

\( A = \) center line of axle

\( s = \) gravity axis

\[ I_A = I_x + \frac{1}{2} M \left( \frac{1}{2} h \right)^2 \]
\[ = M \left\{ \frac{1}{12} (r_2^2 - r_1^2)^3 + \left( r+\frac{1}{2} (r_2-r_1) \right)^2 \right\} \]
Substitution in our formulae we have

\[
\begin{align*}
I_{\text{axle}} & = & \frac{1}{2} M r^2 & = & 70.0655 & \div 64 & = & 1.0655 \\
I_{\text{rim}} & = & \frac{1}{2} M \left( r_1^2 - r^2 \right) & = & \frac{950}{9.64} & \div 9.64 & = & 45 \\
I_{\text{axle}} & = & \frac{M}{12} \left( r_2^3 - r^3 \right) & = & \frac{400}{32} & \div 1.8 & = & 35
\end{align*}
\]

Therefore the total moment of inertia is

\[
I = 80
\]

Since the acceleration (\(a/\)) per second per second is 2.88 the angular acceleration \(\phi\) is

\[
\phi = \frac{A}{R} = 2.88 \div 3 = 0.96 \text{ therefore the force}
\]

\[
S' = \frac{\phi I}{R} = \frac{0.96 \times 80}{3} = 25.6
\]

Therefore we must apply at the circumference of the sheave a force equal to the sum of those opposing motion, i.e.

| In shaft | 12.282.00 |
| Fricton | 86.00 |
| Sheave  | 26.00 |

Therefore the total 12.394.00
Gallows Frame

\[ A \tan 30° = 4 \text{ feet}
\]
\[ A B = 43 + 4 = 47 \text{ feet}
\]
\[ B C = A B \tan 60° = 81.5 \text{ feet}
\]

which is the distance of center of winding drum from center of shaft.

If \( S = \text{pull in shaft} = 12282 \text{#}
\]
\[ P = \text{on rope by motor} = 12394 \text{#}
\]

Then the resultant pull to be resisted will be for the loaded cage.

\[ R_1 = \sqrt{S^2 + P^2 + 2SP \cos 60°} = 21460 \text{#}
\]

and for the empty descending cage since

\[ S = \text{wt. cage + cars} = 2800 \text{ and}
\]

\[ P = 2800 - 112 = 2688 \text{#}
\]

Therefore

\[ R_2 = \sqrt{2800^2 + 2703^2 + 2 \times 3500 \cos 60°}
\]

\[ = 4500 \text{#}
\]

Direction of resultants \( R_1 \) and \( R_2 \) for the loaded cages will be for

\[ R_1 \neq \text{since}
\]

\[ S = 12282
\]
\[ P = 12394
\]
\[ R = 21366
\]

\[ \sin \theta = \sin 120° \frac{P}{R} = 0.5005
\]

\[ \therefore \theta = 30° \text{#}
\]
(10)

\[
\begin{align*}
    &s = 2300 \\
    &P = 2700 \\
    &R = 4800 \\
    \sin \theta_1 = \sin 120^\circ \frac{P}{R} = 50101 \\
    \theta_1 = 30^\circ 4' 
\end{align*}
\]

and

We will therefore place our props for the gallows frame at least the distance

\[
x = 45 \tan 30^\circ 3' = 24 \text{ feet}
\]

in order that their point of support will fall outside the cline of the resultant. We have placed them as is seen from the drawing at a distance of 29 feet.

It is not necessary to exceed the required distance too much as this lengthens the timbers and therefore weakens them.

**Dimensions of Gallows Frame**

Taking moments about A we have

\[
22766 \times 12.9 + 5200 \times 3.9 = 16.1 R
\]

\[
R = 15500, \text{ which is the force to be resisted by each leg of the gallows frame.}
\]
Let \( P \) = breaking load in tons.

Let \( b \) = side of least dimension in inches

\( l \) = length of post in feet

\[
P = \frac{8}{12} \text{ and } b = \frac{4 \pi l^2}{12} = 4 \frac{P \cdot 12 \times 10}{12} \frac{12}{6}
\]

allowing 10 as a factor of safety

\[
\therefore b = \frac{4 \cdot 170108}{16} = 13 \frac{1}{2} \text{ inches}
\]

As seen from the drawing the depth has been reduced in area by cross braces and as the greatest strain comes in this direction we have added six inches, giving for posts and braces the dimensions

13 \( \frac{1}{2} \) x 19 \( \frac{1}{2} \) inches.
Bending Moment.

As shown before by calculation the reaction at B will be = 18500 which corresponds to the graphical solution.

Also from the graphical treatment we see that the greatest moment will occur at the point of application of the greatest force, and since the lever arm is 3.9 feet the bending moment will be at P:

\[ 18500 \times 3.9 = 72150 \]

which is also shown graphically.

Of Sheave Axle:

Treating the sheave axle as a beam which fails by flexure we have the moment which it is able to resist since

\[ M = \frac{R \cdot I}{V} \]

in which

- \( M \) = moment of resistance
- \( R \) = for steel 20000 lbs = safe load
- \( V \) = distance from centre to outer fibre = \( r \)
- \( I \) = moment of inertia = \( \frac{\pi r^4}{4} \)

Therefore

\[ M = \frac{R \cdot \pi r^4}{4} = \frac{20000 \times 20000 \times 216}{32} = 422000 \text{ lbs} \]

so that our axle is amply strong. This is far beyond the necessary strength but it is short, cheap and the safety of the cage depends greatly upon it, so we do not think it excessive.

Dimensions of Cross piece in Gallows Frame

Before we are able to find the dimensions of the cross piece we must find its moment of inertia about the axis A B. This will be expressed in terms of the side of the square of
which which cross section is a part. The bending moment and its point of application was shown graphically to be 72150° and is greatest at the point of application of the greatest force.

Moment of Inertia of Cross Piece.

We will first find the I of the whole square and then subtract from it the 2 I's of the triangles cut off at top and bottom, each having an altitude of 4 inches and a base of 8 inches.

\[ I = \frac{bh^3}{12} + \frac{bh^3}{12} - 2 \left( \frac{bh^3}{4} \right) \]

Taking the triangle A about its gravity axis g we have

\[ I = \frac{bh^3}{12} = \frac{8x64}{36} = 14.2 \]

and about axis xx

\[ I = I_g + A K^2 \]

\[ = 14.2 + 16 \left( 2h - 16/3 \right)^2 \]

And for the triangle B about its base

\[ I = I_g + A K^2 \]

Therefore the moment of inertia of the trapezoid which is our cross piece

\[ I = I \text{ square} = I \Delta A + I \Delta B \]
(14)

Substituting the value of the I's as determined gives
for the moment of inertia I of the trapezoid.

\[ I = \frac{h^2}{3} + 2h \left( h - 4 \right)^2 - 14.2 - 16 \left( 2h - \frac{16}{3} \right)^2 - 43 \]

\[ = \frac{7h^4 - 48h^3 - 96h^2}{3} \]

Therefore representing by \( M, I \) and \( v \) the quantities before
referred to and placing for \( R, \frac{8000}{10^2} \) which is the ultimate strength
of pine with a factor of safety of 10 - then

\[ M = \frac{R}{v} = \frac{800I}{h - 4} \] so that

\[ \frac{M(h - 4)}{800} = I \]

\[ 7h^2 - 48h^3 - 96h^2 = 750.4h - 3172.6 = 0 \]

The highest root of this equation is 10. \( h = 10 \)

the side of the square is \( 10\sqrt{2} = 14.2 " \) and the area of cross
section is 201.64. This is reduced 10 square inches by a 1 inch bolt
so that the side = \( \sqrt{212} \approx 14.5 \) inches, to this we add one inch for the
notch holding the sheave axle/journal boxes so side of square = 15 1/2

Horse Power at Shaft.

The Horse Power required to lift the loaded stage is

\[
\begin{align*}
\text{Time of trip} & \quad 104 \text{ seconds.} \\
\text{Space traversed} & \quad 1200 \text{ feet} \\
\text{Average velocity} & \quad 11.53 \text{ feet per sec.} \\
\text{Force} & \quad 12394 \\
\end{align*}
\]

\[ \therefore \text{Horse Power} = \frac{12394 \times 11.53}{550} = 261 \]
but there is produced by the descending cage since

\[
\begin{align*}
\text{Weight cage and cars} &= 2800^\# \\
\text{Friction} &= 15 \\
\text{Inertia Sheave} &= 26
\end{align*}
\]

and there is therefore an "assisting" horse power of

\[
\frac{275 \times 1150}{5800} = 58 \text{ Horse Power}
\]

Leaving the Horse Power necessary to apply at sheave rim

\[
251 - 58 = 203 \text{ Horse Power}
\]

The lever arm of the forces acting with reference to the winding
drum of motor need not be considered as increasing the horse power
necessary, since the greatest power is required at the start and with
a flat rope drum. At this instant the lever arm is practically nil
as shown by the drawing.

\begin{center}
Underground Transportation.
\end{center}

\[
\begin{align*}
\text{Weight of car} &= 700^\# \\
\text{Weight of ore} &= 3000^\# \\
\text{Friction} &= 5\% \\
\text{Force of friction is } 3700 \times 0.05 &= 185^\#
\end{align*}
\]

If the speed is 10 miles per hour or 880 feet per minute the horse
power necessary for one car is

\[
\frac{880 \times 175}{33000} = 5 \text{ Horse Power}
\]

Using a \text{20 horse power motor engine}

we can pull a train of four cars which considering short turns is as
long as is practicable. If it is wished to pull a longer train, as may
be possible in some parts of the mine, we can do so by moving at the
rate of six miles per hour and drawing seven cars. Since two cars
are hoisted every 2.7 minutes they must be delivered at the shaft at the rate of 45 cars per hour.

Placing a motor on each level or 3 in all

\[
\frac{45}{3 \times 4} = 4 \text{ trips necessary per hour for each engine}
\]

If the average haul is 1500 feet or 3000 feet for the round trip then

\[
\frac{3000 \times 4}{880} = 14 \text{ minutes consumed per hour in moving the cars}
\]

Each man loads \( \frac{45}{3} = 15 \) cars per hour

Allowing two minutes for loading each car and one minute for uncoupling each train at station gives

2 \( \times \) 15 + 4 = 34 minutes for handling so that, barring accidents, the total time consumed in handling cars is

34 + 14 = 48 minutes, thus allowing 12 minutes for getting off track, sticking of ore in bins or an increased haulage if necessary.

If this work is done by trammers considering the rate of travel as 2 1/2 miles per hour, which allows no time for loafing and therefore does not apply to Sweedes and Dagos gives

\[
\frac{5260 \times 2.5}{60} = 220 \text{ feet per minute, therefore}
\]

Time for each trip

\[
\frac{3000}{220} = 14 \text{ minutes}
\]

Loading

Time expended on each car = 16 minutes.

or say 4 cars per hour.

\[
\frac{45}{4} = 12 \text{ men per shift or 24 per day}
\]

24 \( \times \) 250 = $60.00 per day for trammers

Against 6 \( \times \) 2.50 = $15.00 per day for motormen
Cost of 3 motors =
Interest per day =
Depreciation =
Motormen =
Cost of Operating =

Total cost of haulage

Hoisting through Incline.

As the probable increase of hoisting through the incline may reach 150 cars per day, we have here 9 cars per hour.

Allowing 5 minutes for handling per car the time consumed in handling, loading, dumping etc., is 45 minutes, leaving 15 minutes each hour for actual transportation. Since the length of the incline along the slope is 1000 feet, the necessary velocity will be

\[
\frac{9 \times 2 \times 1000}{15 \times 60} = 20 \text{ feet per second}
\]

Power required on incline

- Weight of 1000 feet of 7/8 inch rope 1200#
- Weight of skip
- Weight of ore 7500#

\[
\begin{align*}
F_1 &= 7500 \\
F_2 &= \text{friction for rollers} \\
F_3 &= 3\% \text{ of normal pressure for friction} \\
W &= \text{force applied at head of incline.}
\end{align*}
\]
Rollers are 20 feet apart so have a total of 50 rollers.

Weight of 20 foot cable

Weight of rollers

\[ F_2 = \text{Friction per roller} \times 28 \times 0.02 = 0.56 \]

Total friction of rollers \[ 0.56 \times 50 = 28 \# \]

\[ N = W \cdot \cos \alpha = 6300 \times 0.9659 = 6055 \]

\[ F_3 = 6055 \times 0.03 = 183 \]

\[ F = 1940 + 28 + 183 = 2151 \]

Therefore horse power exerted by motor is

\[ \frac{20 \times 2151}{550} = 68 \text{ Horse Power} \]

Drilling

The ore being composed of Pyrite, Cerusite, Galena and about one-third Limestone and having an average weight of about 320 pounds per cubic foot gives us with 800 cars loose rock at 3000\# per car

\[ 800 \times 3000 = 2400,000 \text{ per 18 hours work.} \]

Using a drill (Van Depole) which will put in a maximum hole of
12 feet depth, 2 inches diameter, with a 4 inch stroke and capable
of doing an average of 500 feet in a 10 hour shift we have in a
4' x 7' breast, 3 - 8 feet holes, breaking 192 cubic feet of rock,
weighing 31440 pounds or 30 cars per drill and requires about 3
sticks of 40' per car.

As the shifts last 9 1/2 and 6 1/2 hours respectively, of the 800
cars broken, the day shift will handle of x day shift cars

\[
\frac{x}{85} = \frac{300 - x}{420}
\]

require \[\frac{420}{30} = 14\] machines

This will require for each machine 2 men on machine and 2 muckers or
in all for 2 shifts 112 men.

If this ground were worked by hand one man would put in 3 - 18"
holes per shift so would require 308 drill men to do the work of
14 machines.

Comparison.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>28 machine men at $5.00</td>
<td>84.00</td>
</tr>
<tr>
<td>28 helpers</td>
<td>2.75</td>
</tr>
<tr>
<td>28 muckers</td>
<td>2.50</td>
</tr>
<tr>
<td>Blacksmithing per shift per drill $0.60</td>
<td>22.40</td>
</tr>
<tr>
<td>Repairs per drill per day $0.60</td>
<td>2.60</td>
</tr>
<tr>
<td>Interest at 6% on 14 drills</td>
<td></td>
</tr>
<tr>
<td>Cost at 6 Horse power per drill</td>
<td></td>
</tr>
</tbody>
</table>

Hand drilling

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>308 men at $5.00</td>
<td>776.00</td>
</tr>
<tr>
<td>Blacksmithing</td>
<td>14.00</td>
</tr>
<tr>
<td>Muckers</td>
<td>70.00</td>
</tr>
</tbody>
</table>
Ore Bins

Volume of bin \(\frac{21.4 \times 23.8 \times 11.4}{2}\) cu ft

and since a car holds 16 cubic feet our bin will hold

\(\frac{2868}{16} = 180\) cars

So taking six bins we can in case of necessity accommodate

180 \times 6 = 1080 cars

or nearly 3 days output since of the 800 cars hoisted 400 go to the waste dump.
Pumps.

In pumping water from the sump to the surface the power exerted by the pump must be sufficient to raise the required amount in the given time and also to overcome the various resistances of friction, valves, etc.

Thus the head due to these resistances is a direct source of loss

\[ w = \text{wt of a cubic foot of water} \]
\[ q = \text{quantity raised per second} \]
\[ H = \text{height of lift} \]
\[ h' = \text{head lost at entrance} \]
\[ h'' = \text{head lost in friction in pipe} \]
\[ h''' = \text{other losses as valves, pumps cylinders, etc.} \]

To find the different values of \( h', H'' \) and \( h''' \) let us first consider a pipe filled with water.

When the water is at rest the pressure at any point depends only upon the head above that point. However, when the water is in motion the pressure becomes less than that due to the head as has been proven by experiment.

Thus let \( W \) be the weight of water passing per second \( - \) then the energy it possess is \( \frac{W^2}{2g} \) while the theoretic energy is \( Wh \) so if there is no losses of energy the remaining energy is \( Wh - \frac{W^2}{2g} \) and this must be equal to \( Wh \), where \( h \) is the head due to the actual pressure of the water, therefore we have \( h = \frac{b^2}{2g} + h' \).

As there are other losses of head however the effective head \( h + \frac{b^2}{2g} \) is generally less than the total head \( h \).
Thus the head which has been lost is \( h' = h - \left( h \frac{v^2}{2g} \right) \) but as outside the pipe there can be no pressure on the stream we have

\[
h' = h - \frac{v^2}{2g}
\]

So we see that the loss of head depends on the loss of velocity. If \( K_v \) be the coefficient of velocity the \( v \), \( 2gh \) therefore

\[
\frac{v}{2g} = K_v \frac{h}{h}
\]

which if substituted above gives us

\[
h' = h - \frac{v^2}{2g} \quad (1 - K_v)^2 \] or in terms of the velocity head since

\[
h = \frac{1}{K_v^2} \frac{v^2}{2g} \quad h' = \frac{(1 - K_v^2 - 1)}{K_v} \frac{v^2}{2g} \]

This loss or rather gain of head which occurs at the lower end of the pipe and due to contraction and resistance of the inner edges we will call the loss at entrance and is the same as in a short cylindrical tube under the same velocity of flow as just demonstrated.

This gain of head we will denote by \( h' \) and the quantity \( \frac{1}{K_v^2} - 1 \) by \( E \) so that \( h' = E \frac{v^2}{2g} \).

Taking up our second gain in head or more properly speaking our second loss of power, i.e. that due to friction - as before let \( h \) be the total head in the pipe \( \frac{v^2}{2g} \) the velocity head, \( h' \) the head lost at entrance and \( h'' \) the head lost through friction. Then if we suffer no other losses

\[
= h \frac{v^2}{2g} + h' + h''
\]
As shown by experiment friction varies

1st. Directly as the length of pipe.
2nd. Directly as the square of the velocity
3rd Inversely as the diameter of pipe.
4th It increases with the roughness of surface.

Or expressing the above in the form of an equation we have

$$h'' = f - \frac{v^2}{d} \frac{1}{2g}$$

Our third loss $h''$ we will place $p = \frac{v^2}{2g}$ and needs no particular discussion as the value of $M$ depends only upon the pump cylinders since we have no appreciable curves and no valves in the pipe.

Returning to our original figure we see that the theoretic work done by the pump per second is $w g H$ but to this we must add the work necessary to overcome the various resistances just mentioned so that if we denote the total work done by the pump per second by $W$ we have

$$W = w g H \cdot w g (E + f + p) \frac{v^2}{2g}$$

Therefore in order to lose as little power as possible, in other words to do the minimum amount of useless work our velocity should be low and this end is best accomplished by making our pipe as large as is reasonably possible.

This we could accomplish by putting in a 10" pipe which since our water is 600,000 gallons per day, would deliver 56 cubic feet per minute. With such a pipe our loss of head, due to all causes, would be only 1.6 feet. Such a pipe however, is not as good in this case as
As shown by experiment friction varies

1st. Directly as the length of pipe.
2nd. Directly as the square of the velocity
3rd. Inversely as the diameter of pipe.
4th. It increases with the roughness of surface.

Or expressing the above in the form of an equation we have

\[ h^2 = \frac{l}{d} \frac{v^2}{2g} \]

Our third loss \( h'' \) we will place \( p = \frac{v^2}{2g} \) and needs no particular discussion as the value of \( M \) depends only upon the pump cylinders since we have no appreciable curves and no valves in the pipe.

Returning to our original figure we see that the theoretic work done by the pump per second is \( w = \frac{w g H}{2} \) but to this we must add the work necessary to overcome the various resistances just mentioned so that if we denote the total work done by the pump per second by \( W \) we have

\[ W = w g H \left( E + p \right) \left( \frac{v^2}{2g} \right) \]

Therefore in order to lose as little power as possible, in other words to do the minimum amount of useless work our velocity should be low and this end is best accomplished by making our pipe as large as is reasonably possible.

This we could accomplish by putting in a 10" pipe which since our water is 500,000 gallons per day, would deliver 56 cubic feet per minute. With such a pipe, our loss of head, due to all causes, would be only 1.6 feet. Such a pipe however, is not as good in this case as
a six inch one owing to its large size, great weight and large first cost.

The quantity of water delivered per second is

\[ q = \frac{600,000}{24 \times 60 \times 60 \times 7.481} = .933 \text{ cubic feet and since} \]

\[ V = \frac{\sqrt{q}}{1/4 \cdot d^2} = \frac{.933}{.7854 \times .25} = 5 \text{ feet per second} \]

Taking for \( n \) a value of .5

\[ N' = .5 \frac{V^2}{g} = .2 \text{ feet} \]

The friction factor \( f = .02 \)

\[ h' = f \frac{1 \cdot V^2}{g \cdot d} = .02 \times \frac{1300 \times 25}{32} = 20.3 \text{ feet}. \]

and for \( p = 4 \)

\[ h'' = p \frac{V^2}{g} = 4 \times \frac{25}{64} = 1.5 \text{ feet} \]

Therefore the additional head against which the pump must work is

\[ H = .2 + 1.5 + 20.3 = 22 \text{ feet}. \]

Giving us a total head of 1322 feet. Therefore the work done by pump is \( W = w \cdot g \cdot H + w \cdot g \cdot (h' + h'' + h''') \)

\[ 62.5 \times .933 \times 1322 = 32625 \text{ feet}^2 \text{ per second}. \]

or \[ 32625 \div 550 = 60 \text{ Horse Power}. \]
(25)

**Thickness of Pipe.**

The pipe may burst by transverse rupture or by longitudinal tearing and it is against the greater of these two that we must provide.

First to find the thickness necessary to prevent transverse rupture if

\[ p = \text{pressure upon a unit area then the total pressure } P = \frac{p}{F} \text{ where } F = \text{area.} \]

If \( h \) = head at any depth then

\[ p = h w \text{ and since } P = \frac{1}{2}(1/2 A B)^2 = \frac{1}{2} \frac{h^2}{r} \]

The pressure exerted at a depth \( h \) is

\[ P = \frac{1}{2} r h w = \frac{1}{2} r^2 p \]

If \( t \) = thickness of pipe then its cross section is

\[ \frac{1}{2}(r + t)^2 - \frac{1}{2} r^2 = rt \left( 1 + \frac{t}{r} \right) \]

If \( S \) be the safe strain then

\[ P = \left( 1 + \frac{t}{r} \right) 2 \frac{r^2}{t} = \frac{r^2}{t} \]

\[ t = \frac{r P}{2(2 + \frac{r}{t})} \]  

We may neglect the friction and write for the thickness necessary to prevent transverse rupture

\[ t = \frac{r P}{2S} = \frac{d P}{4S} \]

Second, for the longitudinal stress we have the mean pressure exerted on a portion of the pipe \( C D \) of length \( l \), since its projection is a rectangle at right angles to \( A B \) is

\[ P = 2 rl \sin \alpha = 2 rl \sin \alpha w \]
This pressure is resisted by the cohesion between particles at C and D, that is by the cohesion in tr. If this resisting force = 0 then \( C = \frac{1}{2} l S \) and \( Q = 0 \) \( \sin \alpha = \frac{1}{2} l S \sin \alpha \) and

Since equilibrium exists

\[ P = 2Q \]

\[ 2 l S \sin \alpha = 2 l p \sin \alpha \]

and

\[ \tan \alpha = \frac{p}{l} \]

\[ t = \frac{pd}{2S} \]

So for longitudinal bursting we require twice the thickness as for transverse strain.

In the pipe under consideration we have

\[ P = \frac{62.5}{1728} \times 1300 \times 12 = 563 \text{ pounds per square inch} \]

\[ t = \frac{6 \times 563}{2 \times 1300} = 3/8 \text{ inches} \]

In which we take the ultimate strength of wrought iron as 4500 \( \# \) per square inch and assume a factor of safety of 10, which we think reasonable on account of the corrosive effects of the acid waters. To prevent this as much as possible give a good coat to pipe within and without of asphaltum or mineral paint.
Riveting Pipe.

Probably in practice a common 6 inch cast iron pipe would be used but we will take a wrought iron riveted pipe.

Let

\[ d = \text{diameter of rivet} \]
\[ t = \text{thickness of pipe} = 3/8 \text{ inches} \]

then

\[ d = \frac{5}{4} t + \frac{5}{16} = \frac{11}{16} \text{ inches.} \]

So the area of rivet is \( 1/4 \cdot d^2 \cdot 3.712 \text{ square inches.} \)

Taking the allowable shear as 7500\( \text{lb} \) per square inch for single shear, the resistance offered by rivet would be \( 5700 \times 3.712 = 21757 \text{lb} \)

Spacing our rivets at 4 inches each rivet will stand

\[ 4 \times 563 = 2252 \text{ lb safely.} \]

Since the area cut out is \( \frac{11}{16} \times \frac{3}{8} \times \frac{1}{4} = \frac{33}{512} \)

we must increase our thickness of pipe to the amount \( \frac{3}{8} \times \frac{33}{512} = \frac{1}{8} \text{ inch nearly.} \)

As is shown a little farther on, the thickness of pipe at 500 ft 1/4 inches with a 5/16 inch rivet.

Taking these maximum and minimum data and plotting them we get all the necessary points from the plot.

The increase in thickness however is so slight that changes will be made only at 500 and 900 feet depth.

The lines for final thickness of pipe and diameter of rivets are not quite parallel since the former increases by 1/33 inches and the latter by 1/16 inches for each 100 feet.
Riveting.

In a similar way diameter of rivets are 500 feet $d = 6/16$

<table>
<thead>
<tr>
<th>Area of rivet</th>
<th>.1104</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allowable shear</td>
<td>628 $#$/per square inch.</td>
</tr>
<tr>
<td>Actual press</td>
<td>220 $#$/per square inch.</td>
</tr>
<tr>
<td>Spacing</td>
<td>4 inches</td>
</tr>
<tr>
<td>Thickness of plate</td>
<td>$6/16 \times 3/16 \times 1/4 + 3/16 = 4/16$ inches.</td>
</tr>
</tbody>
</table>

The pipe will not be made less than this from the 500' point.

upwards as any corrosion in a thinner pipe would increase the weakness due thereto too rapidly.

As in the previous cases plotting our initial and final values we obtain two straight lines whose abscissae give us the diameter of rivet and final thickness of pipe, our spacing remaining 4 inches which if tried will be found to agree very nearly with the calculated amount thus we have at 500 feet $d = 6/16$ final thickness = $4/16$

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;</td>
<td>600</td>
<td>&quot;</td>
<td>7/16</td>
<td>&quot;</td>
</tr>
<tr>
<td>&quot;</td>
<td>700</td>
<td>&quot;</td>
<td>8/16</td>
<td>&quot;</td>
</tr>
<tr>
<td>&quot;</td>
<td>800</td>
<td>&quot;</td>
<td>9/16</td>
<td>&quot;</td>
</tr>
<tr>
<td>&quot;</td>
<td>900</td>
<td>&quot;</td>
<td>10/16</td>
<td>&quot;</td>
</tr>
<tr>
<td>&quot;</td>
<td>1000</td>
<td>&quot;</td>
<td>11/16</td>
<td>&quot;</td>
</tr>
<tr>
<td>&quot;</td>
<td>1100</td>
<td>&quot;</td>
<td>12/16</td>
<td>&quot;</td>
</tr>
<tr>
<td>&quot;</td>
<td>1200</td>
<td>&quot;</td>
<td>11/16</td>
<td>&quot;</td>
</tr>
<tr>
<td>&quot;</td>
<td>1300</td>
<td>&quot;</td>
<td>11/16</td>
<td>&quot;</td>
</tr>
</tbody>
</table>
(39)

Ventilation.

The air in mines is changed in two ways, first by respiration, second, by admixture of foreign gases.

A man at rest will inhale about 45 cubic feet of air per minute or 486 cubic feet in 18 hours, this quantity will be increased fully three fold by a man at work or about 1458 cubic feet in 18 hours. The inspired air may contain only a few ten thousandths of CO₂ while the same when expired will contain 3% or 4% of the gas— with a proportional decrease in oxygen.

This air is already difficult to breathe and at 10% CO₂ produces asphyxia. Oxidation of certain minerals further reduces the percentage of Oxygen as well as does the organic decay in abandoned workings. The action of acid waters on carbonated is another source of CO₂ and the presence of a large amount of water vapor further reduces the proportion of oxygen.

Foreign gases arise from the explosion of powder and the shots also produce and keep in motion impalpable dust, consisting of particles of the ore, the most injurious of which are lead and arsenical compounds and lastly there must be an appreciable amount of the latter elements volatilized by the heat of the blast. To these last elements are undoubtedly due the familiar and dangerous "leading".

By the law of diffusion of gases a mine which has one opening, would without the necessity of circulation be of the same composition as the atmosphere outside, were the source of the impurities to cease, which condition would in time be reached in an abandoned mine.

As a matter of fact however this is not by any means the case so that the diffusion of gases can play no part in a working property.
Air which has been expelled from the lungs contains about 79 parts of nitrogen, 17 or 18 parts of oxygen and 3 or 4 parts of CO_2 and as before stated this air is already irreparable and before reaching 10% CO_2 lamps will not burn in it, so that there is from this source no danger of death, but the effect of the poison still remains and the company cannot but suffer a pecuniary loss in the decreased capacity of the men to perform work.

Take a stope entered through a narrow upraise two or three feet square which has no outlet and in a few hours the effect is decidedly noticeable on a candle flame and on the energy of the workmen. It is not customary to pay much attention to ventilation in quartz mines but I know from experience that it is bad practice and deserves more attention than it has received in the past.

As no data is obtainable regarding the amount of air necessary for lights, we will assume as the approximate composition of a candle

\[
\begin{align*}
\text{C}_0 & \quad \text{H}_0 & \quad \text{O}_0 \\
18 & \quad 56 & \quad 2
\end{align*}
\]

and its weight as about 60 g. Such a candle under the existing conditions will last on an average of about 3 1/2 hours so that about three candles will last a ten hour shift.

We have then

\[
\begin{align*}
284 & = 216 \times 100 : 0 : 0 \quad 76\% \quad \text{or} \quad 45.6 \text{ g.} \\
284 & = 216 \times 100 : 0 : 0 \quad 13\% \quad \text{or} \quad 3.8 \text{ g.} \\
284 & = 216 \times 100 : 0 : 0 \quad 11\% \quad \text{or} \quad 6.6 \text{ g.}
\end{align*}
\]

To convert 45.6 gr. of Carbon to CO_2 requires

\[
\begin{align*}
12 & = 32 \div 45.6 : 0 \quad 121.2 \text{ g} \quad \text{0 for Carbon} \\
2 & = 16 \div 7.8 : 0 \quad 62.4 \text{ g} \quad \text{0 for Hydrogen}
\end{align*}
\]

Rendering necessary therefore the supplying of 121.2 62.4 6.6 177g of Oxygen and since but 23% by weight of the atmosphere is oxygen, therefore 770 g. or nearly 1.7 of air must be supplied and will occupy at zero degrees F. and 14.7 pounds pressure the volume of
21 cubic feet. The existing conditions are 50 degrees F. and a pressure of 24 inches of mercury or 11.8 pounds per square inch and since

$$p = p_0 (1 + \frac{t}{492.7})$$

Therefore

$$\frac{30.4}{4} = 8 \text{ cubic feet per hour nearly}$$

or a total of about $9 \times 40 = 360$ cubic feet of air per hour will be necessary for the combustion of the candles, counting 28 machine men, 14 shovels and 6 timbermen, boss and nipper.

The same number of men with the addition of three trammers, 2 station men and one on incline who all work in places all lighted by electricity will consume air by respiration alone.

If a man at work consumes 81 cubic feet of air per hour, or better say 100 cubic feet we have $100 \times 46 = 4600$ cubic feet necessary so that the supply must be at least $4600 + 360 = 6000$ cubic feet per hour.

This does not include the air used up by explosives, decomposition, etc. nor is it scarcely necessary that it should, since the shooting must be done at the end of each shift with an interval of two hours between the day and night and of three hours between the night and day shift, thus giving ample time to blow out the smoke.

Again owing to the uncertainty of friction both in the pipes and along the tunnel walls as well as the variation of pressure, temperature, etc. in different parts of the mine, the whole is an exceedingly variable, or more properly perhaps, a very difficult quantity about which the necessary details can be obtained without making experimental researches on the spot.

It is not our object however to produce conditions of mathematical exactness, the aim being to produce an atmosphere in which a
man can work without material injury to his own health or what is of a much more delicate constitution, the companies pocket.

Friction of Air in the Pipes.

As with water the loss by friction will vary according to the same factors we could use the formula, i.e. \( h = f \frac{V^2}{2g} \) in which \( K \) velocity of flow and \( m \) the hydraulic mean depth \( 1/4 \), were it not for the fact that here the velocity is treated as a constant, while with air as there is a loss of pressure there will of necessity be a change in the velocity.

Taking an infinitesimal length of pipe however, we may say that in passing through this length, all the air in expanding by an amount \( dv \), does the work \( pdv \) therefore

\[
pdv = f \frac{V^2 dl}{2g m}
\]

But from the fundamental law of gases \( pv = RT \) and \( dv = \frac{-Rt}{p^2} \) dp which substituting gives

\[
f \frac{V^2 dl}{2g m} = \frac{RT}{p} dp
\]

If \( A = \) Area of pipe in square feet.

\( W = \) Pounds of air flowing per second.

Then \( K = \frac{WV}{A} = \frac{WRT}{Ap} \)

Therefore

\[
f \frac{V^2 \frac{2R}{2A} \frac{2g}{2m} \frac{R}{p} \frac{T}{p}}{p} dp\]

\[dl = \frac{1}{RT} dp\] from which

\[
f = \frac{V^2 \frac{2R}{2A} \frac{2g}{2m}}{p}
\]
\[ \frac{W^2}{EA^2m} = \frac{p_2^2 - p_1^2}{RT} \]

But since the velocity at entrance and under pressure \( p_1 \) is \( K_1 \),

\[
\frac{W^2}{RT} \quad \text{and since} \quad \frac{p_2^2 - p_1^2}{RT} \quad \text{we have by substituting.}
\]

\[
\frac{A^2}{gA^2mR^2T^2} = \frac{p_2^2 - p_1^2}{RT} \quad \text{hence}
\]

\[
f \frac{k^2 \cdot L}{gRTm} = \frac{p_2^2 - p_1^2}{p_1^2} \quad \text{and the velocity at entrance}
\]

\[
K_1 = \frac{gRTm}{f_1} \frac{p_2^2}{p_2^2} \quad \text{and}
\]

\[
\text{the final pressure } p_2 = p_1 \left( 1 - \frac{f \cdot k_1^2 \cdot L}{gRTm} \right)^{1/2}
\]

Since \( m = 1/4 \cdot d \)

\[ R = 53.22 \]

\[ \varepsilon = 32 \]

\[ p_2 = p_1 \left( 1 - \frac{f \cdot k_1^2 \cdot L}{430 \cdot Td} \right)^{1/2} \]
The air is forced through a six inch pipe of sheet iron by a Sturtevant Monogram Blower placed at the shaft mouth. From the main pipe, small pipes will conduct air to the stopes; the quantity of air passing through the small pipes, other data being the same, will be directly proportional to their areas so that placing

\[ a = \text{area of small pipe} \]
\[ A = \text{area of large pipe} \]
\[ k = \text{velocity in small pipe} \]
\[ K = \text{velocity in large pipe} \]

\[ a = \frac{AR}{K} \]

As before stated, no attempt will be made to arrive at exact results, so to err always on the right side we will suppose we are to furnish our maximum quantity of air (6000 cubic feet) at the greatest distance necessary (5000 feet) from the surface and at the maximum pressure by the gauge of 32 ounces per square inch, the pressure of the atmosphere being 11.8 pounds per square inch.

We will further base our calculations under the most unfavorable conditions, that is, when the temperature at the surface and underground are equal, namely 80 degrees F.

The necessary velocity will then be

\[ K = \frac{6000}{\sqrt[4]{3600 \ d^2}} = 8.5 \text{ per sec.} \]

and from the proceeding the pressure necessary at the blower is

\[ P_2 = \frac{P_1}{\left(1 - \frac{k^2 L}{430 \ Td}\right)^{1/2}} \]

in which

\[ P_2 = 11.8 + 2.4 = 14.2 \text{ which allows for one inch of mercury or .4} \text{ at} \]
the bottom of shaft.

\[ f = 0.009 \]

\[ K = 8.5 \]

\[ L = 5000 \]

\[ T = 460.7 + 80 = 540.7 \]

\[ d = 0.8 \]

\[ p_1 = \left( \frac{14.2}{1 - \frac{0.009 \times 72.25 \times 5000}{450 \times 540.7 \times 0.5}} \right)^{1/2} = 15 \text{ pounds absolute} \]

or \[ 15 - 11.8 = 3.2 \text{ pounds by the gauge} \]

and \[ \text{Horse Power} = \frac{100 \times 3.2}{35000} = 0.01 \]

allowing an efficiency of 50 \( \% \), also making an allowance for variation of temperature in different parts of mine as well as change in atmospheric pressures we will put in here a small one Horse Power motor.

This will probably meet the requirements and undoubtedly the benefit to be derived will pay a large percent on the investment.
To sum up then we have for:

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hoister</td>
<td>203</td>
</tr>
<tr>
<td>Cars</td>
<td>60</td>
</tr>
<tr>
<td>Incline</td>
<td>38</td>
</tr>
<tr>
<td>Drills</td>
<td>34</td>
</tr>
<tr>
<td>Pumps</td>
<td>150</td>
</tr>
<tr>
<td>Blower</td>
<td>1</td>
</tr>
</tbody>
</table>

Total: 566.

To this we will add 10% for gear friction, etc. (except drills) and allowing 95% efficiency for motors renders therefore necessary the production at the mine of 670 Horse Power or 499620 Watts.

Taking 200 lamps and connecting five in high series since each lamp has a resistance of 200 Ohms gives us $5 \times 200 = 500$ amp. or

$$ \frac{500}{200} \times \frac{1}{5} = 20 \text{ amp} \text{res for the lamps.}$$

On account of danger due to high voltage underground we will not use more than 500 volts which allowing a ten percent drop brings it to 550 at dynamo terminals, therefore the lamps require 11000 watts giving a total of 510850 watts at delivery.

If $W = \text{voltage at mine}$

$e = \text{voltage lost in transmission}$

$i = \text{current}$

$r = \text{resistance of line.}$

Then $Wi = ei + i^2 r$

and

$$i = \frac{510820}{550} = 910 \text{ amp.}$$

The drop between the dynamo and mine is not to exceed twenty percent, therefore
550 + 110 = 660 as maximum voltage at bushes

and since \( I = \frac{110}{910} \) \( r = .12 \) ohms which resistance is not to be exceeded in the four miles of line, the mine and dynamo being two miles apart. Therefore maximum resistance = .03 ohms per mile.

To find the best size of line wire we will use the following data:

\[
\begin{align*}
\$50.00 &= \text{cost per year per Horse power.} \\
\text{w} &= \text{Necessary Horse Power.} \\
\text{w}^2 &= \text{Horse power lost in line} \\
A &= \text{Area of line} \\
a &= \text{cost of poles} \\
b &= \text{constant depending on length of line} \\
x &= \text{total cost of line } a+bA
\end{align*}
\]

Then as is apparent the most economical size of wire is given when

\[
50 (w + w^2) + (a + bA) = \text{a minimum.}
\]

\[
\frac{50w^2}{746} + bA = (a + 50 w) = \text{minimum}
\]

\[
.07 \frac{a^2}{r} + bA + \text{constant} = \text{minimum.}
\]

Taking the data as follows which refers to everything per mile and plotting cost along the vertical and area along the horizontal we obtain for the value \( b \) in the equation \( a + dA \) the value 4080

We have omitted the value of \( a \) in the plot since
(38)

<table>
<thead>
<tr>
<th>Area</th>
<th>Weight</th>
<th>Cost</th>
<th>( r )</th>
<th>( \frac{e^2}{r} )</th>
<th>( 0.07 \frac{e^2}{r} + b ) A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.27 inches</td>
<td>25996</td>
<td>4549</td>
<td>.04</td>
<td>1018</td>
<td>7217</td>
</tr>
<tr>
<td>1.49 &quot;</td>
<td>30329</td>
<td>6065</td>
<td>.03</td>
<td>745</td>
<td>6617</td>
</tr>
<tr>
<td>1.78 &quot;</td>
<td>36828</td>
<td>7365</td>
<td>.025</td>
<td>519</td>
<td>8685</td>
</tr>
<tr>
<td>2.23 &quot;</td>
<td>44411</td>
<td>8882</td>
<td>.020</td>
<td>331</td>
<td>10256</td>
</tr>
<tr>
<td>2.90 &quot;</td>
<td>58492</td>
<td>11698</td>
<td>.015</td>
<td>167</td>
<td>12704</td>
</tr>
<tr>
<td>4.46 &quot;</td>
<td>90988</td>
<td>18196</td>
<td>.010</td>
<td>83</td>
<td>18777</td>
</tr>
</tbody>
</table>

It is a constant and is taken as $400.00 per mile, there being no insulation used.

Again plotting the value of \( 0.07 \frac{e^2}{r} + b \) A which with the constant omitted is the total cost, and \( r \) we obtain from the least ordinate a value = 6617. and the area corresponding is 1.49" which is the most economical for us to use.

A perusal of the results obtained shows the impracticability of the direct current for generating a large horse power when a low voltage must be used. It was intended to contrast this with the alternating current when a high voltage could be used and transformed down to a safe potential at the mine for underground work.

This however has been omitted as well as very exact calculation in the foregoing owing to lack of time to secure the necessary data and work out the problem accordingly.

For the same reason the price of the plant has been given and also a number of drawings omitted.