1882

# Tunnels

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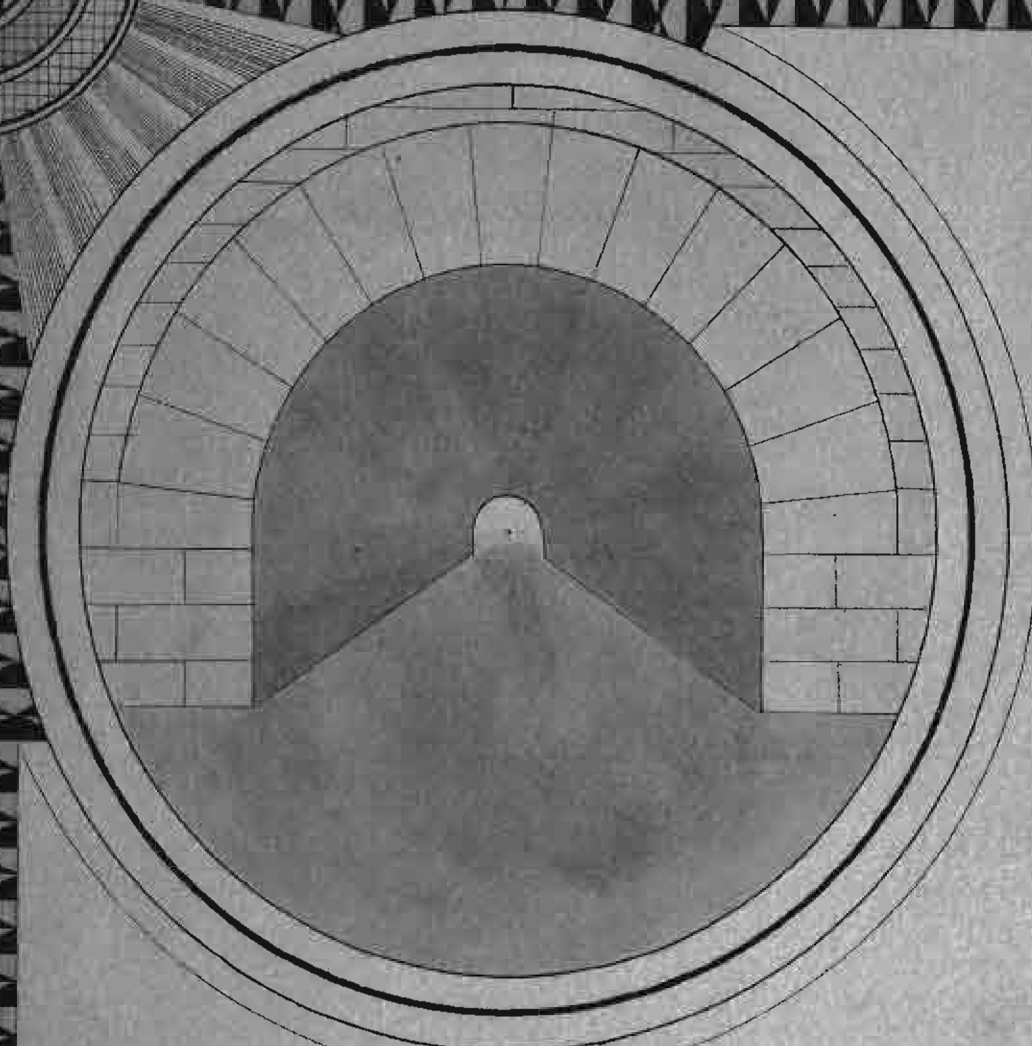



# TUNNELS

## A THESIS

By

A. B. SCHRANTZ





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Among the early tunnels, Herodotus mentions one on the island of Samos, through a mountain 900 ft. high, the length of the tunnel being 4247 ft. and its cross-section 8 x 8 ft.

When Caesar went to Alexandria he found the city undermined with aqueducts. The aqueducts of the ancient Romans, Mexicans and Peruvians include many remarkable tunnels. A tunnel was commenced in 395 B.C. to tap Lake Albanus. It was built at the instance of the Delphic oracle and was 6000 ft. long, and of cross-section 6 x 3.5 ft. Fifty shafts were sunk on its line and the work completed within a year after it was commenced, although it was driven through the hardest lava. From the above it will be seen that tunneling is by no means a modern art, but was extensively practised by the ancients, without the knowledge of explosives, and without even the most simple machinery.

Without considering any of the ancient methods I shall endeavor to treat the subject in this paper as follows.

1. Considerations to be ~~taken~~ made before building a tunnel

2. Compressed air
3. Rock drills, Arrangement of plant &c.
4. Explosives. Blasting.
5. Methods of Excavating
6. " " Timbering
7. Shafts, Ventilation
8. Centres
9. Masonry. drainage
10.

Tunnels are seldom desirable owing to their great cost, but if in an open cut the material has a tendency to slide or run, or if in a mountain region it be exposed to the drifting of snow, a tunnel is preferable or if a frequent crossing of a river can be avoided, or the general alignment of the road be improved so as to warrant the cost a tunnel it should then be made.

Or when the depth of an excavation passes beyond a certain limit, it becomes cheaper to tunnel. To determine when to change from an open cutting to a tunnel; let $e$ be cost per cu. yd. of excavation $t$ the cost per running foot of tunnel $b$ the base of excavation, $s$ the ratio of the side slopes, and $x$ the depth at which the cost of tunnelling and excavating are equal. Then

Cross section of excavation $= x(b+sx)$

Contents for one running ft. $= x(b+sx)$

Cost of running ft. of excavation $= \frac{x(b+sx)}{27} \times e$

" " " " tunnel $= t$

$$\therefore \frac{x(b+sx)}{27} \times e = t \quad \text{from which}$$

$$x = -\frac{b}{2s} \pm \sqrt{\left(\frac{27t}{es} + \frac{b^2}{4s^2}\right)}$$

Unless it be an exceptional case a greater depth than that found by the formula should be had before commencing to tunnel owing to the uncertainty and delays of the work

Tunnels in granite porphyry, gneiss dolerite basalt &c give hard drilling and generally good roofs, and as a rule tunnels in these formations are dry. Tunnels in graywacke and argillaceous mats., even in solid varieties need as a rule artificial support, in the carboniferous and sub-carboniferous slates and sand stones artificial support is needed, for though the rock be quite hard when first excavated it is liable to slack on exposure. In Europe tunnels in the "New red sand stone" and upper cretaceous sand stone are cheap and often require no support, and tunnels in the Permian formations, triassic lime stone, Keuper and Jurassic formations are apt to be difficult, as they are wet and exert great pressure.

Tunnels driven in the marl beds of Rothe, in Keuper and cretaceous formations, in the clays of the Jura formation, and in the sand and marl beds of the tertiary and diluvial groups show great pressure and are very wet.

There are four mountain formations under which tunnels are located, viz. Isolated peaks, Mountain slopes Mountain spurs and divides, Isolated peaks generally slope in all directions

A steady descending or ascending grade is generally required in tunnels of this class to conform with the grade of the balance of the road. Tunnels of this class as a rule encounter but little water, owing to the small area of the deposit, the rock therefore allows but little tendency to disintegrate, and is generally solid. Moreover tunnels through formations of this character are most always short.

In locating a tunnel through any mountain formation, there are many things to be carefully considered. Thus Fig. 1 Plate I if s be a soft stratum between two hard ones h,h, which will exert pressure, the ~~engine~~ at d will tend to bring in more water if the depression be of any great length. This would be more apt to occur with tunnels through spurs, and if there be a water bearing stratum m the flow will be all the greater.

In Fig. 2 Plate I is another example, the stratum s being softer than h,h, may be loosened by the construction of a tunnel in it, and exert great pressure; again it may bear water absorbed from basin a. When the beds are stratified horizontally see Fig 3. Plate I the tunnel may be exposed to a heavy inflow of water, from seams m,m,m. which lead from the plateau above and from the basin a. Tunnels through mountain slopes are apt to be different owing to the fact that they are seldom deep enough to be below the débris of the mountain foot, and the rock is generally somewhat decomposed and water bearing and the pressure is apt to be very excessive, and it is especially dangerous when the strata conform to the slope of the hill, See Fig 2, Plate I in which are embodied all the dangers of water, excessive pressure and ~~water~~ sliding.

Since spurs of mountains are water sheds in themselves, tunnels through them are apt to be unfavorably located, See Fig 4 Plate which shows a tunnel t behind a natural dam w, Fig. 5 shows a tunnel located in a fault, where we may expect much water and broken rock, In Fig 6 t' would have been a better location than t, t being in a water bearing stratum Fig. 7 shows a tunnel located unfavorably below a depression, caused by the fracturing and eroding of the rocks of an anticlinal summit. Geological examinations are of little value if they cover only the ground over the tunnel or in its immediate vicinity. They should extend over a great area, and this can be facilitated by the state and government geological reports.

Tracings are attached

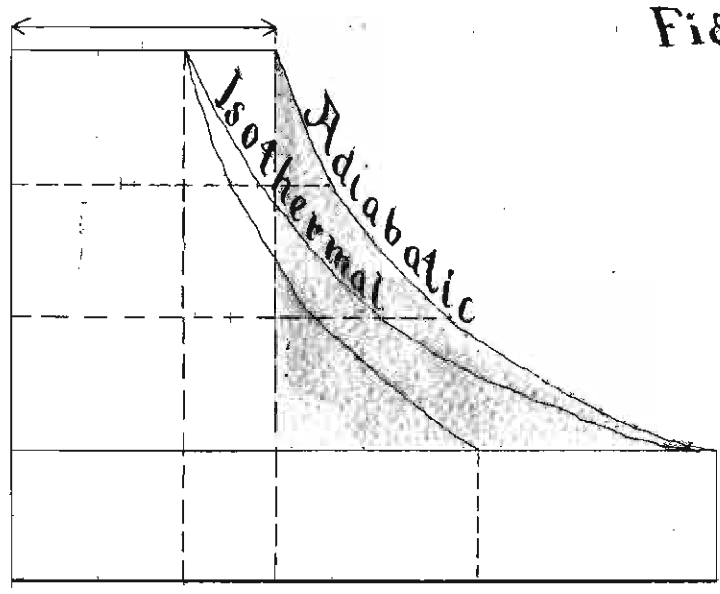



Fig. 2

PLATE

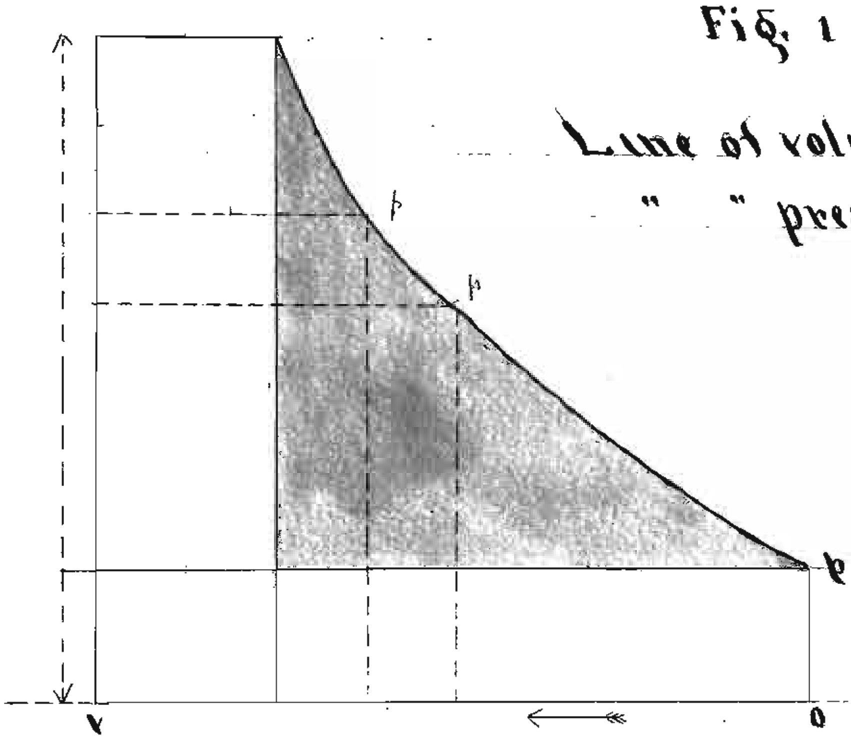



Fig. 1

Line of volume ov
" " pressure op

Compressed air:- Since air is one of the permanent gases it must obey the law that applies to them.

Volume varies directly as the temp. and inversely as the pressure. At a constant pressure the density varies inversely as the volume, which varies as the absolute temperature. From the weight of a gas the velocity of its molecules can be calculated for any pressure. Thus a cu. ft. of air at normal pressure weighs about $\frac{1}{3}$ lb. and the pressure of nearly a ton on each side of the cube is due to the striking of the molecules against it, and may be represented by $\frac{Mv^2}{3}$ (the work accumulated by a moving body represented by $\frac{Mv^2}{2}$) or $\frac{2}{3}$ the kinetic energy. From which $v$ = equals about 20 mi. per min.

The first law of gases may easily be stated thus. $pv$ = constant

$p$ = pressure (in this case 1 atmosphere)
$v$ = vol 1 cyl. full.

From the equation we can draw the curve in Fig. The equation is that of an hyperbola referred to its asymptotes. One property of the curve is, that the area contained by the co-ordinates of any point P. is equal to the area contained by the co-ordinates of any other point, that is all the rectangles p.v. are equal in area. So that for any value of $v$ as at $\frac{5}{8}$ stroke where the vol. is only $\frac{3}{8}$. We may find $p$ by inverting the fraction, representing the new vol. thus, $p$ (see dotted lines) $= \frac{8}{3} = 2\frac{2}{3}$ atmospheres absolute pressure.

The area of the shaded part of the diagram represents the engine power expended in isothermal compression and the remaining portion of the diagram above the atmospheric line represents the power required to deliver the air after compression. It is a common mistake to suppose that during the isothermal compression no heat is generated but it will be found that when delivering air into a receiver at any given pressure more heat is generated during isothermal than during adiabatic compression. In each case the heat is the thermal equivalent of the power expended in compression. Isothermal compression can only be carried out when the heat is carried off as soon as generated. If the air be compressed too slowly the heat will disappear by radiation but if compressed too quickly for the heat to get away in this manner special arrangements must be made to prevent the rise of temperature. Suppose that no attempt is made to keep the air cool, and that the air is compressed in a cylinder

that will neither take up any heat itself, nor allow any to pass out of the air while being compressed. This would be a case of adiabatic compression, and we should find that when the volume had been reduced to one-half the pressure would not be doubled as in isothermal compression, but more than doubled because the heat generated during the compression would still be in the air. In making a diagram to show how the pressure varies in this case, we must not only take into account the reduction of volume but also the effect of heat generated while that reduction was being made.
A simple way to make a diagram of adiabatic compression, is to draw first the isothermal curve, and then add to it at various pressures the extra volume due to heat generated while compressing up to that point. This extra volume can be found by taking the natural number corresponding to .2, the log. of the absolute pressure, which gives the ratio of volume after adiabatic compression to volume due iso-thermal compression. Thus at 2 3 and 4 atmospheres absolute the volumes would be 1.22 137 and 1.485, and as the power expended in delivering the air is proportional to the final volumes

this method of drawing the curve is useful. These numbers give also the final absolute temperature in terms of the absolute temperature before compression. In the equation of the adiabatic curve $\gamma = 1.4$, being the ratio of the specific heats at constant volume and constant pressure, 1.4 is here taken as the ratio of the elasticities of the air. The shaded area represents the engine power expended in adiabatic compression see Fig. 2 which is less than the shaded part of of Fig. but the final volume is so much greater here, that the area of the whole diagram is more than the isothermal diagram.

If there were no objections to working with air at high temperatures, and if it could be taken from the compressor without any heat being lost, air compressed adiabatically would by expanding give back the whole power expended in compressing, neglecting all power lost by friction &c. But as these ends cannot be attained in but few cases, the superiority of the isothermal method will at once be seen.

Plates II. & III show two styles of compressors. The advantage of the inclined steam cylinder in Plate II is to give the steam the greatest advantage when the resistance is greatest. The method of introducing water

water around the cylinder is also seen, in same plate

In the arrangement of plant great care and good judgment should be used so as to get the best results with the greatest economy. All the conditions under which the machinery is to work should be considered before selecting a site for the power. It is better to carry the air or steam some distance if by so doing the compressor and boiler will be handy to fuel and water. The boiler should be near the machinery it supplies, and the steam pipes should be kept well covered to prevent loss of heat by radiation. From the compressor the air should be discharged into a receiver near by, and it is better to pass the air into a small receiver at the end of the pipe. The air should pass in and out of the receiver at right angles, or on the same side of the receiver, if horizontal. A large pipe should be used so as to lessen the friction as much as possible, sharp turns should be avoided, as much power is lost by them.

Rock drills are run by either steam or compressed air. Steam should always be used in preference to air when circumstances will permit. The principle will at once be seen by referring to plate IV which represents the form in which the valve is moved by a tappet which is a common although not the best form of drill, which will become evident when we consider that the tappet is struck by the piston from 3 to 500 times per minute and must therefore wear and break rapidly. The best form is the one in which the valve which admits the steam or air into the cylinder to move the cylinder is itself moved back and forth by the steam or air used in the drill. The piston is a solid bar of forged steel moving back and forth in the cylinder, the same as the piston of an ordinary engine. The drill steel, on the end of which the cutting bit is forged, is firmly attached to the end of the piston by means of a chuck and these two pieces of steel alone receive the shock of the blow. The piston is also rotated at each backward stroke and moves straight and true on the forward or cutting stroke. By this device and an X shaped bit a perfectly round hole can be drilled. In very loose seams of rock a Z shaped bit is sometimes used to advantage.

The supports for rock drills are the tripod, the carriage and the column. The tripod is much used for surface work and for taking up the bottoms of tunnels after the drift has been run. The legs of the tripod can be extended and thus adapted to very rough and uneven surfaces. They are generally weighted to give them greater stability. The drill carriage is a device by which a number of drills may be made to work on the same rock face at the same time. A common form is shown in plate V.

The column for tunneling (see Plate VI.) is a cylindrical bar into which an iron base is shrunk. By means of two jack screws the column is lengthened or shortened and held fast between the roof and floor of a tunnel or the walls of a shaft. For drifting the lateral arm is clamped to the column, and the drill is fastened to the arm by means of a clamp. The drill can be moved in or out on the arm, or up and down or around the column, thus commanding a large portion of the rock face, and making a frequent shifting of the column unnecessary. The drill can be placed to drill holes at any angle up or down or to the right or left.

The screws and top of column must rest on short pieces of plank or timber.

Experience has shown that the column

is the best mounting for drills in drifts and tunnels of ordinary size. (Plate VII, shows drill mounted on column) and it can be used to great advantage in larger tunnels by running a drift of convenient size in the extension of the line of the roof, and taking up the bottom with drills mounted on tripods. In this way a greater number of drills can be used in the work, and each drill can be placed in the most advantageous position, and worked independently and constantly. Immediately after blasting they can be placed in position, without losing time in removing the broken rock.

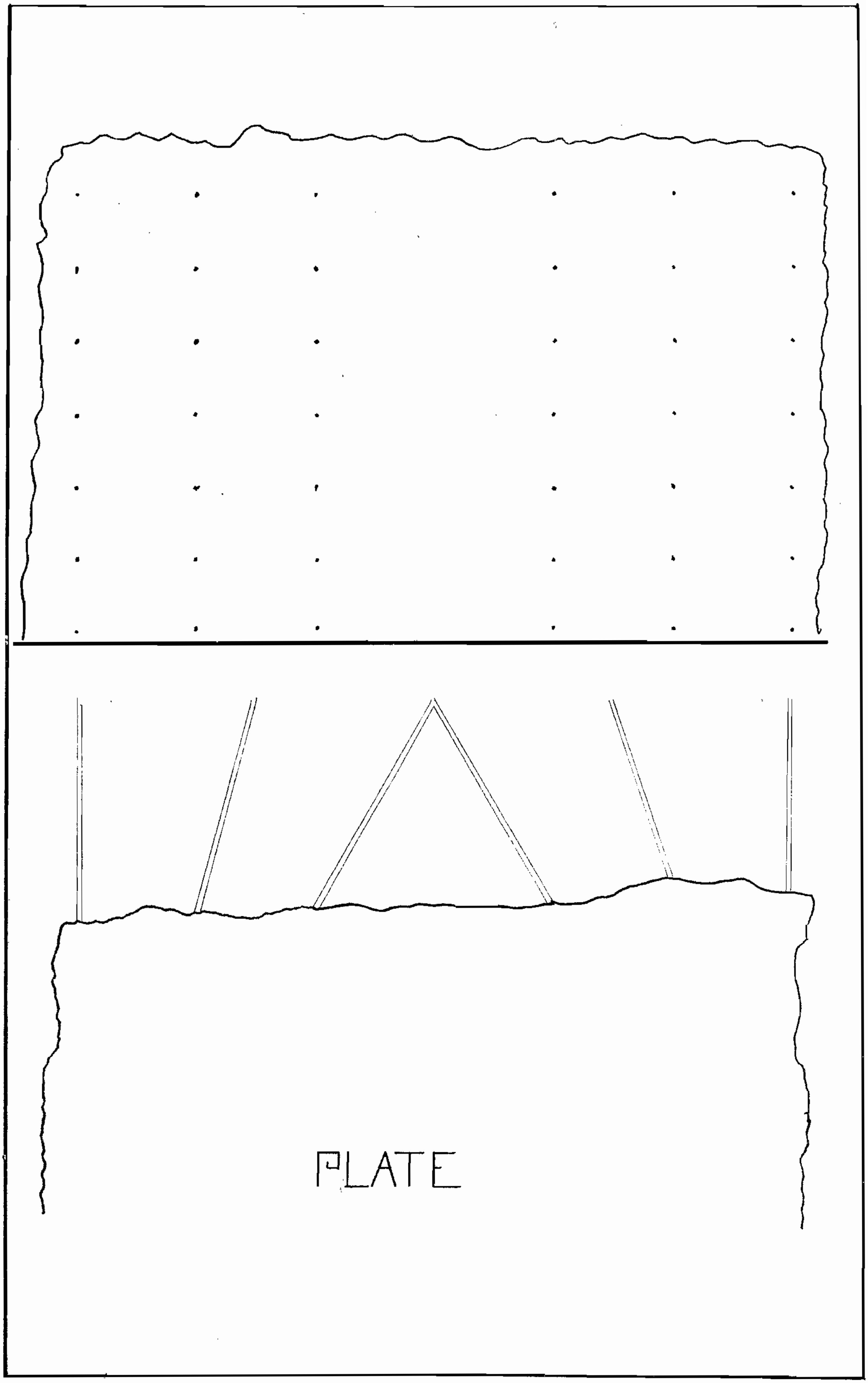
If the drills be mounted on carriages the track must be cleared before the carriage can be advanced into the heading and when there the drills cannot all be worked to the best advantage owing to the uneven face of the rock, and to the fact that each drill is attached to a common base. The diamond drill is inferior to the percussion drill for tunnel work, but is the best for sinking shafts; it is used in the popular "long hole" process of shaft sinking, in which the shape of the shaft is marked out by a requisite number of drill-holes bored to the depth required for the shaft. The ~~space~~ area inclosed by these holes is then honeycentred by drill holes reaching also to the bottom of the shaft. This being done the drills are removed, and the holes filled with sand, after which the blasting and raising of the rock can go on without further use of the drill, Plate VIII. shows diamond drills mounted for shaft work

PLATE

In blasting the explosives most commonly used are black powder, nitroglycerine, and dynamite.

Black powder is being generally replaced in works of this character (tunnels) by the more powerful explosive, nitroglycerine, but owing to the dangers of using this as a liquid, it is absorbed with some kind of absorbent dope, which takes up a great percent of the liquid. The best dope now used, is infusorial earth, which is composed of minute skeletons and silicious shells. There are many other dopes, such as sawdust, etc. The electric machine and platinum fuses, are used in firing blasts, as they have the great advantage of firing any number of charges simultaneously. Plate X. shows a form of an electric exploder. The bigger fuse can be charged by a few turns of the large plate, and then exploded discharged by pressing the button. This is a new and good form, although the one in most common use is a small electro magnetic machine. The arrangement of charges for simultaneous firing is shown in plate X, and a platinum fuse in Plate B. When black powder is used clay is the best tamping, but sand and soft rock are often used. Nitro-glycerine needs no other tamping than water it being an oily liquid and heavier than water it sinks to the bottom of the hole, and does not mix with it. With dynamite the theory is that no tamping is needed; but it is better to tamp well with clay. The exploder should be placed as near the centre of the charge as possible.

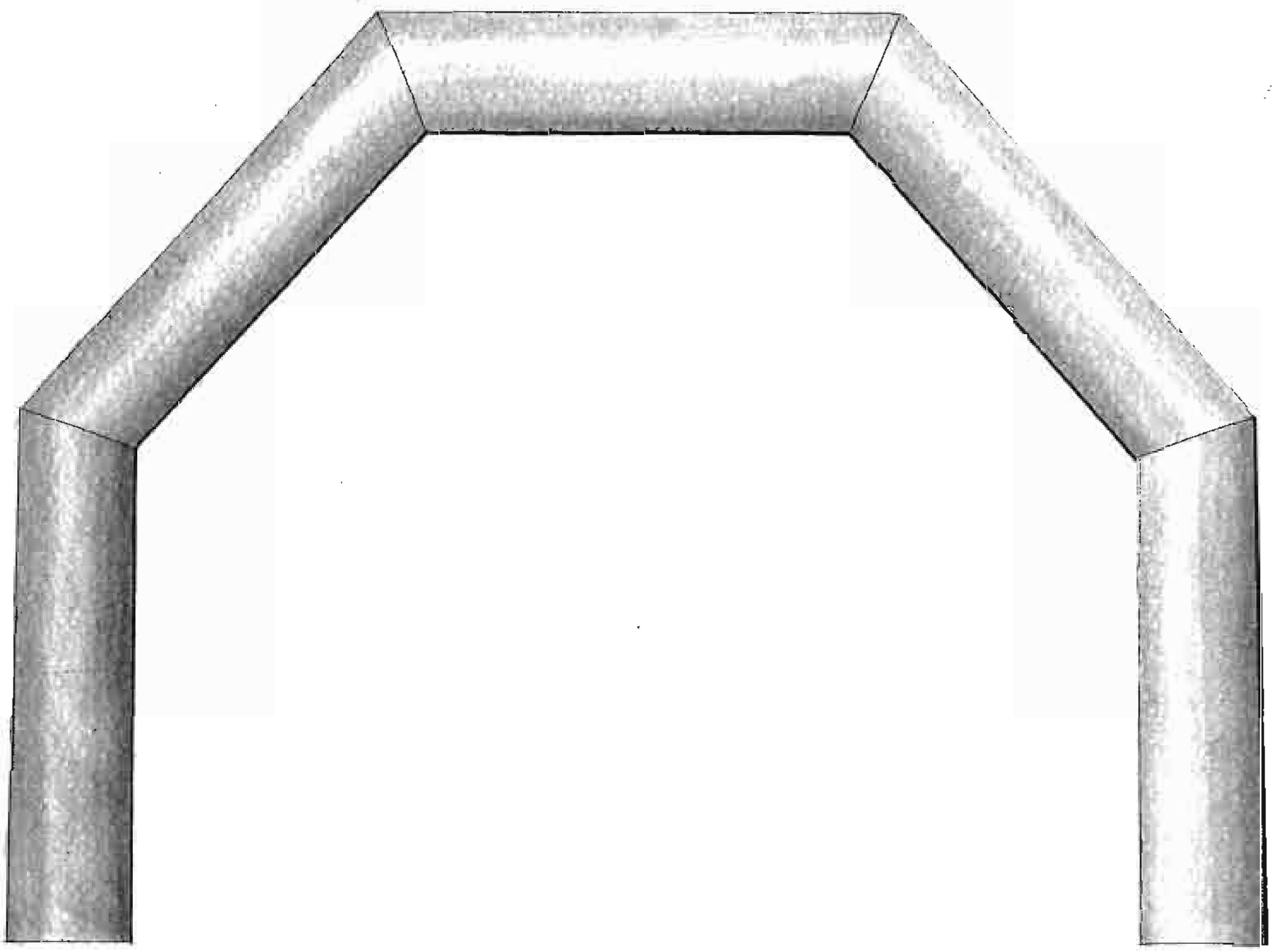
The holes should not be located in the line of least resistance, for the effect in case is always inconsiderable, and when slow burning explosives are used, only the tamping is blown out. As to the depth of holes, for "short fissured or very tough rock shallow holes, coarse moderately tough rock holes of average depth, brittle and solid rock works well with deep holes, And in tough rock wide holes and in brittle rock narrow holes are more economical." The first shot in the face of the rock is always disadvantageously located, but after this advantage should always be taken of the cavity blown out by the first shot. The American centre cut system of heading blasting is shown in ~~Fig~~ Plate C. First the wedge shaped core a a is taken out afterwards the sides b b, c c &c are blown out, and this process repeated as soon as the whole depth d d' is taken out, the rate of advance depends of [illegible] upon the tenacity of the rock



PLATE

A method of excavating more practiced in this country, is to drive a heading at the top of the tunnel. and enlarge it to the required dimensions. another method is to drive the heading in the middle of the required tunnel and enlarge from that, taking up the bottom first. And in what is known as the german centre core system of excavating, three headings are driven, one at the top and one at each side of the bottom, an excavation is thus made around the core of the tunnel against which the supporting timbers are made to abut, This system has one disadvantage in heavy ground, which is the concentration of the whole pressure, upon one particular place, viz the centre core However this disadvantage is experienced in all radial systems of timbering, regardless of the method of excavating

In timbering all depends upon the nature of the material supported, the pressure exerted and the direction of the pressure. In general to timber a tunnel, is to give a firm support to a series of rafter timbers on which is laid a lagging of heavy boards that sup-



PLATE

port the earth. A method of timbering is shown in Plate X. The strength of the timbers should vary directly as the pressure.

A method of timbering much in use in this country is the block arch, which will be understood by referring to plate –

The cross timbers should be placed exactly at right angles to the centre line of the tunnel, otherwise difficulty will be experienced when advancing the arch. The locality will of course influence the selection of timber, but for temporary timbering preference should always be given to the soft woods. Although hard wood is stronger than soft it is less elastic and more liable to suddenly break under great pressure, while soft wood will always bend before breaking and thus give warning in time to put in auxilliary timbers to counteract the pressure. Again soft wood being lighter than hard is more easily handled.

In the block arch system where the timber is put in for a permanent support, hard wood is of course preferable.

In all cases timbers should be so arranged that the pressure exerted will not disconnect the joints but

to bind them more closely together.
Each timber should bear its share of the strain, and centres of rotation should be avoided.
In very heavy ground care should be taken not to weaken the timbers by cutting, and the timbers should be so arranged as to not concentrate the pressure at any one point. In ordinary ground a section of from 10 to 20 feet can be excavated before any ~~sup~~ support is required, but in sand the supports cannot be put in too quickly.
In loose rock, the roof being supported by the repair timbers, a hundred or more feet may be excavated before the abutments are put in.
In taking out the timber care must be taken not to leave to great a section unsupported at one time. When the ground is very treacherous it is sometimes advisable to wall in the timber, with very soft ground, and quick sand it is always necessary to wall in the lagging.
Iron framing has been used for supports in tunnels. It was used to some extent in a few foreign tunnels, and is advocated principally by foreign engineers. Iron has only taken the place of timber in

this country in the sinking of shafts through very soft material

The iron system may come into general use in European countries where the cost of timber is very great, as in most of these systems a great excess of timber is always required. But in America where timber is cheap, and the most economical system of timbering (the block system) has been adopted, it will be long before it will be superseded by iron, probably never.

Shafts are built either for working shafts, or for ventilation. There are two processes of sinking shafts that stand out pre-eminent "The Long hole Process" which is used for ~~such~~ sinking through rock or any hard material, (described under the head of diamond drills), and the Caisson Process for sinking through soft material as quick sand &c. This method of shaft sinking differs little from the method of sinking pneumatic piles and caissons, and will not be described. As to ventilating shafts it may be stated that in general they are an impediment to perfect ventilation

Methods of artificial ventilation have to be resorted to in long tunnels. One is to introduce compressed air in the tunnel and have cocks along the lining at suitable intervals by which it can be drawn off. Currents of air can be made to pass through the tunnel by means of a fan blower at one portal. The old method of building pits under shafts has pretty generally been discarded. Double line tunnels are found to be more easily ventilated than single line tunnels.

Screens and various devices have been used to promote ventilation, which need no detailed description.

For any given length of tunnel there is always a limit to the traffic that can be carried on by locomotives, beyond this limit some other traction power must be used

In moving timber to make centres it should be borne in mind that the centre is not to carry the arch only but the arch plus the weight of the ground, hence great strength is required, and since it should occupy as little space as possible, care should be taken not to add any superfluous material,

There must also be a reserve of strength ening with auxiliary braces without ~~too much~~ closing the tunnel inconveniently

Arrangements must be made for attaching scaffolding for the masons, and the centres must be of simple construction and be easily taken down and set up

The centre should have no connection with the timbering, so that the latter may be removed without any way disturbing it.

Iron centres are sometimes used but are objectionable owing to their great weight. Movable centres have been devised, by which the whole tunnel can be arched with the use of only one centre. They are generally mounted on rollers and have a means of raising or lowering. The method of using is to put the centre in place, build the arch over it allow it to settle a few hours, lower the centre until it clears the arch, push forwards until nearly from under the arch completed, raise it and repeat the operations &c.

A very ingenious method of lowecentres is to have the struts resting in strong wedges filled with sand. These wedges have small orifices at the bottoms, by means of which the sand can be drawn off. When it is required to strike, these orifices are opened, the sand is let out and the centering slowly settles.

Great care should be taken to keep the centres exactly at right angles to the center line of the tunnel, otherwise the tunnel will be narrower at some places than at others.

When selecting material for the arches, stone should be chosen especially with reference to its crushing weight, as great pressures have sometimes to be sustained. The stone selected should be of a kind that will not disintegrate on exposure. Brick are often used for arches, being sometimes cheaper than stone, the clay taken from the tunnel being made into them. Of machine and hand made brick the preference is always given the latter, as the mortar adheres more closely to them, forming a kind of monolith.

The form of the arch depends upon the direction of its pressure, if the pressure be vertical, the oval arch is better adapted to resist it, (on long axis vertical) if lateral the flat arch, but for all kinds of ground, whether the pressure be vertical horizontal or otherwise, the full center arch is well adapted.

In rock of any character a tolerably good foundation can be had without trouble, though in loose rock all the interstices should be carefully filled with hydraulic mortar. In very soft material there is generally an upward pressure which must be met by an invert, this invert also serves as a foundation on which to build the other masonry of the tunnel.

When the upward pressure is very great or such as would tend to close the tunnel this invert must be laid in advance of the other work thus giving a firm footing to the timbers that support the ground before the masonry is put in.

Whether the masonry be of stone or brick, it should be well laid in hydraulic mortar, and the extrados of the arch should be covered with a thick coating of the same material, to protect the [illegible] from water. In all cases the arch should be well packed with broken stone, to prevent any settling that would otherwise take place.

When possible, the floor of the tunnel should have a gentle slope from the centre towards each portal, so as to carry off any water that penetrates. In such cases the bottom of the tunnel is lined with broken stone through which runs a drain. When this grade cannot be had, pumps must be resorted to, or a small heading run from the lowest point in the tunnel to some point on the surface sufficiently below this to carry off all water.

It has been tried to drain the outer masonry by leaving holes where the greatest flow of water was noticed, but this has proved a failure in nearly all cases and it is found better to make the arch as near water tight as possible.

When the work is progressing from working shafts the inflow of water is often a great hinderance, and must be gotten rid of either by pumps or when the height will permit a siphon may be employed. It is always best to connect the shafts and portals with a small heading as soon as possible and get rid of the water by this means.

Tunnels now in progress.

The Hudson River tunnel, is to be a double track railway tunnel under the Hudson River, and is to connect New York and Jersey City. it will when completed be something over 5000 feet long, and as determined by borings will be through silt over two thirds the distance. Work was commenced on the Jersey side in Nov. 1874 but the working shaft was sunk on the New York side only during the past winter. The shaft was sunk by means of a pneumatic caisson the dimensions of which are, bottom 48. by 29.5 ft. top, 46 by 27.5 ft height 26 ft. The interior space is 23 ft high, and is divided in two parts by means of a floor.

All the fine material is forced out by means of the pressure of the air, while the coarse material is shoveled to the upper floor and raised from there to the top by means of a hoist.

On the Jersey side the same method of excavation is employed in the headings, the clay is puddled and forced out by means of the pressure of the air maintained, the sand is blown out dry.

The length of the sub-marine tunnel under the sea from the English to the French shore will be 22 miles, and taking in the approaches at each end there will be a total length of 30 miles of tunnelling

The approach of the tunnel on the English side descends from the surface with an incline of 1 to 80 The shaft near the shore is 160 ft. deep and penetrates the white chalk after passing through 40 feet of débris

The present heading is 7 feet in diameter, and machinery is being constructed by which it may be enlarged to 14 feet by cutting an annular space of 3.5 ft. width around it

The heading is driven by the Beaumont and English boring machine, the total length of which is 33 feet. its work is done by the cutting action of sharp steel cutters fixed in two revolving arms with 7 cutters each, The borer moves forward 5/16 of an inch with every complete revolution of the cutters, A circular tunnel is thus formed having a diameter of 7 feet, The shape of the tunnel when completed will be a circle 14 feet in diameter, flattened at the bottom to receive the rails. It will be lined with two feet of concrete cement made from the gray chalk excavated from the tunnel itself.

The Mullen Tunnel on the line of the Northern Pacific rail-road will be 3850 feet long, 16 feet wide and 20 feet to the crown of the arch.

As the work will consume considerable time, preparations were made to begin as soon as the the route through Mullen pass was decided upon.

On Jan. 8th 1882 a great number of the citizens of Helena Mt. and other places went to the scene of the undertaking to see the drills begin their work in piercing the barrier of granite. The Governor of Mt. was given charge of one drill, the Mayor of Helena the other, the compressed air turned on, and the task commenced. The material to be penetrated is expected to be solid granite through the entire length. Against this six drills will be ~~to~~ brought to bear, impelled by two air compressors. Giant powder is to be used for blasting, and the rate of progress as is estimated will be five feet per day. The work is expected to be finished by the summer of 1883

The tunnel will be 363 feet below the top of the mountain through which it passes.

This is the first tunnel ever

undertaken through the continental divide, and upon its completion will take its place as an engineering feat with the Suez canal, Hoosac tunnel &c.