1886

Tunnels and tunneling

James E. Fulcher

THESIS

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TUNNELS AND TUNNELING

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FULCHER

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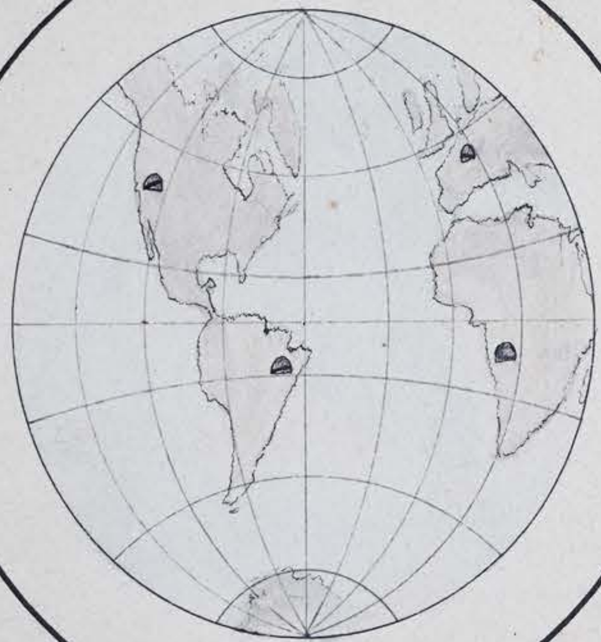

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A thesis for the degree of
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By J. E. Fulcher.

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Tunneling, at the present day, has become of such importance, that it is in its-self a profession.

The subject of Tunnels and Tunneling properly treated would require a large volume, but taking into consideration the time and space allotted to the preparation of this thesis, I shall be brief; and in order to treat it to the best advantage, I shall place it under the following heads= Historical and Descriptive; Explosives and Blasting; Drills and Drilling.

The history and description of tunnels has been selected from the best authorities.

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Historical and Descriptive.

We have records of tunnels as early as 398 B.C., one of which was begun in that year and finished a year later. It was 6000 ft. long, 6 ft. high and 3½ ft. wide. Fifty shafts were driven along the line of the tunnel, although it passed through the hardest lava. Another similar work was undertaken about four centuries later, but of much greater magnitude. About 30,000 men was employed in its construction for 10 years. It was completed in the year 52, at a vast expenditure. We, also, have accounts of other tunnels of ancient times many of which were pushed through with surprising rapidity. The accuracy with which surveying was done is astonishing when we take into consideration the rudeness of the instruments with which they had to work. The leveling instruments were of the rudest class. The following is a description of one of that class: It consisted of

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a rod or plank about 20 feet long, supported at its extremities by two legs of equal length. These legs were secured by diagonal braces, on which were, accurately marked, vertical lines. A plumb line secured at the extremities and passing over the diagonals indicated whether the instrument was level. There must have been various other instruments but of which we have no accurate description.

There may be found descriptions of many other tunnels of ancient times, but I shall now pass to tunnels of modern times. The advantages of tunnels are to avoid deep excavations, (the limit for such being about 60 feet,), steep grades, excessive length of road, &c. They also have disadvantages, such as the increased length of time and cost of their construction, and the want of fresh air, light and drainage. The latter may be effected by a slight grade, but in case of failure to get the proper grade, pumps will have to be resorted to. It is desirable that they be on a tangent throughout,

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both for the admission of light and
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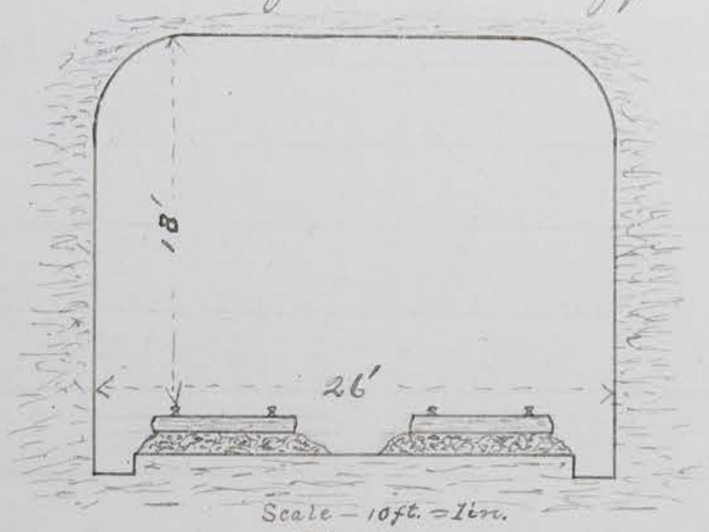
The Mont Cenis tunnel was first opened
on a straight line but ~~curves were~~
a curve was subsequently excavated
at each end.

Tunneling through "soft ground" is
a term used to designate excavations
through such substances as clay and
loose earth. Tunneling through "rock"
indicates that the substance through
which the tunnel passes is rock,
either solid, or loose and seamy.
If loose, an arch of masonry must
be built to sustain the pressure;
but if solid, and of a durable character,
the roof will support itself.



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tunnel with double track, whose walls and roof are rock and sufficiently strong to support the pressure. Figure 2 shows

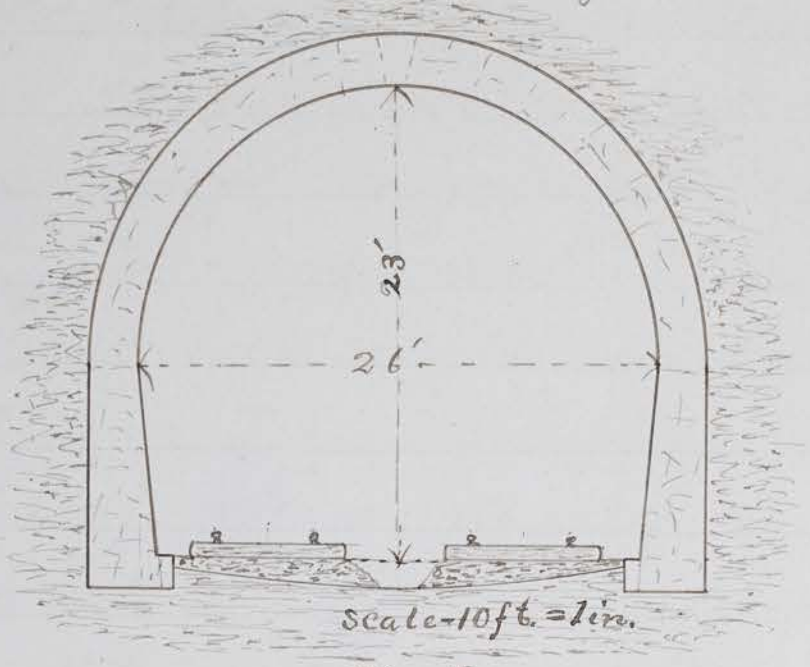

Fig. 2.

the cross section of a tunnel through soft ground – the arch being circular.

Short tunnels may be built by working from the ends only; but as this limits the number of work hands, for very long tunnels, shafts are sunk along the line of the tunnel from the surface to the grade line, and then work is pushed in both directions. This operation, however, involves large expenditure, as all the drainage, removal of materials, ventilation, &c

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must be effected through the shaft.

Usually, in tunnels which are to be cut through rock, work is carried on in the following manner: A small party of workmen carry forward a small heading, six or eight feet square and a larger company follows enlarging it to its proper dimensions, and putting in masonry when it is required.

After a tunnel has been driven about four or five hundred feet, artificial ventilation becomes necessary. This is effected in various ways. The foul air may be removed by means of a chimney with fire at the lower end. The upward current of heated air carries out the bad air and that is replaced by fresh air from without. The compressed air used to drive drilling machinery may also be used for the purpose of ventilation. Exhaust fans are sometimes used for the same purpose. In the Mont Cenis tunnel a horizontal partition was built to create a current, thus securing ventilation.

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Forms of Arches.

Figures 1 and 2 are the ordinary forms of the cross sections of tunnels, but the old adage says "circumstances alter cases;" this holds good in the case of tunnels. The center of pressure on an arch should fall in the middle third of the thickness of the arch.

The debth of a tunnel beneath the surface of the ground should, at least, to a great extent determine the form of arch to be used.

The elliptic arch is a form sometimes used, the major axis lying in the direction of greatest pressure. The following equation will give the ratio of the two axes of an elliptic arch:

$$\frac{\text{horizontal semi-axis}}{\text{Vertical semi-axis}} = \sqrt{\frac{p_y}{p_x}} = \sqrt{\frac{1-\sin\phi}{1+\sin\phi}}$$

p_y being the horizontal, and p_x, the vertical pressure, and ϕ, the angle of repose of the earth. In a tunnel which is to be used for drainage, the entire ellipse may be used; but in rail way tunnels where nearly a flat floor is needed, only the upper two-thirds or three-fourths of the ellipse is used, and the

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Another form of arch is frequently used, called three-center, or five-center arch, and is formed of arcs of circles with three or five centers. An arch of this class is an approximation to the elliptic arch.

The exact form of arch for tunnels is that of the <u>geostatic</u> arch, and more especially when the tunnel is near the surface of the ground. This form of arch is best suited for such substances as loose earth, in which the pressure varies with the debth.

Let x_0 be the debth of the crown of the arch x_1 be the debth of the greatest horizontal diameter, below the surface; from these data a geostatic arch may be designed either exactly or approximately

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Timbering.

In the construction of tunnels, especially through soft ground and loose rock, it becomes necessary to support the roof and walls to keep them from Caving. This is done by timbering in different ways. There are several different systems of timbering as caried on in the world; The American system, the English system, the German system, the belgian system, and the Austrian system, are the leading systems. The american system is used in this country, also the other systems are sometimes used.

I shall next notice the principles used in timbering in tunnels, as this differs greatly from the ordinary framing and wood working followed by carpenters and wood workers above ground. The object of the carpenter is to joint his work in such a way by dove tailing or otherwise, that the pieces of the structure will not separate. Such is not the case with the "under ground carpenter." His joints are of the simplest class.

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The object he has in view is to guard against compression; his joints are made plane because the greater the pressure, the stronger will be the joint, and the less attention is paid to joining the timbers to keep them to-gether. In cases where timbering is put in to support certain kinds of rock, where the pressure is not great, dovetailing, then, is not out of place, but becomes useful. The following are among the chief joints used in timbering:

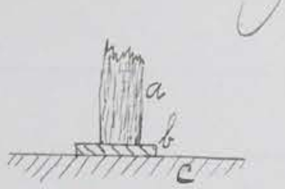

Fig 3

1. – The standing joint. – This is one of the simplist forms of joints, and is used principally in props and supports. The prop a, simply rests a block or plank b (Fig. 3) to distribute the pressure over a greater surface.

2. – The beveled joint. – This kind of joint is used where radial props to the roof are centered to one point. This is rather a bad form as the pressure is concentrated to one point on the sill, instead of being

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3. – The corner joint. – This form of joint is shown in figure 4, where b is beveled to fit the angle between a and e.

4. – The butt joint. – This is a slight modification of the standing joint. It is made where the ends of two pieces come to-gether as in Figure 5.

Fig 5

5. – The Scarf joint – Figure 6. shows the form of the scarf joint. It is very seldom used in under ground timber-ing, as it weakens the timber.

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There are various other joints such as the hollow joint, Fig 7. The frog mouth joint Fig. 8, the collar joint &c but these are of less importance.

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Often there is such great pressure that it is impossible to remove the timbers; but if wedges are used they may be either knocked out or cut out, and this loosens the timbers.

There are two kinds of timbering in the construction of tunnels

1st. Heading timbering, – this is about the same as ordinary timbering in mines; 2nd – Tunnel timbering proper, – in which the roof and wall of the tunnel is supported, after it is enlarged to its full size, and is removed as the arching is put in.

The principal pieces used in timbering are: the lagging – which supports the earth; the rafters or bars which supports the lagging; and the proping below which supports the rafters.

The wood should not be weakened by squaring or mortising the timbers at the foot.

The sills or foundation timbers should be solid, so that no sinking will occur.

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The Mont Cenis Tunnel.

The Mont Cenis tunnel was first
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plan to the king, for piercing the
mountain. Some years after he also
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of Commerce, of Chamberry, but again,
without success. Although this
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This is one of the longest tunnels ever constructed; it being nearly 7.4 miles in length. It has no shafts, having a debth of more that a mile in the deepest place.

For drainage, it is graded from the French end to the center at the rate of 117.22 feet per mile, and from the Italim end to the center, at the rate of 2.64 feet per mile. The Italim end is 435 feet higher than the French end.

The tunnel is lined with masonry through-out, The wall being of stone, and the arch on the Italim being of brick. The masonry is about 2 feet thick. Recesses are made in the sides, at intervals, large enough for several men; also tool chambers are provided every 550 yards. The average advance of this tunnel, per year, was about 2600 feet, and the expenditure per year averaged about $790000.

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The Hoosac Tunnel

In the year 1825 the project of tunneling the Hoosac Mountain was broached and a board of commissioners with L. Baldwin as engineer, was appointed to ascertain the practicability of tunneling that mountain, for the purpose of making a canal from Boston to the Hudson river. They reported in its favor, but railways being shortly introduced, the canal project was dropped. In 1828 several surveys were made for a rail road. In 1848 application was made for a charter, which was granted and the corporation was organized June 1st '48, with capital limited to 3½ million dollars. In 1854 the state of Massachusetts loaned the corporation 2 million dollars. This total amount was yet insufficient for its completion. Many difficulties were met with, several contracts fell through. It was finally pushed through under the direction of the state at a total cost of about $10 000 000. The total lenght of the tunnel is 24,416 feet.

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Drills and Drilling.

It is thought by some, that the ancients were acquainted with the diamond as a means of rock boring. Some of the ancient writers such as Pliny, Italiana, and others, refferred to the diamond as an important adjunct to the "hewers of stone". It is thought by some writers that diamond point-tools were used by Solomon, in building the temple, as "there was neither hammer, nor axe, nor any tool of iron heard in the house while it was in building."

There has been many vast improvements in the way of rock-drills since their introduction, and they have been of vast service in the the construction of tunnels and in excavations. By referring to some of the works on tunnels and tunneling it will be seen that the rate of progress increased greatly after the introduction of drills, particularly, the compressed air machine-drills.

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The situation of the place in which the holes are to be drilled is often difficult of access with a machine, so that the time and expense employed in adjusting a machine, would make it preferable to employ manual labor. But, however, if large holes are to be drilled, machines driven by compressed air furnished by steam or water power, is by far more desirabl and, in fact, all modern drilling on a large scale is effected by means of machine rock drills.

The following is a description of some of the rock drills that are, and have been in use: The most simple of all drills is a straight bar of iron pointed with steel, and flattened at one or both ends. They are of different sizes, and are to be used by hand, with an up and down motion, like that of an ordinary piston rod. This up and down motion causes it to force its way into the

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In 1683, a man by the name of Henning Huthmann, proposed the first "boring machine" in the form of a drop drill. It was raised by a rope drawn by two men and then dropped. It is said, this drill, in ten blows, would sink a hole one and one half inches deep, and a hand breadth in diameter.

In 1721 another machine was invented for drilling and boring, and in 1803 a machine was made that is said to work "quicker than a miner."

In 1813 rock drilling by machinery was said to have been suggested.

The drill of note, which I shall mention is the Burleigh Drill. It is a percussion drill, driven by compressed air. The bit is attached directly to the piston rod. This drill is but an improvement of the original Fowle drill, which was first suggested to the inventor in the following manner: Fowle happened to pick up an old steam cylinder and by

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In 1683, a man by the name of
Henning Huthmann, proposed the first
“boring machine” in the form of a drop
drill. It was raised by a rope drawn
by two men and then dropped. It is
said, this drill, in ten blows, would
sink a hole one and one half inches
deep, and a hand breadth in diameter.

In 1721 another machine was invented
for drilling and boring, and in
1803 a machine was made that is
said to work “quicker than a miner.”

In 1813 rock drilling by machinery
was said to have been suggested.

The drill of note, which I shall
mention is the Burleigh Drill. It
is a percussion drill, driven by
compressed air. The bit is attached
directly to the piston rod. This drill
is but an improvement of the
original Fowle drill, which was first
suggested to the inventor in the
following manner: Fowle happened to
pick up an old strain cylinder and by

blowing into it, forced the piston
in and out, and thus using it to
drive tacks in the wall.

The Ingersoll drill is very
effective in excavating open cuts.
It is run by steam or compressed
air, is also a percussion drill.
It has a screw for driving the drill
forward, which may be moved by
hand, or by an automatic ratchet
movement.

There are various other styles of
drills, but I shall now give a brief
description of the diamond drill.
The essential parts of the diamond
drill = first, a bit usually hollow,
with black diamonds set in one
end in such a way that the hole made
is somewhat larger than the drill;
second, - a drill, also hollow, an on
which the bit is screwed; Third, - some
rotating machinery for rotating the drill.
The hollow in the drill is partly
filled by a core of rock while drilling.
A stream of water is forced through the
hollow also to wash out the cut rock &c
The diamond drill has been chiefly ap-

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Explosives and Blasting.

The term explosion is defined as a sudden or extremely rapid conversion of a solid or liquid body of small bulk, into gas or vapor of bulk many times larger than that of its solid state. An explosion may be occasioned by the removal of pressure from an expanding force, as in the case of steam boilers, but it is more frequently the case of a sudden generation of gases by chemical reaction. This sudden expansion of volume is attended by an exhibition of force, and is more or less powerful, according to the nature of the substance exploded, the circumstances, &c. The principal elements contained in explosives are carbon, oxygen, and nitrogen, the latter slightly combined with the oxygen, thus forming a condition of chemical unstable equilibrium, which is necessary. When explosions take place the oxygen parts from the nitrogen and unites with the carbon, forming carbonic anhydride (CO_2) and carbonic

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oxide (CO) gases, and the Nitrogen is set free. Such explosions are attended with generation of great heat.

The principal explosives used in blasting are powder, gun cotton, nitro-glycerine, and dynamite. Gun powder was invented in the year 1320 by Berthold Schwartz. In the beginning powder was made by hand but later in the 14th century powder mills were introduced. Finally stamp mills. took the place of the old fashioned powder mills in which mill stones were used to grind the powder, the latter being found too dangerous. At first powder was ground fine, but this attracted moisture, and was easily caked. Consequently, graining was decided on in 1525. In 1778 experiments made in France showed 16 parts of nitre, 3 parts of carbon, and 1 part of sulphur to be the composition for the strongest powder.

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glycerine was brought into use as a blasting agent, and in 1867 it was applied in the form of dynamite, by mixing it with silicious earth.

Another explosive compound is composed of charcoal, salt peter, ferro-cyanide of potassium, and some cyanide of potassium; it is called Haloxyline, is made in grains, like powder, and burns slowly in the air without exploding. It is only ignited by a spark or flame, at 480° F. No smoke results from combustion, and the gaseous products are neither unpleasant nor injurious. In blasting with it the rocks are torn up slowly, the fragments are not scattered, as with other explosives, and the report is dull.

Another form of explosive, called white gun-powder has the following composition: Chlorate of potash 48 parts, Yellow prussiate of potash 29 parts, finest loaf sugar 23 parts.

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of acid is removed. Part of the hydrogen in the cotton is displaced by nitrogen and oxygen, and but feebly combined. Several formulae are given for it one of which is $C_6H_7O_3N_{11}$. It is not affected by water. On being exploded it burns to water and gases without leaving any smoke or residue.

Nitro-glycerine is one of the most important explosives of the present day. It is a light yellow, clear, oily liquid, odorless, has a pleasant, sweet taste, and is poisonous when taken into the body in any way. Its formula given by Hill is $C_3H_5.O_3N_9$. It is composed of Binoxide of nitrogen 20.36%, Carbonic acid 45.72%, and nitrogen 33.92%. It is a detonating compound and is best fired by fulminating caps.

Dynamite is composed of Nitro-glycerine and any dry, inert substance. It was introduced into Europe in 1867. The best material for mixing the Nitro-glycerine with is a kind of silicious earth, know as silicious marl or tripoli. The firing point of dynamite is about 356° F, the same as Nitro-glycerine.

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Blasting

Blasting is defined as the rending or tearing asunder any solid body, by the sudden development of gases from an explosive. Good blasting depends almost altogether on the manner and position in which a blast is set. Blasts are usually put in holes in the rock, drilled for that purpose. The powder is put at the bottom of the hole and tamping of clay, soft rock or sand, (the former being considered the best) is put on top of the powder and thoroughly packed. A piece of fuse is inserted into the powder and passes out through the tamping for the purpose of ignition.

If nitro-glycerine is used the tamping is simply water poured on top. Nitro-glycerine being heavier than water and having no affinity for it, it will stay at the bottom.

With dynamite, some deem it non-essential to have tamping, but it is generally considered best; at any rate close confinement promotes the effect.

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Before the inventions of machine drills and the higher explosives, all

tunnel work was done with black powder, and in fact it is used to a great extent yet.

As a general thing, in rock tunnels, particularly in the United States, a heading is taken out at the top, the full width of the cross section and about 7 feet high. Blasting with high explosives offers the advantage, that owing to their great strength the holes can be set perpendicular to the face or at a very acute angle, while with powder, that angle must be 45° or less in firm rock. In European tunnels where the headings are narrow, the holes are set normal to the face of the rock, while in American practice, deeper holes are drilled, and at a less angle with the normal, than could be used with powder. There can be no definite rules given for blasting. The operater must be guided by judgment trained by experiance.

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