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Tech Talk: Supporting Underground Tunnels

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With thoughts of the miners in Chile, and suggestions that a rescue tunnel will also be started to try and drive down through the broken rock, I thought I would write a little today about holding rock together. For those of a slightly cynical nature, I recently used the example of the Forth Road Bridge, in comparison with one of the bridges that the Romans built in France. The latter is over 2,000 years old and still standing, the former was built in 1964 and is now being scheduled for replacement, since the cables in the old one are corroding and snapping. The point of the comparison being that if you know what you are doing with rock, you can build a structure that can carry load for a long time. (And if you think about it, the rock that the Romans built with is bits of broken rock, rather than the solid structure that a tunnel starts out drilling through).

The Roman Bridge at Chaves (James Martin)

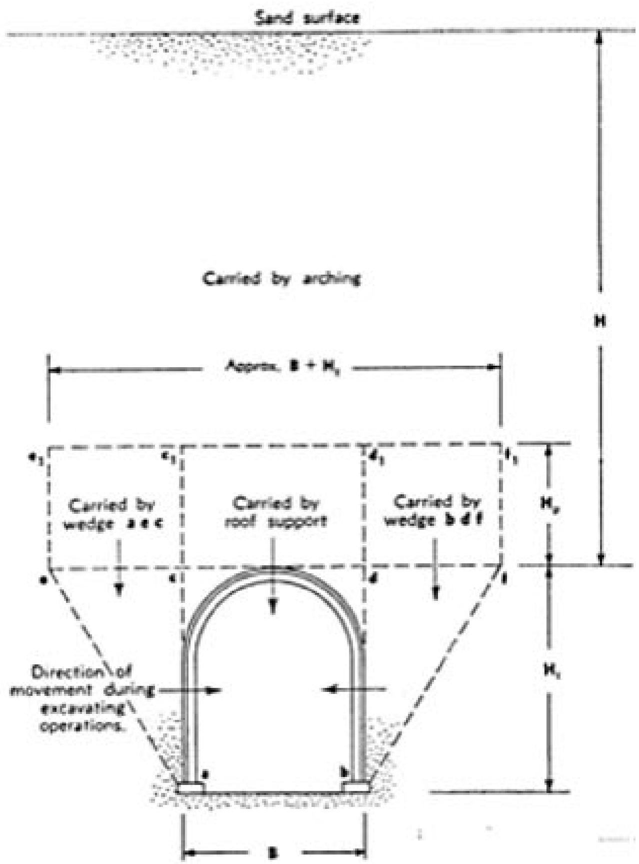
When man first started digging into rock, whether to get flints, create shelter or extract some coal that would burn, it was a relatively slow process. The miner relatively slowly dug out the rock, giving the loads around the hole some time to redistribute, and small holes could be made that would be stable for a long time. That is only a generalized statement and not always true, there are several factors that limit its validity. The first is water. Of the underground hazards water is one of the worst. In its most visible form it can fill the hole, and drown all those in it. There have been many disasters where water has invaded a mine, either from the surface, or from nearby underground workings. (For example Quecreek).

But water has a more insidious role underground, travelling into the mine with the air that the miners must breathe. Underground the ground temperature stays quite constant, and for many mines nearer the surface, the temperature can be quite cool (one I was in recently was at 58 F). So in the days of high humidity of the summer, the moist air moves into the mine, meets the cooler rock, and the moisture condenses onto the rock. It soaks into the rock, and usually weakens it – some shales (the more common rock in coal mine roof) will lose 60% of their strength when they get wet. And it is often why there are more accidents from roof falls in the summer – while in the winter it is more the time for gas explosions – another story).

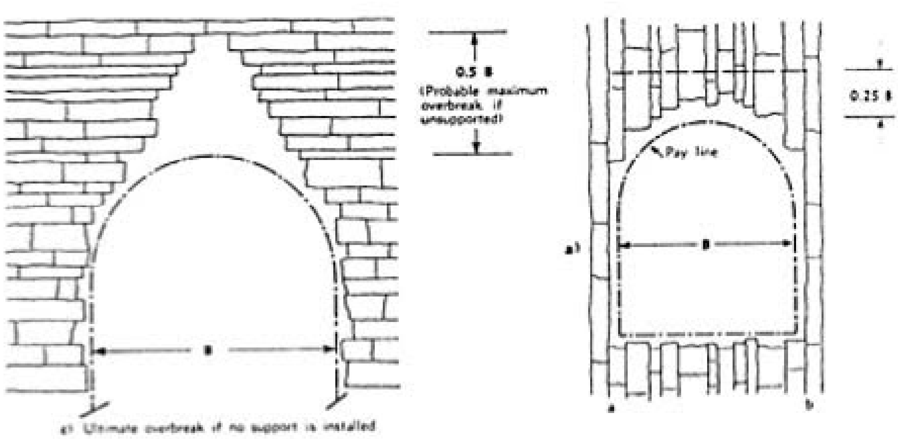
The second problem that affects the rock relates to the number of cracks in it. If you drive along a road and pass through a road cut where you can see the cracks that develop around individual lumps of rock. Some, the bedding planes, are formed when the rock was first laid down as a sediment, some were formed as the rock was twisted and distorted over geologic time, or during the time that it changed from the sediment into the rock structure encountered today. And some cracks are made as the opening in the tunnel is made. We want to break the rock in the tunnel face into small pieces that we can pick up and carry away, and so we place explosive in known patterns of drilled holes in the face that will break the rock into bits, when the explosive is set off. Generally the charged holes are set off in a sequence, so that after breaking out the middle of the face, successive rounds (they are set off with timed detonators) will blast successive layers of rock into the opening until the desired shape has been removed. In the process some cracks from the outer ring of blast holes will extend out beyond the intended wall of the tunnel and into the final wall. (Seems to happen more on Mondays and Fridays for different reasons).

So there are several concerns that face an engineer that is going to try and drill a tunnel through rock, whether it is solid or already broken into boulders and smaller pieces. The first is to get some idea of the general strength of the rock – designs that work in something like a granite won't work in a very weak shale, for example. Once the rock strength is known, then the amount of cracking, either natural or man induced needs to be found. There is a very simple way of doing this that a group at Urbana/Champaign developed called the Rock Quality Designation (RQD), under Don Deere to simplify how it is measured, you drill a core through the rock layers that you want to drive the tunnel under. You recover the core and measure the core lengths that are more than 4-inches long. That total value, divided as a percentage over the length of core recovered gives you the RQD. Over time (it is now 40-years old) it has been shown to give a very good first estimate as to how badly broken the rock is, and it is used in many design programs to decide how best to hold the roof up.

When working out how to hold the roof of the tunnel up, the engineer knows that he is not trying to hold the weight of all the rock between the tunnel and the surface. The work that most of us used to refer to as the basis for the support of the tunnel was written by Karl Terzaghi. Again, to simplify a relatively complex subject, he came up with a simple method of classifying rocks so that, the designer of the support would know how much rock load from above the tunnel, the supports would have to carry. And very often it was only a small additional amount above the height equaling the width of the tunnel. (The presence and actions of water being the main factor that would make it a lot worse).



Karl was starting the knowledge base that now allows engineers to classify rock and thus design the tunnel supports before the tunnel gets started. It was only a start, however, because back in those days (beginning in 1925) most of the tunnels were supported with large steel arch girders. Because those had to be ordered and delivered before the tunnel was started, getting that size wrong could be very expensive, and there have been many lawsuits as to whose fault that was. (Very awkward, for example, if the tunnel is half-way under a harbor when you discover the steel beams aren't big enough).



Possible heights of overbreak that have to be supported over the tunnel

Since then a new method of support, which works more on helping the rock to support itself, along the lines of the Roman arch bridges, has been shown to often be more effective. Although it has been generally more effective, and more flexible, it has become more popular, but I will write about it, and the change from steel arches to sprayed on concrete (shotcrete) and rock bolts, next time.