Tunnelling Methods – an Overview for the Insurance Market

In the past decade tunnelling claims have been relatively high profile in the Insurance Market giving credence to the definition of a tunnel as "a long hole in the ground with an optimistic engineer at one end and a lawyer at the other".

Following recent introductions such as the Munich Re wording and the Tunnelling Code of Practice it may therefore be of interest to detail the engineering basics of the three different types of tunnelling i.e.:-

(1) Cut and Cover Tunnel – where a trench is excavated, the tunnel constructed in the trench then backfilled over to original ground level.

(2) Immersed Tube Tunnel – similar to a cut and cover tunnel except that the trench is under water (e.g. river estuary/sea) and the precast tunnel elements are floated into position then sunk in the trench and joined together before backfilling.

(3) Bored Tunnel – where a hole is bored through existing ground.

The "cut and cover" method is often preferred for the construction of shallow tunnels. The normal procedure is to excavate the site in open ground and protect the sides by forming embankments or by close/secant piling or sheet piling. If it is important for the site to be reinstated as soon as possible then the "top down" method could be used e.g. by inserting the piles along the line of the outside of the proposed "tunnel walls" then excavating only sufficient ground to construct the "tunnel roof" spanning between the rows of piles. The site (and any services, etc) above the "tunnel roof" may then be reinstated. Commencing at one (or both) end(s) the ground beneath the "tunnel roof" can be excavated at leisure and the tunnel constructed.

The first immersed tube tunnel to be constructed in the UK was the Conwy Tunnel almost 20 years ago and other immersed tube tunnels now exist in Medway and Cork. The method of construction comprises:-

(1) Pre-fabrication (in a casting basin) of the tunnel sections – usually of reinforced concrete but sometimes of steel.
(2) Flooding the casting basin and floating the units out and into position over the pre-dredged trench.
(3) The trench has a prepared bed with foundation pads supporting jack legs.
(4) The units are sunk into position on the jack legs.
(5) They are joined together using eg Gina gaskets.
(6) Sand is injected beneath the units to take their weight.
(7) The jacks are removed.
(8) The settlement rate monitored to ensure uniformity.
(9) Then: backfilling around and over the units
bulkhead removal
ballast infill
ballast tank removal
joint sealing completion – steel plates and rubber gaskets
placing of carriageway and services
painting and finishing

The Gina gaskets mentioned in (5) above, are air filled steel gaskets from which the air is pumped out thus using atmospheric pressure to "compress" the units together to form a water-tight seal. The gaskets curve in and out towards top and bottom and are allegedly named after the actress, Gina Lollobrigida, who was "somewhat admired" by their design engineer who perceived "design similarities" between actress and gasket.

During the construction of the Conwy Tunnel, severe flooding of the River Conwy occurred before the sand injection had been completed beneath the units and the Insurance Market's recollection of this project concerns paying for divers using garden rakes to remove tree branches, drowned sheep, etc, washed under the units during the flood.

The method of construction of the third type of tunnel, the bored tunnel, depends on the nature of the ground and may comprise either rock tunnelling or soft ground tunnelling.

Modern methods of rock tunnelling utilise:-

(1) multi-boom drilling machines
(2) full face and boom cutter excavation machines for all but the hardest rock, or
(3) controlled blasting by milli-second delay detonating.

Where it is necessary to drill and blast, the holes are drilled in the tunnel face to a depth of about 2 metres to insert the charges. The holes are drilled at about 1 metre centres but no charges are placed in the drilled holes at the centre of the tunnel face – these are there just to create a void. The next ring of holes around the centre are drilled at an angle and the charges in them are the first to be detonated so that the rock collapses inwards and away from the tunnel face. The next charges to be denoated are those in the rock surrounding the void created in the centre and likewise they cause that rock to collapse inwards. The next charges to be detonated are those in the next layer of rock surrounding the centre -- and so on!

The spoil is removed by truck and, where necessary, temporary support provided to the sides and roof by timber struts or rock bolts. If required, a permanent lining may be constructed – this could be for (a) cosmetics, (b) frost protection or (c) ground with "time dependent" stability. The lining could comprise insitu concrete (with steel lining if in a high pressure water tunnel for a hydro-electric scheme), pre-cast concrete segments, cast iron or sprayed concrete/shotcrete/gunite.

For the temporary supports mentioned above, rock bolts are now more common than timber struts. There are several types but basically they are just a reinforcement rod surrounded by epoxy mortar. Initially they look like long sausages containing compartments of the epoxy resin and filler and when the rod is "screwed up the sausage" it mixes the resin and filler to form the mortar and hence the bond.

(It is possible to obtain "sausages" containing mortar with different setting times so that the rod can be anchored at its extremity then stressed before the rest of the mortar sets to produce pre-stressed bolts).

The normal length of rock bolts is between 3 metres and 6 metres and their use is very conducive to sprayed concrete linings where a mesh reinforcement is usually inserted before spraying on the concrete. This is the basis of NATM (the New Austrian Tunnelling Method) where a thickness from about 100mm to 300mm is used depending on the ability of the ground to support itself. NATM was originally used in rock ground but is now used in soft ground, providing it is self supporting. It is a subject in itself but basically the design varies depending on the observations made as construction proceeds - there are several standard designs and the one adopted depends on the conditions encountered.

The above rock tunnelling methods are used from hard rock to weak fissured rock but, for projects in decomposed rock, eg the Hong Kong Metro, or "soft" ground, then soft ground tunnelling methods may be necessary. Such methods include:-

(1) excavation by (powered) hand tools.
(2) excavation by hand tools using shields.
(3) excavation by machines with shields.

The method adopted will depend on (a) the ground conditions e.g. type of soil/presence of ground water and (b) the size of the tunnel. (The longer the tunnel the more likely it is to be economical to bring in a tunnel boring machine (TBM). Similarly the larger the diameter of the tunnel the more danger there is of collapse and hence the more advisable it is to use a TBM).

In cohesive soils (soft and hard clays, soft marls and weakly cemented sands) tunnelling is relatively easy as the ground is sufficiently self supporting to enable prefabricated linings to be erected immediately behind the excavation.

In cohesionless soils or subaqueous ground, however, to overcome the poor conditions it will be necessary to:-

(1) Use compressed air.
(2) Stabilise the ground by:-
    (a) freezing (by pumping in either very cold brine solution or liquid nitrogen)
    (b) grouting/chemical injection, or
    (c) de-watering, or
(3) Use a full face machine.

A type of full face TBM now in common use in poor ground conditions is an EPBM (earth pressure balancing machine) – this reduces the risk of collapse of the tunnel face by balancing the extraction rates from the plenum chamber (via a screw conveyer) against the rate of advance controlled by the thrust rams.

Another advance in tunnelling is the use of radar – in the Elbe Tunnel in Hamburg the Employer insisted that a radar device be inserted in the head to detect old bombs, etc, and recent research is producing more sophisticated methods in this field.

Tunnel construction has come a long way since Brunel drove the first tunnel under the Thames (the Rotherhithe Tunnel) between 1825 and 1842 – this was done using a rectangular shield with cells each containing a miner excavating the face. The shield dimensions were 33ft wide and 29ft high with bricklayers following the miners and constructing a brick arch. Tunnelling, however will always be a risky business because no matter how many boreholes are taken there is never any certainty about ground conditions and there will be no surprises if tunnelling claims continue to be relatively high profile in the next decade.

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