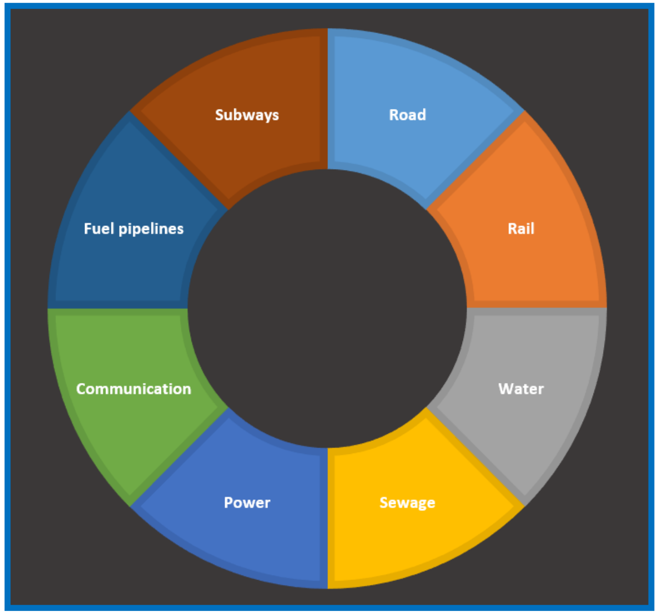
TUNNELLING

By Adam Suttle

Why are tunnels used throughout history?



The Romans created vast networks of underground tunnels (aqueducts) to transport water from underground springs, through hills and mountains to towns and cities.

In the 17th Century, many tunnels were constructed across Britain for canals, the main transport system.

As technology improved and trains developed, there were huge breakthroughs in tunnelling infrastructure. In 1841 the **Thames Tunnel** finished and the **Severn Tunnel** in 1886.

Crossrail Limited is building a new railway for London and the South East. Developing 118 km of new tunnels and connecting 10 new stations., while improving 30 existing ones. The investment is ~ £2.3 billion.

Geological considerations

- Lack of seismic activity
- Rock type(s)
- Attitude of strata
- Geological structures
- Groundwater

Rock type

Tunnelling may occur through competent, incompetent, consolidated or unconsolidated, hard or soft rock.

Hard igneous and metamorphic rocks (**crystalline**) are often **left unsupported** when tunnels are dug through them. Due to their high strength, **drilling and blasting** is often used.

Explosives must be carefully controlled to reduce the risk of **Overbreak** (extracting too much rock) or **Underbreak** (extracting too little rock). The process is also slow and expensive.

Another problem is that hard rocks at depth in tunnels have a **high confining pressure** so can cause **dangerous rock bursts.**

Softer rocks allow for **cheap and fast tunnelling** (up to **30m a day** when using special tunnel boring machines). However, tunnels generally need to be supported with **steel ribs or concrete shells**.

Sandstone, limestone and chalk are fairly strong and make ideal tunnelling materials.

Unconsolidated and incompetent rocks are very **weak** and difficult to tunnel through since they are **prone to collapse** and **sever leakage**. Clay and shale are incompetent and gravels and sands are unconsolidated, all are weak, so are avoided where possible.

Lateral variation makes tunnelling very difficult; the rocks **have differential responses** since they vary in strength, permeability, porosity, rates of compaction and cementation, resistance to weathering Etc…

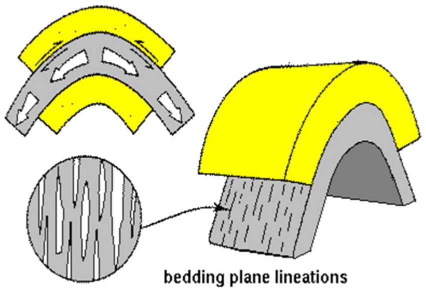
Contacts between different rock types are exploited as zones of weakness and leakage. Porous and permeable rocks allow water to seep into tunnels so there is a **flooding possibility**.

Rocks will slip at bedding planes or allow leakage. Different rock types require different degrees of support. Generally:

Competent—fails by slipping
Incompetent—fails by slumping

Attitude of strata

Horizontal, competent and uniform strata are best for tunnelling. Whereas, dipping beds are prone to **slippage along bedding planes** and may lead to **rock falls** within the tunnel. If the beds do dip then **multiple rock types may be encountered** along the tunnel length.



Geological structures

Faults: present zones of **weakness, movement and permeability.** They can have **fault breccia and gouge clay** along them so are weak. If they intersect the tunnel path they may cause **flooding. Different rock types** may be in contact either side of the fault. In the event on an earthquake, the fault can be **reactivated** and **collapse** the tunnel.

Joints: also zones of **weakness and permeability**. **Loose blocks** of rock can fall as **rock falls from the tunnel roof**. They are often more **closely spaced** than faults so **more problematic**.

#Lineations = linear structural features such as bedding planes, cleavage and foliation.

These are only really in sedimentary and metamorphic rocks, presenting zones of weakness, slippage and movement.

Folded rock sequences make tunnelling difficult due to the **changing angle of dip** and the **probability of slippage or leakage** of water along folded bedding planes. However, if a **gentle syncline** is present then the **tunnel may follow a single competent bed.**

Many of the world's major cities occur on active fault lines and so it has been necessary to dig tunnels in less than ideal places. Tunnels specifically designed to withstand earthquakes are expensive to engineer.

Groundwater

If the tunnel is situated below the water table then flooding may occur.

- Water may be free flowing through the unconsolidated sediments.
- Strong flows may occur along joints in limestone.
- Sandstones can develop high pore fluid pressures. This can cause instability.
- Saturation of clays can lead to mobilisation and failure by slumping.

Ground improvement to prevent collapse and flooding of tunnels

To prevent collapse

⇒ Lining the tunnels with concrete segments or steel ribs

⇒ Use of rock bolts to secure loose blocks

To prevent flooding

⇒ Grouting the surrounding rocks (or shot concreting)

⇒ Rock drains

Tunnels case studies

Marmaray Rail Tunnel, Istanbul, Turkey

Istanbul, Turkey lies at the crossroads of Europe and Asia.

The city is divided by the **Bosporus Straits**. Construction of the railway began in 2006. **The tunnel passes within 16km of on of the world's most active faults**.

In the past 70 years there has been 7 earthquakes of magnitude 7 or higher.

The tunnel therefore has to be designed to be **earthquake proof as an Istanbul earthquake is inevitable**.

1. It will be a **submerged tube sitting in a trench on the seabed.**
2. **It will have flexible joints made of rubber rings, reinforced by steel**.
3. There will be **floodgates at both ends** should the middle of the tunnel flood, both ends will be closed to enclose the water.
4. **Foundation will extend 16m below the seabed and mortar will be injected below that to prevent soil liquefaction**.

Marmaray Rail Tunnel, Istanbul, Turkey –

…is a partially operational rail transportation project in the Turkish city of Istanbul. It comprises an undersea rail tunnel under the Bosphorus strait, and the modernization of existing suburban railway lines along the Sea of Marmara from Halkalı on the European side to Gebze on the Asian side.

Construction started in 2004, with an initial target opening date of April 2009. After multiple delays caused by the discovery of historical and archaeological finds, the first phase of the project opened on 29 October 2013.

The second phase of the project was scheduled to open in 2015, but the work has been stopped and it is unknown when it will be finished

Tunnels case studies

Channel Tunnel

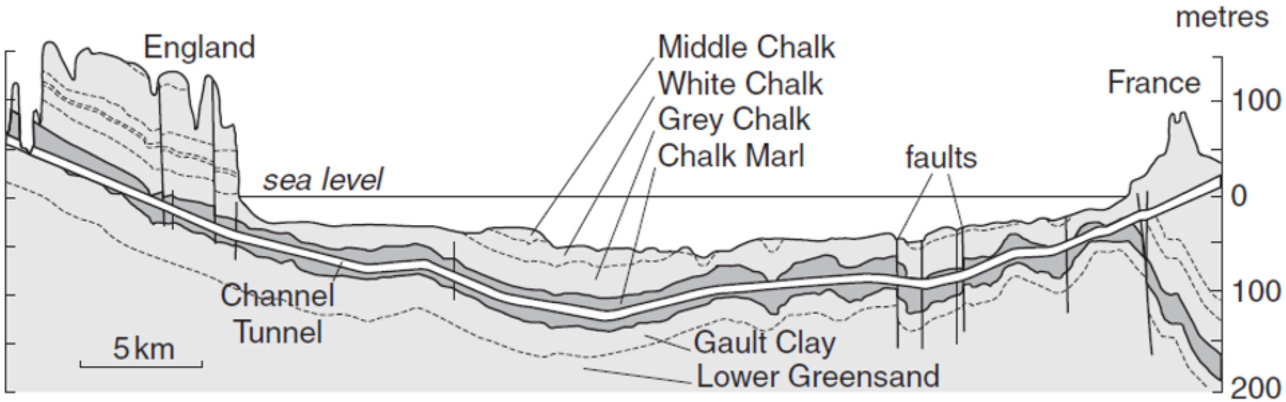
At 50.45 km long it is the second longest rail tunnel in the world. It actually consists of 3 tunnels—two for trains, with a smaller service tunnel for emergency escape.

In 1881, engineers started digging tunnels either side of the channel, but progress was suspended when there were fears of France invading Britain in 1883.

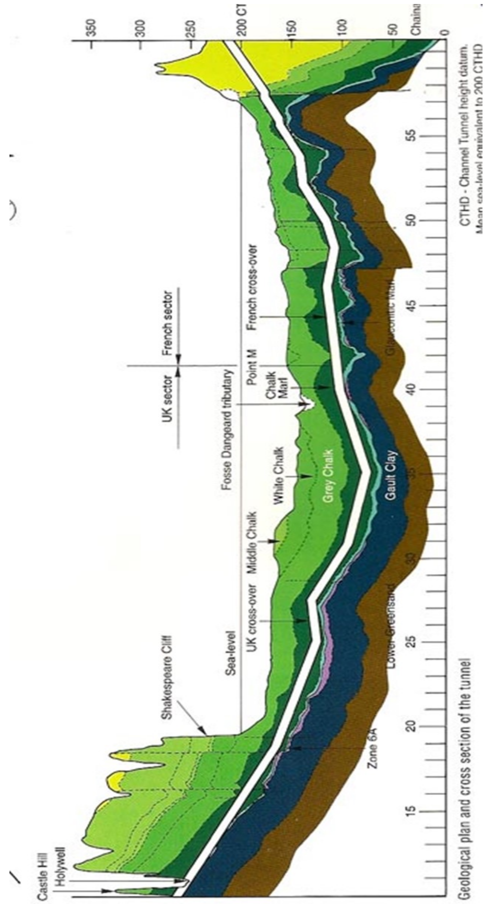
It was not until 100 years later that Geologists undertook surveys on the geology using exploration drilling and boreholes.

The structure was found to be a gentle syncline but by new faults. This allowed for 85% of the tunnel to by dug in the Chalk Marl—a carbonate mudstone. This was considered an ideal tunnelling material. It is soft, strong but with low permeability.

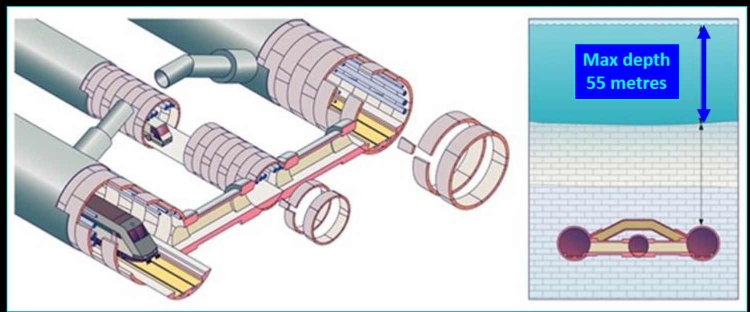
As the tunnel boring machines advanced, each section of the tunnel was grouted before being lined with concrete or cast iron rings depending on the ground conditions.



It



The tunnel development began in 1988 and the tunnel opened in 1994.



Piston relief ducts 250 metres apart link the rail tunnels to manage pressure changes due to movement of trains

The **Chalk Marl layer** is ~ **25m to 30m thick.**

The **average depth below the sea bed is 45m.**

Chalk Marl is a type of **calcareous mudstone** with **30% - 40% clay.** This has **relatively few joints/bedding planes/ faults** and is referred to as **massive.**

It is **impermeable to groundwater** so flood risk is reduced.

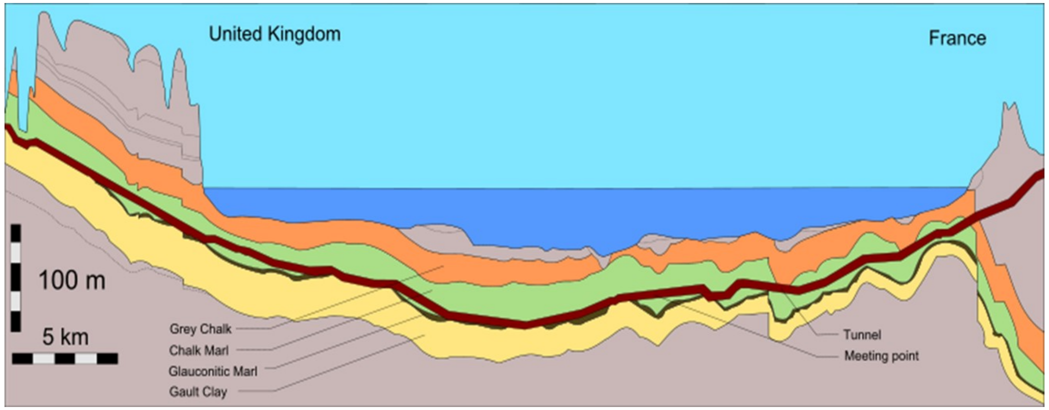
It is **quite soft but mechanically strong so easy to tunnel**.

The advantages of the syncline is that **only one rock type** needs to be encountered and the structure takes the tunnel **deeper under the middle of the sea**.

There are two ways for surveying alogn a transect beneath the sea.

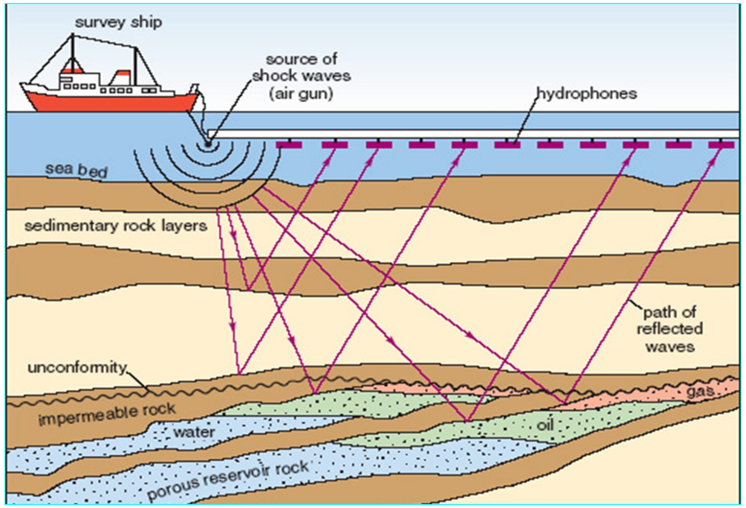
- **Boreholes**
- **Seismic reflection surveys**

Land and sea boreholes: 166 boreholes in the English Channel (130m apart) with 70 boreholes on land (180m apart).



Boreholes allow the **horizontal geology to be linked up** along the Channel Tunnel.

This also enables the detailed **vertical sequence of rock to be established** and the properties of rocks to be **tested from cores**. Boreholes identify problematic areas where rocks are **fractured, faulted or where cave systems occur**.

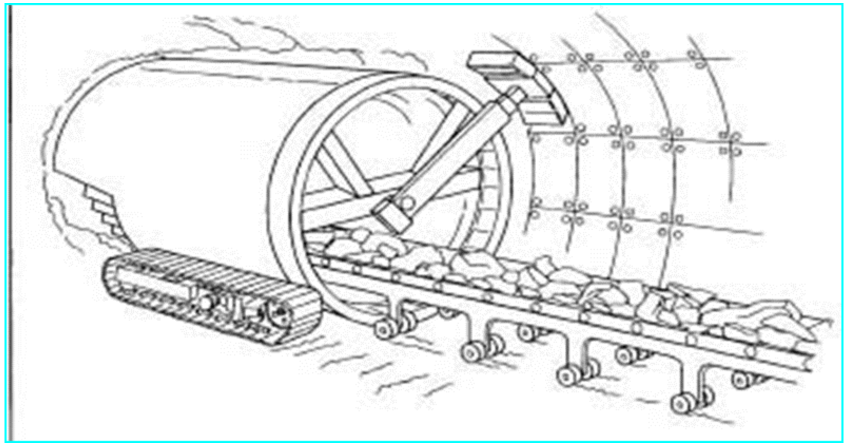


Seismic reflection at sea. Is accomplished by towing a sound source that emits acoustic energy in timed intervals behind a vessel. The transmitted acoustic energy is reflected from boundaries between various layers with different acoustic impendences.

Acoustic impendence is defined as the bulk density of a medium times the velocity of sound within that medium.

An array of hydrophones towed behind the ship can be used to receive the reflected signals. The analogue signal is converted to digital and interpreted by high speed computers into a map.

How was the channel tunnel reinforced?



Reinforced concrete segments were bolted together to form a ring structure. The concrete ring was grouted using shotcrete to ensure it is water tight.