Excavation Methods

Selection of a tunnelling system (i.e. tunnelling method with/without additional measures, e.g. ground conditioning) involves choosing a method that is suitable for and compatible with the given ground and project constraints.

Consideration is generally given to:
- the ground conditions and its variability;
- the geometry, diameter and length of the tunnel;
- the tolerance of nearby structures to ground movement;
- the consequences of ground losses;
- the tunnelling cost;
- the safety of tunnel workers.
Cut & Cover

For shallow tunnels, cut & cover provides one of the most cost effective means of tunnelling (in terms of direct construction costs and operating economics, although incidental costs can change the balance completely).

Construction typically involves excavating a trench and placing pre-cast concrete tunnel segments in the trench. The trench is then backfilled and the road restored.

Bracing & Shoring

Shoring: involves any method used to prevent the collapse of ground surrounding an excavation, built top-down as excavation proceeds.
Richmond-Airport-Vancouver Rapid Transit

Approximately 75% of the Vancouver segment of the Canada Line will be built by "cut and cover" method.

Cut and cover is generally quicker than tunnel boring and more predictable in terms of scheduling.

Plans are to vertically stack the two operating tunnels along Cambie St. in order to narrow the footprint of the cut & cover construction site and to help minimize disruption to traffic.
It is believed that most of the cut & cover tunnel will be excavated in tills with boulders, and in places, some marine sandstones, siltstones and mudstones. However, near Queen Elizabeth park, the tunnel will encounter basalts, which will require blasting.
Tunnel Excavation in Soft Ground Conditions

Tunnelling in soft, water saturated ground began with Marc Brunel in the early 19th century, when he invented the principle of shield tunnelling and undertook a contract to tunnel under the Thames.

His shield consisted of 12 independent cells with three floors in each cell, in which workers hand excavated the ground behind a secure wall of ‘poling boards’. One board would be removed to provide access for digging, after which it would be replaced and pushed forward by hydraulic jacks to re-engage the face support.

Brunel’s shield was 22’3” high and 37’6” wide, and enabled 36 miners to work the tunnel face at one time. The brickwork built right behind the ‘shield’ served as an abutment for the whole frame. On average, progress was 8’-14’/week.

Harding (1981)

Tunnel Excavation in Soft Ground Conditions

Started in 1825, flooding was a constant problem for Brunel in tunnelling under the Thames. In one such flood 6 men drowned. Brunel’s complaint to those offering advice on tunnelling in such difficult conditions, “In every case they make the ground to suit the plan and not the plan to suit the ground”.

Completed in 1843, Brunel’s tunnel is still in full use as part of London’s Underground railway system, exactly as built!

James Greathead’s tunnel under the Thames (the 1869 Towers Subway) was built using a 7’1½” (?) diameter circular shield propelled by screw jacks, that employed the first use of cast iron segments for the lining. Greathead’s circular shield became the model for later open-face shields.
**Shield Tunnelling**

Advantages of shield tunnelling in soft ground:

1. Tunnel construction can be performed as one step at its full dimensions.
2. Constant support is provided to the advancing tunnel even though it takes the form of a moving system.
3. Omission of temporary support is compensated for by virtue of the immediate installation of the permanent lining.

Open- & Closed-Face Shields - When the tunnel face is free standing and does not require continuous support, the shield is operated in 'Open Mode'. The face is mechanically supported by the cuttinghead while the flood control doors regulate muck flow from the face to the cuttinghead chamber. The excavated muck is rapidly extracted by the conveyor. With a closed-face, an airlock and bulkhead are used to allow the "excavation chamber" to be pressurized with compressed air or a slurry to aid face support.
Shield Tunnelling - Compressed Air

James Greathead solved the problem of containing groundwater during the construction of subaqueous tunnels in loose soil, by combining shield tunnelling with the use of compressed air during his 1886 construction of the London Underground. This led to a considerable increase in the number of shield driven tunnels worldwide. At the beginning of the 20th century, the majority of the tunnels were built with Greathead shields.

Factors to account for when tunnelling with compressed air:

- Air pressure must be kept in balance with the hydrostatic pressure;
- Maximum pressure cannot exceed 4 bar (or 400 kPa), i.e. 3 bar excess pressure;
- Earth pressure cannot be resisted directly, it has to be withstood by natural or mechanical support;
- Ability to maintain pressure may be compromised by the air permeability of the ground (i.e. leakage);
- Cover above the tunnel must be 1-2 tunnel diameters (depending on ground type) to avoid blowouts;
- Shorter working hours result from loss of time during compression and decompression;
- Reduced performance of miners (danger of caisson’s disease);
- Increased danger of fire (due to increased oxygen content).

Maidl et al. (1996)
Slurry Shields

Due to problems regarding health and safety as well as operational aspects (in highly permeable ground, maintaining air pressure at the tunnel face is difficult), compressed air shields are being used less and less. Instead, slurry shields and earth-pressure balance shields are being favoured more.

Slurry shield operating principle:
- Tunnel face is supported by bentonite slurry (i.e. tunnel is free from compressed air);
- The slurry is mixed and pumped into a closed excavation chamber;
- The slurry enters the ground, sealing it (filter cake) and enabling pressure to be built up and balanced with the earth and water pressure.

As the ground is excavated, it is mixed with the slurry in the excavation chamber. The ground/suspension mixture is then pumped to the surface. In a separation plant, the slurry is separated from the ground. New bentonite is added as required, and the fluid is pumped back to the tunnel face.

Overall, slurry shields provide a safe tunnelling method causing low settlements. Application is possible in all kinds of loose ground with/without groundwater. Disadvantages include the separation plant (cost, space, energy requirements) and environmental hazards related to tailings (non-separable bentonite slurry containing fines).
Earth Pressure Balance Shields

With a growing percentage of fines, slurry shield tunnelling requires an increasing degree of sophistication and cost for separation (and increasing frequency of slurry renewal). Apart from the high costs and environmental hazards involved, the confined space in most major cities makes the installation of a separation plant on surface difficult. Such were the conditions encountered in the early 70's in Japan, which led to the development of Earth Pressure Balance shields (EPB).

EPB Shields: provide continuous support to the face by balancing earth pressure against machine thrust. As the cutterhead rotates and the shield advances, the excavated earth is mixed with foams in the cutterhead chamber to control its viscosity. The pressure is then adjusted by means of the rate of its extraction (by screw conveyor).

The key advantages of EPB Shields are that no separation plant is required and that the method is economically favourable in ground with a high percentage of silt/clay.

When using EPB tunnelling mode, no bentonite and special treatment plants are necessary and the outcoming soil is nearly natural. If additives like Foam or Polymers are used, highly biodegradable versions exist which can be 95% destroyed after 28 days.
An Earth Pressure Balanced system will be used for the RAV. The TBM will be launched from 2nd Ave., advance under False Creek, along Davie and Granville St. A TBM exit shaft will be constructed on Granville south of Dunsmuir to extract the TBM. The TBM will then be brought back to 2nd Ave. to be launched again to construct the second bored tunnel.
The TBM will then move northwards excavating the 1st tunnel.

The TBM will then excavate under False Creek.
Once the TBM reaches the end, it will be lifted out on an exit shaft, transported back to the entry shaft, so that it can excavate the 2nd parallel tunnel.
Open shields are favoured where the ground is free standing.

Closed shields are favoured where the ground is very weak, such as soft clay, silt or running sand.

Slurry shields are favoured for water saturated sandy soils and gravels (<10% clay and silt content; e.g. running sand).

EPB shields are favoured for water saturated silty soils (>7% clay and silt content; <70% gravel content).
Tunnel Excavation in Soft Ground Conditions

### Special Cases - Immersed/Floating Tunnels

Immersed tunnels can be constructed in otherwise difficult/expensive conditions (e.g., soft alluvial deposits characteristic of large river estuaries). They can also be designed to deal with the forces and movements in earthquake conditions.

Submerged floating tunnels allow for construction in extremely deep water, where alternatives are technically difficult or prohibitively expensive. Likely applications include fjords, deep, narrow sea channels, and deep lakes.
Lecture References


