News of the breakthrough on the new Gotthard tunnel had been announced on this day.

Mr Brown said tunnels are built to overcome restrictions of Nature. Constructing them goes back thousands of years - it can be dark, dusty and dangerous with little health & safety. Most early tunnels were for irrigation, others for mining metals; and there are ancient catacombs. The Greeks and Romans left records. An interesting entry in De Re Metallica of 1576 shows a water wheel driven fan for tunnel ventilation, developed in Germany. In 1650 the French were the first, in the Malpas Tunnel, to use explosives – drill & blast; a method still in use where the rock is not suitable for a tunnel boring machine (TBM). Canals needed tunnels that were level, then railways at a defined gradient (by 1900 over half of railway tunnels were longer than 1.5km). The Swiss built the first Gotthard tunnel with the railway spiralling up the side of the mountain, looping into it to emerge higher for another loop and so on, up to the 15km tunnel proper. Mr Brown showed a picture of a deep cut & cover tunnel for the Colorado aqueduct – saying that a TBM would be used today.

The first recorded tunnel under a river was in 2160 BC, under the Euphrates. The second was the Rotherhithe Tunnel, begun by Richard Trevithick in 1807, but abandoned due to extensive flooding. Marc Brunel revived the project in 1824; having developed a crude shield in 1818. This held the surrounding rock of a newly dug section while a man dug out the tunnel face; then the shield would be jacked forward (from the brick lining of the previous section of tunnel) and the newly exposed rock would be lined. The shield actually comprised cells, each with a tunneller, to spread the work across the tunnel face. Even with this the works flooded twice more and were not completed until 1846, Marc’s son Isambard then being Chief Engineer. No one would normally build a tunnel so close to the river bed as the Rotherhithe Tunnel, an extremely risky project in any era. Mr Brown also mentioned the 1909 tubes under the Hudson built for the New York Subway.

The London Underground was promoted by Charles Pearson (1793-1862), the first line being Paddington to Fenchurch Street in 1863. This was built by cut & cover, along roads, causing much inconvenience. London has clay down to 450ft, easily bored, and deep tubes were adopted. These were lined with cast iron segments, and grouted behind. Modern tunnels have concrete segments, at one third the cost. At Piccadilly where several lines cross there are tunnels from 45 to 105 feet down. Subsidence can be a problem, tunnels bedding down over 10 to 20 years, causing buildings above to move; the Big Ben tower was affected by the Jubilee Line and is now 2.5 cm off vertical.

The pumped water storage scheme at Dinorwic is an impressive example of rock tunnelling in the UK, with its tunnels that handle large volumes of water to and from the vast underground turbine hall, and the associated transformer hall. It is capable of 300 MW output, and is used for peak-lopping on the national grid.

Ideas for a Channel tunnel go back 2500 years. The Channel Tunnel was built from 1986 and opened in 1994. Mr Brown was closely involved as its Chief Engineer. He had been approached to run the British works, but found himself in charge of the French too, when their man lost his job. The Tunnel has three bores, a small service tunnel, with a pair of running tunnels either side. Despite a wealth of existing borehole and seismic records of the Channel seabed, ten more boreholes were made along the proposed route – taking advantage of a rig that was free at the time (one reason being a possibility of unexploded bombs). Most of the tunnelling was through chalk marl, quite soft and easily bored, for which an ‘open’ type of TBM was used; however on the French side there was fissured rock and a ‘closed’ TBM was necessary. To prevent water from the fissured rock from entering the tunnel a closed TBM has a bulkhead behind the cutter head – through which spoil is removed and tunnel lining segments & grout are taken in – a slow process. Mr Brown showed a picture of many different cutter heads, each optimised to hit different types of rock at the correct angle and speed. The cutters are carbide tipped steel discs, usually mounted in pairs on an axle, many of these mounted across the cutter head. The first UK works were on the Kent coast at Shakespeare Cliff, where the largest sheet piled coffer dam in the world was put in to take the spoil from the tunnels; then, as it was filled, to act as a way station for tunnelling supplies; after completion it became a nature reserve. A shaft from the top of the cliff was dug down to
tunnel level, and the tunnels bored from there: to Folkestone; and to France, 28 miles away. The pilot tunnel was bored first. After a while it was realised that neither the British nor French knew precisely where they were - a laser beam is subject to refraction like all light... Mr Brown called in a German firm to help. As the bores got close they put a drill on the front of a TBM, as a probe, eventually breaking through 0.7m off centre. Two crossovers, ⅓ and ⅔ through the Tunnel were built in large caverns from the pilot tunnel using roadheaders – tracked vehicles with a boom mounted cutter. The running tunnels were then bored and lined by large TBMs (400 ft long, weighing 200 tons). The pilot tunnel is now the Service tunnel, also used for ventilation. (Normally a train will pass straight through a crossover, separated from the other track by a longitudinal steel gate, but if necessary it can be diverted to the other line.) Equipment in the tunnel was specially shaped to reduce drag.

Mr Brown was invited to advise in the design of the new Gotthard tunnel. The Swiss have many railway tunnels, with a hundred year history of safe running, none of them have a service tunnel and, not wanting to retrofit their older tunnels, did not plan one here. It is a twin bore tunnel 57km long, with two stations (deep underground) at ⅓ and ⅔ points, where, if necessary, passengers could transfer to a train on the other line. Shafts down to these stations enable boring from them as well as from the ends. The tunnel is to open to traffic in 2017.

Another tunnel, said to be the best engineered of 20C, is a Japanese Shinkansen line linking one of the islands. In 1954 after five ferries were lost in a typhoon a tunnel was planned. Adits were dug in 1964; tunnelling begun in 1971 by drill and blast, as the rock was unstable; and completion, after being flooded four times, in 1986. The tunnel did not pay, and is now freight only. Another Japanese tunnel is the Tokyo Aqua, across the bay; bridge-tunnel-bridge with artificial islands (fitted out as attractions in their own right). The tunnel was bored by fully automated TBMs, 14m in diameter.

The Big Dig in Boston was centred on a 14 lane road tunnel to relieve the pressure of highways all heading into the centre of the city, and provide a connection to the Logan airport – without undermining buildings or too much disruption.