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Long Undersea Tunnels: Recognizing and Overcoming the Logistics of Operation and Construction

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ABSTRACT

Long undersea tunnels, and particularly those that are built for transportation purposes, are not commonplace infrastructure. Although their planning and construction take a considerable amount of time, they form important fixed links once in operation. The fact that these tunnels are located under the sea generally involves unique challenges including complex issues with construction and operations, which relate to the lack of intermediate access points along the final route of the tunnel. Similar issues are associated with long under-land tunnels, such as those under mountain ranges such as the Alps. This paper identifies the key issues related to the design and construction of such tunnels, and suggests a potential solution using proven technology from another engineering discipline.

1. Background to the issues

Compared with their under-land counterparts, the construction and operations of undersea tunnels that are used for transportation purposes have their own unique challenges and constraints—particularly for the longer tunnels. The Channel Tunnel between the UK and France is the longest undersea crossing in the world and provides a link between the high-speed rail network in the UK and that of France and the mainland of Europe. The overall tunnel is approximately 50 km in length, with the undersea portion being 38 km long. In Japan, the Seikan Tunnel has a total length of 53.8 km, with the undersea portion being 23.3 km. The layout of the overall Channel Tunnel is shown in Fig. 1.

For the trans-alpine tunnels that have been built or are under construction, the fact that the tunnel is located under a mountainous region similarly limits of the positioning intermediate access points, such as shafts and adits, along the length of the route. The Gotthard Base Tunnel of the AlpTransit project between Italy and Switzerland has a total length of 57 km.

Other long transportation tunnels are being considered around the world, both undersea and under land, including the Fehmarn Belt Tunnel between Germany and Denmark (18 km undersea), the Lyon–Turin Tunnel between France and Italy (57 km under land), Jeju Undersea Tunnel in Korea (79 km undersea), Bohai Strait Tunnel in China (up to 110 km undersea) and, potentially, Taiwan Strait Tunnel in China (150 km undersea).

As described in the following sections, it would be advantageous for these fixed links to have intermediate access points along the length of the tunnel for both construction and operational purposes. Such access points would facilitate multiple facets of the construction of the tunnel, and would provide emergency egress points for the evacuation of passengers in the event of an incident. However, such facilities would be difficult to provide for an undersea tunnel, unless it were to pass below a series of islands, whether natural or man-made, which is unlikely to be the case in deep-sea conditions.

2. Construction logistics

When considering the longest tunnels mentioned above as examples—that is, the Channel Tunnel, Seikan Tunnel, and Gotthard Base Tunnel—it is recognized that all three projects were built using multiple tunnel drives. Although the overall length of the Channel Tunnel is approximately 50 km in length, the longest tunnel drive was 22 km. This was the drive that extended from the UK shoreline to connect with the French tunnel boring machine (TBM) drives at a meeting point under the English Channel. The shorter drives extended from the shorelines back to the portals at each terminal.

For the Gotthard Base Tunnel, a number of adits and shafts were formed along the length of the route in order to subdivide

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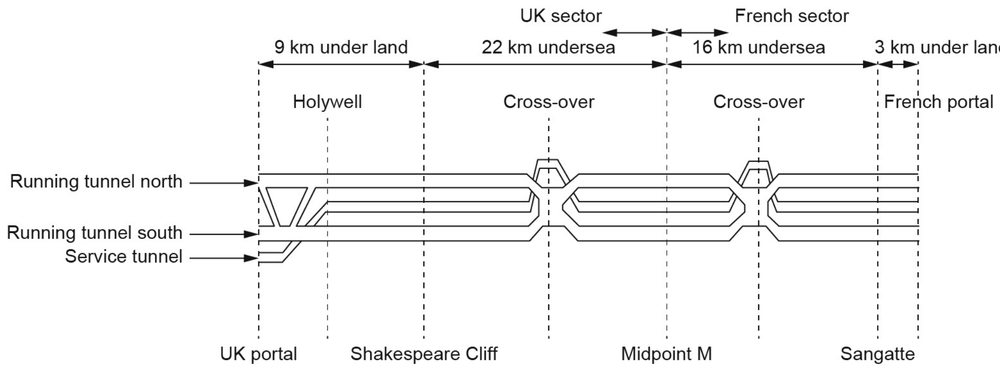

Fig. 1. Layout of the Channel Tunnel between the UK and France.

the overall tunnel into a number of sections and facilitate multiple drives. The schematic layout of the Gotthard Base Tunnel is shown in Fig. 2. Indeed, the deepest of these adits was 800 m, which is a substantially deep excavation; however, this meant that the longest tunnel drive was 14 km in length. It is therefore clear that the constructors of these schemes considered that the provision of intermediate construction points along the length of the tunnel would be beneficial to both cost and program.

2.1. Tunnel ventilation

Whether a tunnel is excavated by drill and blast or by TBM, there will be a need to ventilate the tunnel face with fresh air throughout the construction phase. This ventilation is provided by ducting, which generally runs along the soffit of the constructed tunnel. For longer tunnels, chillers may be needed at points along the length of the ducting to ensure cool air at the tunnel face for the health of the workforce. Although delivered at the tunnel face, the ventilation actually provides clean air for the entire length of the excavated tunnel. Clearly, the longer the tunnel drive is, the more air must be delivered, and the greater the size of the duct will be. For an extremely long tunnel, it is possible that the construction requirements—that is, the size of the duct and cooling equipment—could actually determine the diameter of the constructed tunnel. This would not be a cost-effective solution. It is therefore beneficial to divide the overall tunnel into a number of shorter sections.

2.2. Flexibility with converging drives

The use of multiple staging areas for construction, and tunnels driven in both directions from these locations, means that a certain amount of flexibility and assurance is provided for the construction logistics. If one TBM were to experience a breakdown, then the machine coming in the opposite direction could complete the overall tunnel. This would not be possible with a single heading, which relies on a single TBM completing the full length of tunneling. Again, multiple drives are advantageous in ensuring completion of the work within a reasonable timescale.

2.3. Access to the tunnel face

Access to the tunnel face for both the delivery of materials and the workforce is generally provided by locomotives that run along the completed tunnel. For the safety of the workers within the tunnel, the speed of these delivery trains is around 20–25 $km \cdot h^{-1}$. Considering that the longest drive of the Channel Tunnel was 22 km, it is clear that as the TBM neared the end of its drive, the TBM crew would spend an hour at the start of each shift (and a similar time at the end) just traveling to their workplace. Longer drives would take even more time. Labor costs could be a major issue for very long tunnels, if 20% of the working day is spent traveling to and from the tunnel face. Thus, the logic of dividing the tunnel into reasonable lengths, as demonstrated in the Gotthard Base Tunnel, can be seen as benefiting the overall cost.

3. Operational issues

Among the issues that need to be considered for the operational logistics of the completed tunnel are: air quality/ventilation, aerodynamics (particularly for a railway tunnel), temperature, drainage, and fire and life safety. In addressing these items, reference is given to the Channel Tunnel between the UK and France, including the studies that were conducted during the design of that project.

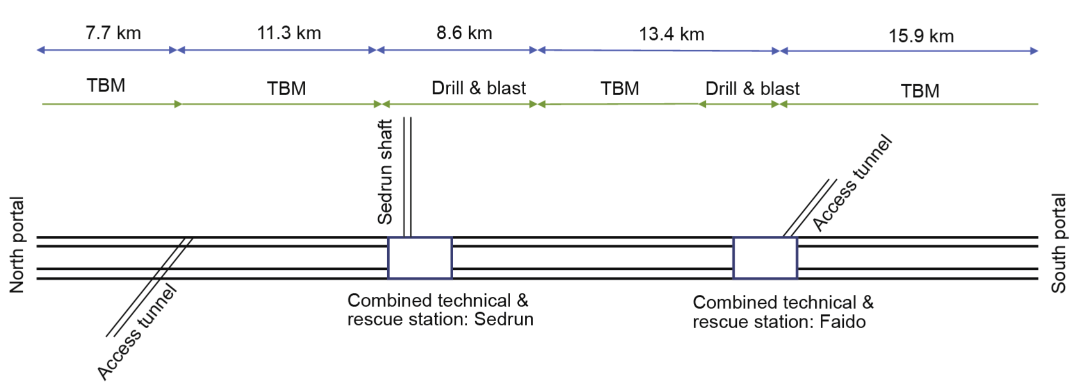

Fig. 2. The Gotthard Base Tunnel, between Italy and Switzerland.