Review of Construction Technology of Typical Immersed Tube Engineering

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Abstract. This paper introduces the development status of sea-cross passage, the classification and construction technology of immersed tunnel. Taking the Femern tunnel as an example, its construction process is analysed in detail and it is compared with the HK-Zhuhai-Macao Bridge. The results show that the construction technology and engineering equipment of immersed tunnel in China have reached the world leading level.

1. Background
With the rapid development of modern society, the sea-cross passage has been put forward under higher new requirements. The traditional marine transport has been unable to meet the requirements of economic development. With the development of science and technology, the sea bottom has been the new highlight. In order to break through the restrictions of the straits, bays and islands on the traffic, the construction of the sea-cross passage has been a new topic for human society. Unprecedented new modes of traffic, such as sea-cross bridges, undersea tunnels and undersea pipelines have gradually emerged in front of the world. Up to now, more than 100 sea-cross passages have been built under construction and to be built all over the world\textsuperscript{1-4}.

2. Classification of sea-crossing passage
At present, the most common cross sea engineer in the world includes the railway ferry, the cross sea bridge and the combination of subsea tunnel and bridge tunnel.

Railway ferry is a kind of cross sea channel which connects railway and ferry through port, wharf and dock to realize the combined water-land transportation. There are a lot of projects and the technology is very mature. Compared with the subsea tunnel and the sea crossing bridge, the railway ferry is obviously much easier.

The sea-crossing bridge is a kind of project which uses modern bridge construction technology to connect the straits, bays, islands, etc. The advantages of the sea-cross bridge are of strong passing capacity, convenience and rapidity, flexible transportation mode, high ornamental value and low operating cost. Compared with the tunnel, the bridge construction technology is mature and the construction period is short. The disadvantages are that the sea crossing bridge is easy to be affected
by strong wind, fog or bad weather. The construction of long-span, high pier and deep-water bridge is difficult; the requirements for structure and strength, wind resistance and earthquake resistance are high.

The advantages of the subsea tunnel are that it can be operated all day without being affected by severe weather such as typhoon, rainstorm and fog. During the operation period, there is no impact on the shipping on the sea. The disadvantages are that the engineering technology is very difficult involved with geological survey, line selection, long-distance ventilation, anti-seepage and disaster prevention. Also the construction period is long and the cost is huge.

Aiming at the merits and demerits of the bridge and tunnel, the combination of the tunnel and the bridge is a new sea-cross passage mode for long-distance, complex engineering geological and hydrological conditions. This kind of combined structure not only solves the technical problems such as long tunnel, construction and operation, ventilation, anti-seepage and disaster prevention but also solves the disadvantages of sea-crossing bridge, such as hindering navigation, affecting ecological environment, etc.

3. Construction technology of Femern tunnel

3.1. Basic parameters
The Femern immersed tunnel project is part of the pan European railway project, connecting Germany and Denmark, as shown in Figure 1. The length of the whole tunnel is 18.1km, of which the total length of the immersed pipe section is 17.6km. The length of the tunnel tube is 217m, the width is 42.2m and the height is 8.9m with 40m buried depth. The single tube is as heavy as 73500 tons. The whole immersed tunnel consists of 79 standard tubes and 10 special tubes. There are 2 vehicle lanes and 2 rail transit lanes for the standard sections. Individual channels are set between the lanes for ventilation and pipeline placement, as well as for escape. The special tube, which is larger than the standard tube is placed between the standard sections at every 1780m interval. A space is added on one side of the tube to park the tunnel maintenance equipment and vehicles. The staff can also shuttle in the lower space for emergency refuge (as shown in Figure 2). The whole project is expected to consume 3.2 million tons of concrete and 360000 tons of steel bars. The total investment is about 54.79 billion yuan, and the construction period is 8.5 years. After completion, the train time is 7 minutes, and the car time is 10 minutes [5].

![Figure 1 Current landforms](image-url)
3.2. Prefabrication yard construction
The construction of the immersed tube prefabrication yard starts in the town of Rodbyhaven, which is located on the east side of the existing ferry terminal. The factory covers an area of 1.5 million square meters, equivalent to 200 football fields, and will become the largest prefabrication field in Denmark. The construction company adopts different methods to transport materials required for construction. In the prefabrication of concrete tubes, the largest amount is sand and aggregate, which are transported by conveyor belt. The second is cement. The construction company uses pneumatic pipeline to transport the cement to the silo. Steel bars are transported by ship.

The tube production area is divided into three areas. The left side is the reinforcement installation area, the middle is the pouring and maintenance area, and the right side is the dry dock. Tube pouring is the core process in the production process, and the construction pace of all processes is adjusted and kept consistent with the tube pouring.

The main production area of the reinforcement cage is divided into three parts: the binding area of the bottom plate, the binding area of the wall and the binding area of the top plate. The three areas are connected by a retractable sliding track. After part of the reinforcement cage is completed, it is lifted by the lifting platform and slides along the track to the next area.

The whole tube is poured as a whole. The concrete consumption per hour reaches 100 cubic meters. In the tube maintenance area, the connection between the tubes can be started and further completed in the dry dock.

3.3. Construction procedure

3.3.1. Construction of operation port. Construction of working wharves on both sides of the Femern island and the Lolland island for the transport of large quantities of construction materials for the construction of tunnels. Due to the prefabrication of tube in Lolland Island, the wharf on this side is larger which is expected to hold 6 ships' loading capacity per month. It is also used as the transportation wharf for the cast-in-place tube.

3.3.2. Dredge construction. The tunnel trench is about 17.6km long, 90m wide and 16m deep. When the depth is more than 25m, grab dredger will be used for dredging. For hard moraine layer, it is necessary to loosen the soil layer with the pullbox dredger firstly, and then cooperate with the grab for dredging. The whole dredging process is expected to take 1.5 years, and a total of 19000000 m³ of sediment will be excavated. More than 3k m² of land will be reclaimed on the southern coast of Lolland island, so as to reduce the damage to the surrounding environment caused by the transfer and stacking of muck.

3.3.3. Floating of the tunnel tube. The transportation of tube out of the dry dock is divided into several steps. Firstly the dry dock is filled with water. Special tubes are transported by truss pontoon and
standard tubes are transported by two pontoons. After the tube reaches the designated position, the pontoon is anchored on the previous tube.

3.3.4. **Installation of tunnel tube.** Use GPS, echo detection, ballast water tank, winch, cable to control the position of the tube. During sinking, the floating vessel is used for positioning and its position is controlled by the mooring cable connected to the seabed anchor. The ballast water tank is filled with water to control the tube sink gradually. In the process, the floating ship and the immersed tube are still connected by many cables. The winch cable is gradually loosen and the water is injected into the water tank to ensure that the sinking process of the immersed tube is controlled.

3.3.5. **Join of submerged tube.** After the immersed tube is installed to the foundation bed and arranged in a row, the hydraulic arm on the installed tube is used to drag the new installed tube to make it closely connected with the installed tube. The hydraulic arm is equipped with a hook, which is connected with the fixed bracket of the newly installed pipe. In order to ensure the tight connection of pipe, it is necessary to install a specially designed rectangular rubber waterproof at the butt end of pipe during the prefabrication of pipe. The hydraulic arm drags the newly installed pipe until the tip of the rubber waterproof touches the end of the installed pipe and then a seal chamber is formed between the two pipes end seal doors.

4. **Inspiration of construction of sea-cross passage in China**
According to the investigation material, some inspiration of construction can be obtained as follows:

(1) Strengthen the preliminary investigation, research and design of the project. Construction of tunnel tube involves many disciplines and fields and its research, demonstration, construction and operation often involve many departments and regions. Therefore, it is necessary to establish a special investigation and research institution to carry out the preliminary investigation and research of the project in an all-round way. Key technologies are developed and evaluated to provide reference for national decision and project planning and construction.

(2) Technical confidence is necessary. After the construction of the sea-cross passage of HK-Zhuhai-Macao Bridge, construction enterprises and engineering technicians in China have accumulated fruitful sea-cross channel construction technology and formed a core equipment group represented by floating-installation ships and levelling ships. Taking the ShenZhong Link and Dalian bay subsea tunnel project under construction as examples, the construction difficulty of the project is no less than that of the same type of project that has been completed abroad. It is believed that in the near future, Chinese construction enterprises will be able to apply the immersed tube construction technology and equipment to the overseas cross-sea channel construction.

**References**

[1] Guo X.Y. (2007) Comments on some engineering and technology issues related to building sub-sea tunnels in China. Tunnel Construction, 27(3):1-5.

[2] Chen B.C., Liu Z. (2000) Development of underwater tunnel engineering in the world and the visualization of Taiwang Strait Tunnel[J]. Journal of Fuzhou University, 28(4): 51-55.

[3] Liu X.H., Liu L.Z. and Hou X.M. (2006) Retrospect and prospect of the development of cross sea channel at home and abroad. Science and Technology Review, 24(11): 78-89.

[4] Tang H.C. (2004) World famous Strait traffic engineering. Chinese Railway Press, Beijing.

[5] Femern A/S. (2015). The tunnel across Fehmarnbelt. https://femern.com/en.