Created in China

Seabed Wonder

Xiamen Xiang'an Tunnel

Xu Jingming

China Intercontinental Press

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Foreword

Xiamen Xiang'an Tunnel is the first undersea tunnel from the Chinese mainland. It has the largest cross-section among all the existing undersea highway tunnels that have used the drilling and blasting method around the world. The investigation, design and construction have all been independently completed by China, which is a milestone in Chinese tunnel construction history.

Tunnel construction is a difficult, high-risk, and cutting-edge technology which represents the complex integration of different fields related to tunnel construction technology, as well as showing the comprehensive national strength. At present, 40 undersea tunnels which have used the drilling and blasting method have been built. They are mainly found in European countries, Japan and a few other developed countries. Although China is good at using the drilling and blasting method in mountain tunnel construction, this experience cannot help to completely solve the series of technical problems arising in undersea tunnel design, construction and operation. Before Xiamen Xiang'an Tunnel, there was no precedent domestic undersea tunnel project meaning that there was no workable technology model.

Xiamen Xiang'an Tunnel is constructed in a complex construction environment and poor geological conditions: the terrestrial completely and strongly weathered soft strata, the shallow water-rich sand stratum, and the undersea weathered slots (pockets of weathered rocks). The section with poor geological conditions accounts for about 54% of the total length and the overburden stratum is thin. It has to cross the Chinese White Dolphin National Sanctuary. The mixture of unfavorable geology, the scale of the project, the risks involved and the complex construction conditions have not been seen before for tunnels around the world which have chosen to use the drilling and blasting method. It also has problems that have to be overcome using world-class technology and extra construction risks.

The total length of Xiamen Xiang'an Tunnel is 8.695 km, with 6.05 km under the sea, and the deepest point of the tunnel is 7 m from the sea level. The construction of Xiamen Xiang'an Tunnel officially started on September 6, 2005, and the tunnel was finally opened at 10 o'clock on April 26, 2010, totaling 4 years and 8 months of construction. The excavated earth and stone alone added up to about 2.35 million cubic meters, which could almost fill up one of Egyptian pyramids. 55,000 tons of steel was used, which equals the amount of steel required to construct seven Eiffel Towers. 2,500 tons of explosives and 870,000 cubic meters of concrete were also used. High-performance, corrosion-resistant, domestically-developed concrete, which lasts over 100 years was used in the construction, and was strengthened to withstand an earthquake which reaches level 8 on the Richter scale. The construction process succeeded in achieving a global standard, and it was one of the three national model projects.

This is one of this century's grand projects. After the completion of Xiang'an Tunnel, the driving time from Xiamen to Xiang'an is shortened from 90 minutes to 8 minutes. It greatly improves the quality and speed of the integration strategy for urban and rural development inside and outside of Xiamen Island. It is included in the national strategy for the construction of the Western Taiwan Straits Economic Zone. It has great and far-reaching significance and will reap significant social and economic benefits.

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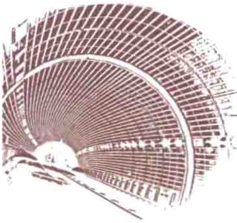
Xiang'an Tunnel Construction Background and Decision-making Process



Realization of Human History through the Seabed

Undersea tunnels were products of the times. Oceans divided the land into a number of areas which had different geological conditions, and so barriers to travel existed. Today, with advances in technology and the deepened ties among people's lives and the economies, the construction of tunnels to connect continents has become important for enhancing economic opportunities.

Meanwhile, as the speed of urban development has gradually accelerated, the conflict between the demand for more space in which traffic can operate and land resources has increasingly deepened. While underground transportation methods, such as the subway, have been built, the tunnel has entered the mainstream in the development and utilization of underground space. Those in the field of engineering believe that in the 19th and 20th century there was an era for building long, large bridges and high-rise buildings, but that the 21st century will be an era for building long tunnels and for engineering the development of underground space.

The undersea tunnel development idea can be traced back to the Eurotunnel which was proposed in 1751. However, limited by the technical and financial difficulties, this great idea did not become a reality until 1994. In the 1940s, Japan built the world's first cross-strait tunnel (the construction started in 1939 and completed in 1944) in the Kanmon Straits. In the years after the 1970s, a large number of undersea tunnels were constructed in Japan, Norway, the United Kingdom, among others. In 1988, Japan constructed the Seikan Undersea Railway Tunnel crossing the Tsugaru Strait, with a total length of 53.85 km. The Seikan

Tunnel in Japan and the Anglo-French Channel Tunnel were called the most ambitious tunnel constructions of the 20th century. Since the completion of the Seikan Tunnel, the enthusiasm for tunnel constructions to cross water straits around the world had been rapidly rising. Many ambitious plans for crossing straits, which were previously considered "dreams", all finally became a "reality".

▶ Seikan Tunnel in Japan

It is a Shinkansen railway tunnel through the Tsugaru Strait, with a total length of 53.85 km, and a undersea segment length of 23.3 km, which used the drilling and blasting method during construction. The tunnel has a maximum depth under the sea of 240 m, and a water depth of about 140 m, an average thickness of the rock at the top of the tunnel of 100 m, and a designed maximum longitudinal slope of 12%. The tunnel consists of two main tunnels and an auxiliary tunnel. The main tunnel has a two-lane horseshoe-shaped cross-section, with a diameter of 9.6 m. Paralleled with the main tunnel, the auxiliary construction trench was located 30 m from the main tunnel. With a 5 m diameter, the auxiliary tunnel's function was to conduct geological surveys, deal with any problems of water bursting into the main tunnel (water gushing) during construction, increase the working face, and act as a maintenance tunnel and ventilation tunnel after the completion of the whole tunnel. Six inclined shafts and 2 vertical shafts were constructed. The undersea segment of the tunnel project was officially started in 1972, the pilot tunnel was completed in 1983 and the tunnel was opened to traffic in March 1988.

The rock strata that the tunnel goes through are mainly made up of fractured volcanic and Meso-Cenozoic sedimentary rock and the underground water is composed of bedrock fissure water. Furthermore, there was always the possibility of water gushing through the fragile rock as a result of the fault lines and due to the pressure from the seawater. There were 9 large faults along undersea segment of the tunnel and as well as between 1 and 3 smaller faults for every kilometer of the tunnel. As you might imagine, the geological conditions made the building process very complicated.

During the construction of the Seikan Tunnel, in order to prevent water gushing, several precautionary measures were taken, such as drilling horizontal boreholes ahead of the main tunnel construction work, grouting reinforcement, etc., but the possibility of water gushing was still hard to detect. During the Seikan Tunnel's construction, all the water gushing accidents occurred along fault lines despite the fault zones having had grouting reinforcement. There were four big main gushing accidents, which occurred during the construction process of the Seikan Tunnel. These accidents had a great impact to the construction work with the longest gushing accident taking nearly a year to handle.

▶ The Channel Tunnel

The Channel Tunnel is the tunnel which best represents the use of the TBM (Tunnel Boring Machine) construction method. The tunnel has a total length of 50.5 km, with a undersea segment of 37 km. It has three parallel chambers, two of which are single-track railway tunnels, each with a diameter of 7.6 m, and situated 30 m away from each other. In the middle is the service channel, with a diameter of 4.8 m. Each main tunnel has a single main railway track and a sidewalk. The service channel is used for ventilation, maintenance and overall security, and was also used for anticipating geological problems during the construction period.

The tunnel lies 40-50 m below the seabed and 11 heading machines were used during the construction of the tunnel. Furthermore, the cross-segment and cross-channel adopted the drilling and blasting method during construction. The frame for the auxiliary equipment of the heading machine was several hundred meters long. When they worked around the clock, the rate of advance the tunnel's construction reached 1,400 m per month, and it only took four years to cut a tunnel through the undersea rock. It was finally completed in 1994.

The Channel Tunnel line was demarcated in the 19th century based on the underlying blue chalk layer there. This kind of rock is strong but not too hard, and it is impermeable, which makes it ideal for tunneling. The English Channel was formed by ancient sedimentary strata, which was very stable. There were no faults, no signs of seismic activity, and no folding in the rock.

The Channel Tunnel construction site was the one of the largest construction sites seen in the 20th century. The plan was for the whole project to take seven years, but actually it only took four years, which was very short amount of time for such a large project. To complete the construction so quickly, 11 sets of TBM were used simultaneously for the tunnel excavation. The teams on the TBM took continuous day and night shifts and there were five teams on each working face.

▶ Denmark Storebaelt Channel Railway Tunnel

The Storebaelt Channel Railway Tunnel is 7.9 km long, 7.26 km of which was constructed using the shield method, with the shield having a diameter of 8.782 m, and the tube sheet having a thickness of 0.4 m. The project was 18 km long, at a total cost equivalent to about 4 billion Yuan. There were two features of this project which are known as "World Firsts": first, the large-scale drainage system was used to reduce the water pressure in the rock pores surrounding the route of the tunnel below the Storebaelt Channel, which made the main cross-channel tunnel construction easier and more convenient; second, a multi-stage protection strategy was adopted to ensure that the engineering structures had a lifetime of 100 years.

The outer diameter of the tunnel reached 8.5 m and every 20 m of the tunnel there was a permanent track landmark plate was set up in order to facilitate the laying of a permanent track, the erecting of the framework of overhead transmission lines, and the taking of simple regional measurements. The tunnel used lined-up sumps located in the lowest point of each tunnel to drain away the water. Furthermore, under normal operating conditions, no tunnel ventilation would be needed.

▶ Undersea Tunnels in Hong Kong, China

5 undersea tunnels were constructed in Hong Kong in the 1970s and 1980s, including 3 road tunnels constructed using the immersed tube method, and 2 Hong Kong metro (MTR) line tunnels constructed using the TBM method. These tunnels were all about 1.5 km long. These tunnels included:

Road Traffic Tunnels:

1. Western Harbor Crossing, dual three-lane carriageway, immersed tube method;

2. Hung Hom Cross Harbor Tunnel, dual three-lane carriageway, immersed tube method;

3. Eastern Harbor Crossing, dual three-lane carriageway, immersed tube method.

Metro Line Tunnels:

1. MTR Central Link Tunnel, twin-tube boring machine (TBM) tunneling method;

2. MTR Tseung Kwan O Line Tunnel, twin-tube boring machine (TBM) tunneling method.

In addition, there were a number of water supply and sewage conveyance tunnels in Hong Kong, most of which were constructed using the TBM method.

From the tunnel construction process and the experience gained from building each of these tunnels, much was learnt. In fact, during the Xiang'an Tunnel construction process, the foreign experts who were consulted during these tunnel projects were also consulted during the Xiang'an tunnel project so that their knowledge could be used as a reference point in order to help the construction of China's first undersea tunnel.

List of Some Undersea Tunnels in the World

Tunnel	Type	Completion Time	Length	Deepest Point	Buried Depth	Construction Country	Sectional Area	Rock
Kanmon Tunnel 1	Railway	1944	3.6 km	-40 m	9.5 m at mimimum	Japan	76.9 m^2	Grayish green tuff, granite
Kanmon Tunnel 2	Double-lane Highway	1958	3.4 km	-50.1 m	20.7 m at minimum	Japan	95 m^2	Diorite-ophiolite, porphyritic hornfels
New Kanmon Tunnel	Railway	1975	18.71 km	-50 m	68.5 m	Japan	74 m^2	The undersea part of the tunnel was located in the porphyrite and the granodiorite
Seikan Tunnel	Railway	1988	53.85 km	-140 m	240 m at maximum, 100m on average	Japan	37 m^2 109.48 m^2	Andesite, igneous rock, sedimentary rock
Alesund-Ellingsoy	Triple-lane Highway	1987	3.49 km	-140 m	40 m at minimum	Norway	68 m^2	Precambrian gneiss
Ellingsoy-Valderoy	Triple-lane Highway	1987	4.17 km			Norway	68 m^2	Precambrian gneiss
Ellingsoy	Highway	1987	3.5 km	-140 m		Norway	68 m^2	Gneiss

Tunnel	Type	Completion Time	Length	Deepest Point	Buried Depth	Construction Country	Sectional Area	Rock
Valderoy	Highway	1987	4.2 km	-137 m		Norway	68 m^2	Gneiss
Godoy	Highway	1989	3.8 km	-153 m		Norway	48 m^2	Gneiss
Hvaler	Highway	1989	3.8 km	-120 m		Norway	45 m^2	Gneiss
Byfjord	Highway	1992	5.8 km	-223 m		Norway	70 m^2	Phyllite
Mastraf-jord	Highway	1992	4.4 km	-133 m		Norway	70 m^2	Gneiss
Freifiord	Highway	1992	5.2 km	-130 m		Norway	70/54 m^2	Gneiss
Anglo-French Channel Tunnel (Service Tunnel)	Service Tunnel	1993	48.5 km	-100 m	20-70 m 40 m on average	Britain, France	36.17 m^2	Cretaceous marl and marly clay
Anglo-French Channel Tunnel	Railway	1994	50.5 km	-100 m	20-70 m 40 m on average	Britain, France	95.5 m^2	Cretaceous marl and marly clay
Tromsoy-sund	Highway	1994	3.4 km	-101 m		Norway	2×57 m^2	Diorite-gneiss
Htira	Highway	1994	5.3 km	-267 m		Norway	70 m^2	Gneiss
Troll	Water Supply	1995	3.8 km	-260 m		Norway	66 m^2	Gneiss