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Big Challenges and Innovative Solutions at HZMB Link Project

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ABSTRACT: One of the world's most challenging immersed tunnel projects, the Hong Kong – Zhuhai – Macau Bridge Link (HZMB) in the Pearl River Estuary, connecting Hong Kong Special Administrative Region (SAR), mainland China (Zhuhai) and Macau SAR, was completed and opened to traffic in 2018. It consists of 6km Immersed Tunnel with two artificial islands. Since the project was built in the open sea, the design and construction of the tunnel and artificial islands faced a series of grand engineering challenges. For example, the long distance ventilation and safety design, prefabrication of elements weighing nearly 80,000 tons each, foundation, siltation, towing and installation under high water pressure as well as construction of the west and east artificial islands. This paper discusses the major challenges faced during the HZMB Link project design and construction, and gives examples of innovative solutions to overcome those challenges.

KEYWORDS: Artificial Island, Immersed Tunnel, Foundation, Siltation

1. INTRODUCTION

With the advanced technologies and the innovative solutions in immersed tunneling in the recent years, deeper and longer sea crossings with longer design life criteria under challenging ground and environmental conditions became feasible and competitive compared to other tunneling methods. The construction of the HZMB Link, including bridges, immersed tunnel and two artificial islands construction completed in 2018 as shown on Figure 1. The tunnel and bridges are accommodating a dual carriageway with 3 traffic lanes in each direction. Since the project was built in the Zhujiang River Estuary and open sea, the design and construction of tunnels and artificial islands faced a series of grand engineering challenges, for example, the long distance ventilation and safety design (6-kilometers in length and 40-meters in depth) of the tunnel, fabrication of precast elements weighing nearly 80,000 tons, severe environmental conditions, foundation, siltation as well as construction of the west and east artificial islands.

2. CHALLENGING ENVIRONMENTAL CONDITIONS

2.1 Geological conditions

The tunnel sections at both ends of the whole immersed tunnel (ITT) are located in newly reclaimed artificial islands and the original seabed level ranges from -8m to -10m. After the completion of the island the reclamation thickness will be approximately 20m. Due to the settlement of the island, it is necessary to ensure smooth transition and avoid differential settlement between the tunnel and the artificial islands. Figures 2 and 3 show plan and longitudinal profile of the artificial islands and immersed tunnel.

Figure 1 HZMB Project plan

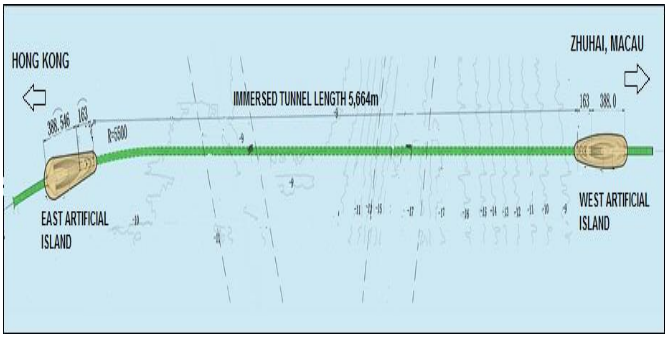

Figure 2 Plan of artificial islands and immersed tunnel

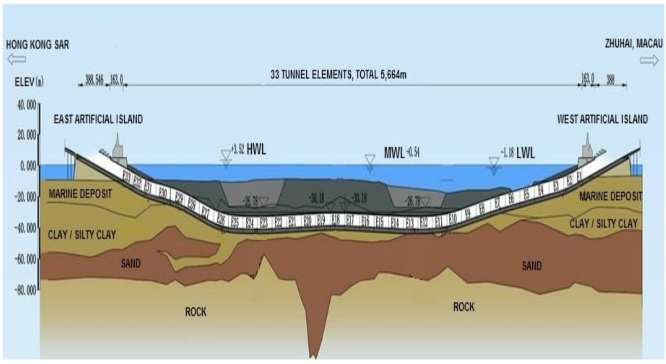

Figure 3 Longitudinal profile

The length of the tunnel is approximately 6km and the bottom slab of the tunnel elements pass through very soft marine deposits, clay, silty clay and sand strata.

The loads from the immersed tunnel on the foundation along the alignment varies due to different soil cover thickness on top of the tunnel. At both connecting locations with the artificial islands heavy shore protection comprising concrete dolosse and breakwater walls sits above the tunnel. At the central part of the tunnel, other than the navigation channel areas, the backfill thicknesses reaches around 23m and sediment effect needs to be considered for long term as well.

2.2 Construction of west and east artificial islands

The two artificial islands located at both ends of the tunnel have a length of approximately 625m. The original seabed mostly consists of clay and silty clay which required ground improvement which was explained further in section 2.3. The locations of the west and east artificial islands are shown in Figure 4.

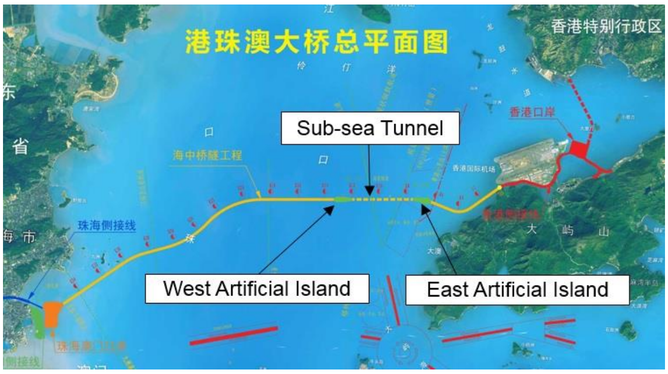

Figure 4 West and east artificial islands

The construction of west-island is divided into two phases. The front portion where the ITT is connected to the cut and cover tunnel on the island was reclaimed first, utilising a cellular cofferdam with 22 nos. of 22m diameter steel tubes, whereas 45 nos. of similar tubes were required for reclamation of the rest of the island. The average depth of these 67 nos. steel tubes was 42m and the total weight each tube was 450 tonnes. Figures 5 and 6 show the concept of the steel cofferdam and installation sequence for west artificial island.

Figure 5 West artificial island 3D image

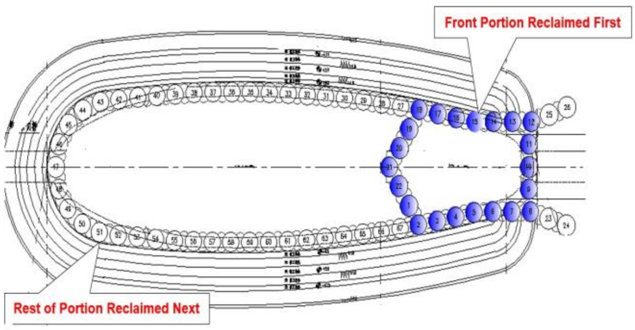

Figure 6 West artificial island cofferdam installation sequence

As it can be seen from Figure 6, at first the smaller island portion of the west island was reclaimed, within which cut & cover tunnel is constructed for immersed tunnel connection. The reclamation works for the smaller and bigger island portions are shown in Figures 7 - 9.

Figure 7 West artificial island smaller island reclamation

Figure 8 22m diameter pipes for steel cofferdam

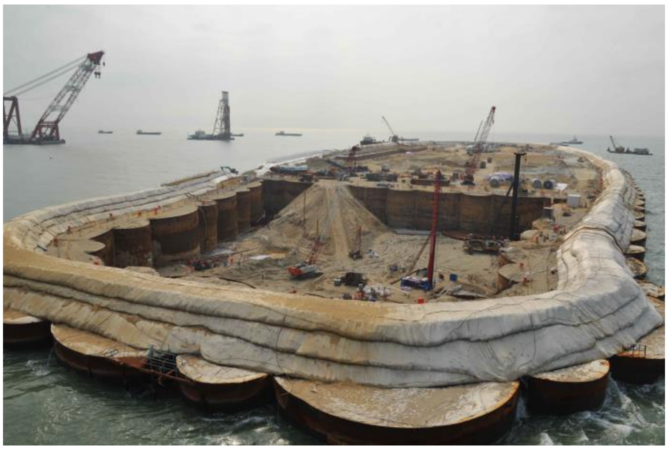

Figure 9 Reclamation of the west island

After completion of the steel cellular cofferdam structure, the island was backfilled by sand and plastic vertical drains were densely installed which helped to expedite the consolidation settlement. The process of the applied surcharge and settlement process are shown in Figure 10 below.

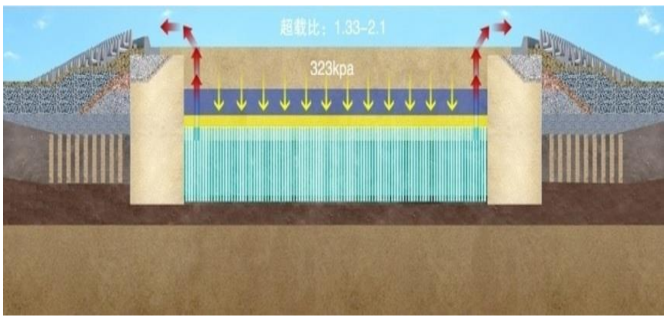

Figure 10 Surcharge and vertical drain

Immersion of the tunnel elements started from the west artificial island, therefore a smaller island in the west island was required in order to construct the cut and cover tunnel earlier to which the first immersed tube unit is connected. However, for the east artificial island there was no necessity of a smaller island since the immersed tunnel connection would be constructed considerably later. Therefore, the east artificial island was constructed in a single procedure as one big island. A view from the east artificial island is seen in Figure 11.

Figure 11 East artificial island cofferdam construction

2.3 Trench excavation and trench cleaning

The cutting gradients of the trench for the immersed tunnel varied at shallower and deeper sections. Tunnel elements E1～E3 and E31~E33 had a gradient of 1:7 and tunnel elements E4~E7 and E30 had a gradient of 1:5.

For the remainder of the tunnel section (e.g. E8~E29), two different gradients were adopted depending on very soft marine deposit soil and clayey soil (including sand strata). For these sections, 1:5 and 1:2.5 were adopted in principle respectively.

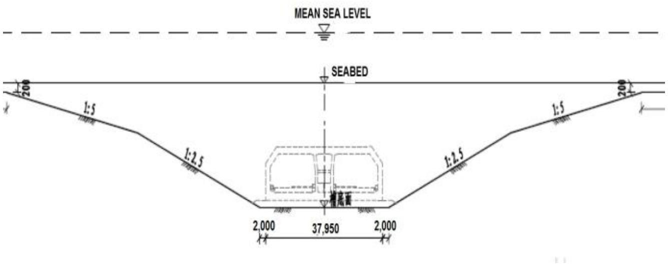

Figure 12 Typical trench section

Grab Dredgers and Cutter Suction Dredgers were used for trench excavation as shown in Figure 13.

Figure 13 Cutter suction dredger for trench excavation

Sediment (siltation) was a major problem for HZMB project and from time to time a significant amount of sedimentation occurred during formation of the tunnel foundation and immersion operations of tunnel elements. Siltation during construction due to typhoon and sediment flows from the northern part of the Zhujiang River delta caused interruption of the construction works from time to time. At some periods, average siltation thickness per month exceeded 400mm.

In order to mitigate siltation problem, various methods such as use of suction dredger and silt curtain were adopted. Before formation of foundation and immersion operations, high accuracy survey methods were used to assess the siltation amount.

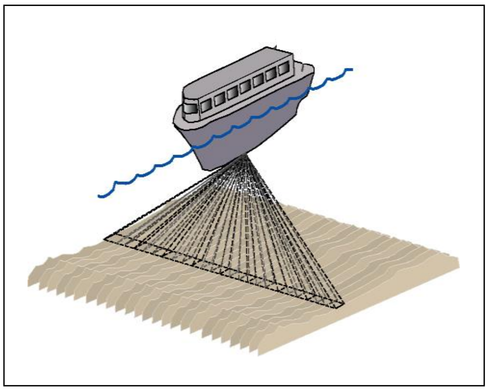

Figure 14 Multi-beam surveying method

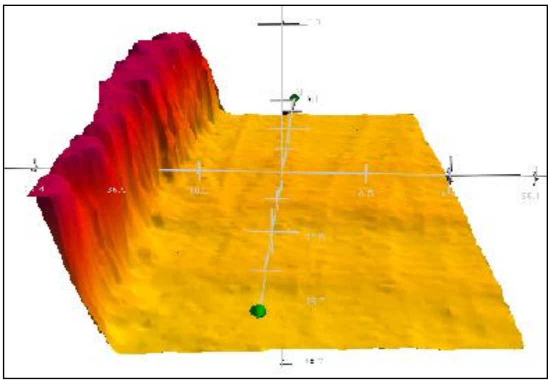

Figure 15 3D rendering of trench survey

2.4 Tunnel foundation, backfill and ground improvement

The tunnel foundation design had to take into account loads from self-weight of tunnel structure, backfill, armour protection on the tunnel and sediment as well as tunnel operational loads (e.g. traffic load). It was essential to construct a robust tunnel foundation in order to control total settlement and minimize differential settlement between tunnel elements and cut and cover section. Longitudinal profile and two typical cross sections for foundation and backfill are shown below. Figure 17 shows a cross section near the artificial islands and at general section.

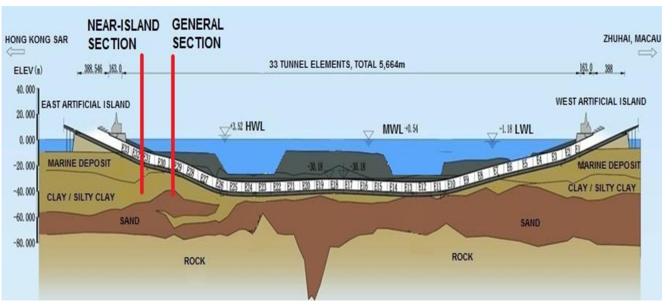

Figure 16 Longitudinal profile

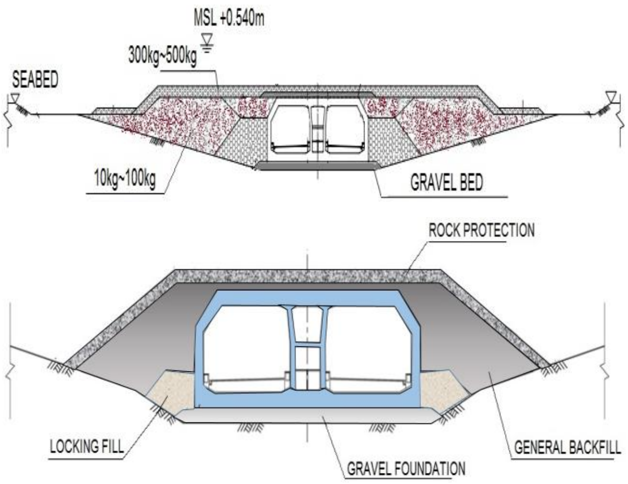

Figure 17 Typical foundation and backfill section (Top: Near-island, Bottom: General section)

Challenging geological conditions required detailed settlement analyses and innovative foundation design solutions in order to have smooth transition between the artificial island, cut and cover structure and tunnel elements. Some of the main challenges were as follows:

i. Both ends of the immersed tunnel section were connected to newly reclaimed artificial islands with cut and cover tunnels. The original seabed elevations ranged from -8m to -10m. After the completion of the islands, the elevation of the island surface was +5m. The total settlement of the islands was large and it was a challenge to provide a smooth transition between artificial islands and the immersed tunnel.

ii. The length of the tunnel is around 6km and the bottom slab of the tunnel element passes through very soft marine deposit soil, clay, silty clay and sand strata. Having varying weak soil strata and large variation of soil stiffness required careful analyses of design criteria as input for foundation and structural design.

iii. The load distribution along the immersed tunnel varied significantly. Heavy armour concrete blocks were installed at the island connection areas as near-shore protection against waves and to protect the tunnel against vessel collision. In addition, some parts of the tunnel had approximately 23m thick backfill which also needed to take into account future sediment effect.

iv. After immersion of the tunnel elements, various load combinations had to be taken into account such as after backfill, with partial sediment, with full sediment, etc. Detailed analyses had to be carried out to cope with most unfavourable cases.

As a result of detailed studies as well as construction method of foundation and immersion operations, Sand Compaction Piling (SCP) method was applied at the transition zone between artificial islands and tunnel elements. The concept and application at site are shown in Figures 18 – 19.

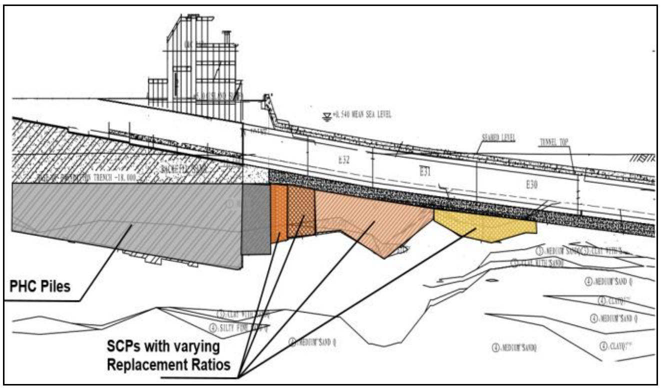

Figure 18 Ground improvement at transition zone between island and immersed tunnel

Figure 19 Sand compaction pile (SCP) application

3. CONCLUSION

Facing to the open sea in the South China Sea and being located at challenging geological conditions in the large river mouth delta, the design and construction of artificial islands and immersed tunnel as part of the Hong Kong – Zhuhai – Macau Bridge Link project included significant engineering and environmental difficulties. Innovative solutions together with utilization of the latest advanced technologies helped to minimize the risks and overcome the difficulties.

4. REFERENCES

Hong Kong – Zhuhai – Macau Bridge Link Design and Construction Methodology Documents by CCCC