Design and Construction of the Hong Kong - Zhuhai - Macao Bridge Project

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I^3C Symposium on Infrastructural Developments
Singapore, 23rd November 2017

1,604 miles / 2,566 km
Where are Hong Kong and Macao?

Hong Kong Fact Sheet

- Formerly a British colony
- Returned to China on 1 July 1997
- Population ~7 million
- Area ~1,100 km²
Macao Fact Sheet

- Formerly a Portuguese colony
- Returned to China on 20 Dec. 1999
- Population ~0.56 million
- Area ~30 km²

10 Mega Infrastructure Projects

1. Joint development of Lok Ma Chau Loop
2. HK-Shenzhen Airport cooperation
3. New development area
4. Guangzhou-Shenzhen-HK Express Rail Link
5. Sha Tin-Central Link
6. Kai Tak development plan
7. South Island Line
8. Western Kowloon Cultural District
9. Hong Kong – Zhuhai – Macao Bridge
10. Tuen Mun-Chek Lap Kok Link, Tuen Mun Western Bypass
Hong Kong – Zhuhai – Macao Bridge
Functions of the Project

- To meet the demand of passenger and cargo interflows among Hong Kong, Mainland China and Macau
- To establish a new land transport link between the east and west banks of Pearl River
- To enhance the economic and sustainable development of the three major cities in the Pearl River Delta region

Connectivity of HZMB
3 Major Components

- Zhuhai/Macao Boundary Crossing Facilities, Zhuhai Link Road, and Guang-Zhu West Expressway
- The Main Bridge – 22.9-km dual 3-lane carriageway and 3 cable-stayed spans between 280 m and 460 m, and 6.7-km long sub-sea tunnel
- The Hong Kong Link Road, Hong Kong Boundary Crossing Facilities, Tuen Mun-Chek Lap Kok Link, Tuen Mun Western Bypass
Geotechnical Works

- Reclamations
- Onshore foundations
- Offshore foundations
- Sub-sea tunnels
- Artificial islands
- Earth-retaining structures
- Roadworks
Marine Geology

Marine deposits
Alluvial clay
Alluvial sand
Residual soil
Bedrock

Plasticity of Clays

Plasticity Index (%)

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Liquid Limit (%)

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<td>MH</td>
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<td>ME</td>
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<td>I illites</td>
<td>Halloysites</td>
<td>Kaolinites</td>
<td>Mortimers</td>
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Undrained Shear Strength $S_u$ (kPa)

$s' - t'$ Plot of Marine Clays
Challenges and Constraints

- The Project is extensive, large-scale, diversified and complex
- The weather and marine environment are rough
- The marine traffic is heavy
- Operating height is restricted
- The marine environment needs to be protected
- The long spans of the bridge
Lingding West Channel

- The deep channel is required to navigate 300,000-ton ships
- It requires a 80-m high bridge and a 200-m high bridge tower
- The Hong Kong International Airport does not allow anything higher than 88 m
- **A bridge is technically impossible!**
Immersed Tunnel

- The air traffic channel is unobstructed
- The navigation channel is open at all times
- The length of the artificial islands is shortened from 1 km to 625 m
- The longest immersed tunnel ever built – 6.7 km
- 33 segments of 180 m long, 33 m wide and 11 m high, and weight 76,000 tons each
Immersed Tunnel Foundations

Installation of the Immersed Tunnel
Artificial Island

The artificial islands are necessary to provide the transition between the tunnel and the viaducts.

Existence of soft marine deposits of approximately 20 m thick.

Backfilling with rock is practically not feasible.

Dredging of such large quantities of soft marine deposits will adversely impact the environment.

Site Constraints
Large Steel Cylinders

- The two artificial islands are retained by 120 large cylinders.
- Each cylinder is 22.5 m in diameter, 55 m high and weighs 550 tons.
- Each cylinder is fabricated in Shanghai using 72 pieces.
- 12960 6-ton steel plates were used.

Artificial Island (Cross-section)
Construction of Artificial Islands

Foundations of Buildings
Artificial Island and Hong Kong Link Road
Reclamation for Zhuhai/Macao Boundary Crossing Facilities

Rock-socketed Large-diameter Bored Piles
Precast Pier and Pile Cap

Bridge Segment
Reclamation for Hong Kong Boundary Crossing Facilities
Reclamation for Hong Kong Boundary Crossing Facilities

Hong Kong Boundary Crossing Facilities
Challenges and Constraints

Northern Section
Construction Sequence

Tuen Mun

TBM Launching Shaft

TBM Diameter Changed

3 Traffic Lanes

TBM Diameter Change Shaft

TBM Diameter Changed

NORTH TUNNEL PORTAL

NORTH VENTILATION BUILDING

SOUTH TUNNEL PORTAL

SOUTH VENTILATION BUILDING

MARITIME NAVIGATION CHANNEL

Deepest part of the Sub-sea tunnel at approx. 52m below sea level

Deepest part of the Sub-sea tunnel at approx. 52m below sea level

HKBCF

North Bound Tunnel

South Bound Tunnel

TBM Design and Operation

**TBM S880**
- 19” single disc cutter 117 Nos.
- 19” double disc cutter 6nos.
- Scrapers 200 nos.

**TBM S882**
- 19” single disc cutter 97 Nos.
- 19” double disc cutter 4 nos.
- Scrapers 114 nos.

- Slurry type TBM
- TBM fabrication were in both Germany and China by Herrenknecht AG.
- The S880 TBM started assembly on 24 Jan 15 and launched on 24 Apr 15
- The S882 TBM started assembly on 8 Mar 15 and launched on 12 Jun 15
Northern Approach Tunnel (Northbound)

S880 TBM
- Tunnel ID: 15.6 m
- Tunnel Length: 650 m
- Cutter head dia: 17.63 m
- Shield dia: 17.56 m
- Shield length: 13.22 m
- Shield weight: approx.: 3,000 tonne
- TBM length: 120 m
- Backup weight: approx.: 1,325 tonne

Subsea Tunnel (Northbound)

S881 TBM
- Tunnel ID: 12.4 m
- Tunnel Length: 4,030 m
- Cutter head dia: 14 m
- Shield dia: 13.95 m
- Shield length: 15.1 m
- Shield weight: approx.: 2,200 tonne
- TBM length: 122 m
- Backup weight: approx.: 1,325 tonne

Northern Approach Tunnel + Subsea Tunnel (Southbound)

S882 TBM
- Tunnel ID: 12.4 m
- Tunnel Length: 4,680 m

S880 TBM commissioned on 28 October 2014 and delivered on site on 12 December 2014

S882 TBM commissioned on 12 December 2014 and delivered on site on 6 March 2015
TBM Design and Operation

TBM Tunnel Lining Segments

TBM Tunnel Lining Segment

- Thk = 0.55 m (0.7 m)
- I.D. = 12.4 m (15.6 m)
- Width = 2.2 m (1.7 m)
Cross Passage Construction

- 58 nos. Cross Passages
- Approx. I.D. = 3.9 m
- Spacing = 100 m
- Length = 1.5 m ~ 13 m
Cross Passage Construction

Mini TBM
Viaduct

Green Measures

- The new direct route will avoid detouring and help minimize use of fossil fuels and gas emissions by vehicles
- It helps to reduce vehicle CO$_2$ emission by at least 1,100 tonne/day
- The adoption of the non-dredging method for the reclamation of the HKBCF reduces the quantity of soft marine deposits to be dredged and disposed of by 97%, the quantity of backfilling materials by 50%, and the marine construction traffic by 50%
Green Measures

- Combining the reclamations for the HKBCF and the Southern Landfall of the TM-CLKL sub-sea tunnel reduces the total length of seawalls by 1.8 km, minimizing the impact on the marine environment.

- The adoption of TBMs for the construction of the approximately 5 km sub-sea road tunnel for the Northern Connection of the TM-CLKL will avoid the dredging and disposal of some 11 Mm$^3$ of marine sediments required for construction using the traditional immersed tube method.

Green Measures

- The non-dredging method of reclamation will reduce the quantity of suspended particles by 70% during construction.
Preservation of the Chinese White Dolphin Habitat

- Non-dredging methods are adopted for reclamation and seawall construction
- No underwater percussive piling is allowed
- No formation of underwater rock sockets for bored piles is allowed during the peak dolphin calving season in May and June
- Noisy construction equipment mounted on marine construction vessels is acoustically-decoupled to minimize underwater noise

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Preservation of the Chinese White Dolphin Habitat

- Marine construction vessels have to follow pre-defined regular travel routes to avoid the active areas of Chinese White Dolphins
- Marine construction vessels have to travel at a speed lower than 10 knots in the areas of work site, marine park and proposed marine park
- Skipper of marine construction vessels working in the areas have to undergo specific training on local dolphins and porpoises
Preservation of the Chinese White Dolphin Habitat

- A dolphin exclusion zone (DEZ) of 250 m radius is implemented during the silt curtain installation and the bored pile casing installation works.
- Works will be suspended if any dolphin is found within the DEZ.
- Silt curtain enclosed areas are regularly checked and works will be suspended if any dolphin is found within the enclosed area.
- The population of Chinese White Dolphins in the northwestern waters of Hong Kong is regularly monitored.

Preservation of the Chinese White Dolphin Habitat

- The best available construction practices are adopted to minimize sediment dispersion during construction, and to avoid impact on water quality.
Summary

- The Hong Kong-Zhuhai-Macao Bridge Project, being situated at the waters of Lingdingyang of the Pearl River Estuary, is a mega sea-crossing infrastructure project currently under construction in the Pearl River Delta of China.

- It consists of a series of bridges, sub-sea tunnels, viaducts and artificial islands connecting the Hong Kong, Zhuhai and Macao, three major cities situated on the Pearl River Delta in China.

Summary

- The geotechnical works associated with the HZMB Project, including reclamations, onshore and offshore foundations, sub-sea tunnels, artificial islands, earth retaining structures and roadworks are extensive, large-scale, diversified, challenging and complex.
Summary

- The background of the mega project and pertinent geotechnical works of the Project, in particular components contributed by the Hong Kong Special Administrative Region Government, are presented.
- Green measures implemented to reduce environmental impacts during the design and construction stages of the Project are also presented in this special lecture.