The First Subsea TBM Road Tunnel in Hong Kong

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ABSTRACT: Subsea tunnels for transportation are traditionally constructed in the form of Immersed Tunnel (IMT). With the technical advancement of mechanized Tunnel Boring Machine (TBM) construction, subsea TBM bored tunnels were successfully constructed in different parts of the World over the last decade. Using a TBM has benefits over the IMT when excavating beneath the sea, since it does not require dredging and marine access. This makes it particularly favourable when coping with environmental concerns and constraints within existing shipping passages. Since the first subsea tunnel across the Victoria Harbour in Hong Kong was constructed in 1972 by immersed tunnel method, four other additional subsea immersed tunnels were constructed across the same Victoria Harbour between 1979 and 1997. The subsea tunnel of Tuen Mun – Chek Lap Kok Link (TM-CLKL) was also originally proposed using immersed tunnel method in the feasibility study stage. However, the tunnel scheme was changed to TBM bored tunnel in the Investigation and Preliminary Design Stage. The TBM bored tunnel scheme was further developed in the Detailed Design Stage and the project is now under construction. This would be the first subsea TBM road tunnel in Hong Kong and this paper discusses the key considerations and rationales in changing the original IMT scheme to the TBM bored tunnel scheme for the subsea tunnel section of TM-CLKL.

KEYWORDS: Subsea tunnel, Tunnel boring machine (TBM), Immersed tunnel (IMT), Mixed ground conditions

1. INTRODUCTION

In the past, all subsea road tunnels in Hong Kong were constructed using immersed tunnel (IMT) method. With the technical development and achievement of mechanized Tunnel Boring Machine (TBM), several subsea TBM bored tunnels were successfully constructed in different parts of the World over the last decade. Both construction methods (IMT method or TBM bored tunnel method) have merits and deficiencies. Detailed assessment of the tunnel scheme is therefore of paramount importance for successful implementation of the project. With the existing site condition of TM-CLKL, using a TBM method has benefits over the immersed tunnel in that it does not require dredging and marine access when excavating beneath the sea. Thus, this makes it particularly favourable when considering environmental concerns and constraints within existing shipping fairways. However, there are several important technical issues such as high water pressure, difficult ground conditions and hyperbaric intervention, which would be required to be resolved in using the TBM bored tunnel scheme. It should also be noted that once successfully constructed using TBM, TM-CLKL will be the biggest and deepest TBM road tunnel in HK with cutting edge technical achievement.

This paper presents the key considerations and reasons behind in changing the original IMT scheme to the TBM bored tunnel scheme for the subsea road tunnel of TM-CLKL. The difficulties encountered and technical development required of the TBM bored tunnel scheme will also be discussed.

2. PROJECT BACKGROUND

2.1 TM-CLKL Subsea Tunnel

The proposed TM-CLKL comprises a 9 km long dual 2-lane carriageway between Tuen Mun and North Lantau. The alignment commences at a connection with the North Lantau Highway (NLH) at Tai Ho of Lantau. It heads northwest on a 1.6 km long sea viaduct to the proposed Hong Kong Boundary Crossing Facilities (HKBCF) near the Hong Kong International Airport (HKIA). After landing on the eastern edge of the proposed HKBCF, the alignment turns north and heads into a 5 km long sub-sea tunnel, which is to be constructed by large diameter TBMs under the Urmston Road. After crossing the Urmston Road, the alignment daylights at a reclamation just east of the Tuen Mun River Trade Terminal and then heads eastward on an elevated structure over Lung Mun Road, before joining a toll plaza in Tuen Mun Area 46. The project includes three main civil works contracts: Contract I – Southern Connection Viaduct Section, Contract II – Northern Connection Sub-sea Tunnel Section, and Contract III – Northern Connection Toll Plaza and Associated Works. The layout plan of TM-CLKL project is shown in Figure 1. At the date when this paper was being prepared, the three civil works contracts were in progress.

Figure 1 Project Layout of TM-CLKL

2.2 Site Constraints

The subsea tunnels pass through several important facilities: (a) submarine power cables and telecommunication cables, which are the only power and telecommunication supply to the HKIA; (b) Urmston Road, which is one of the busiest marine navigational channels in Hong Kong; and (c) marine borrow area, mud disposal ground and contaminated mud pits located nearby the project site. In addition, the project site is located within the active zone of Chinese White Dolphins and it will be very sensitive for any marine works to be carried out in the project site. The site constraints are shown in Figure 2.

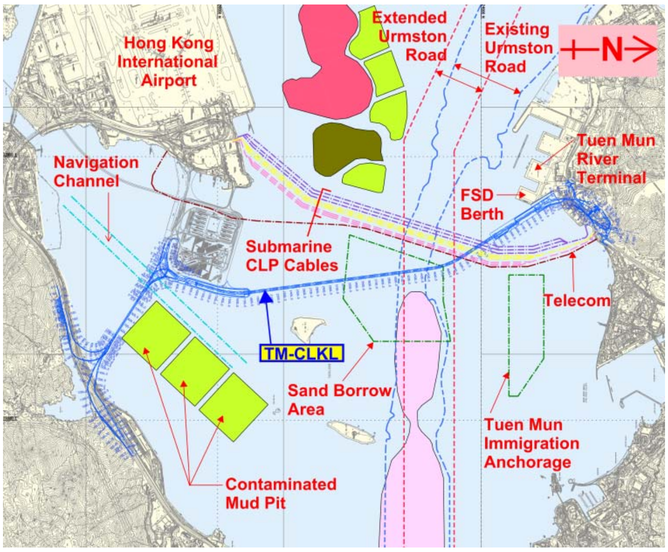

Figure 2 Site constraints

2.3 Geological Conditions

The geological conditions along TM-CLKL subsea tunnels have been reviewed based on the published records, available GI records, GI works under Investigation Assignment and Design & Construction Stage. The findings of the marine GI works are generally in line with the published geological information. The inferred geological longitudinal section is shown in Figure 3. The sub-surface profile along the proposed tunnel alignment consists of marine deposit overlying alluvium, which is underlain by completely decomposed granite (CDG) and bedrock.

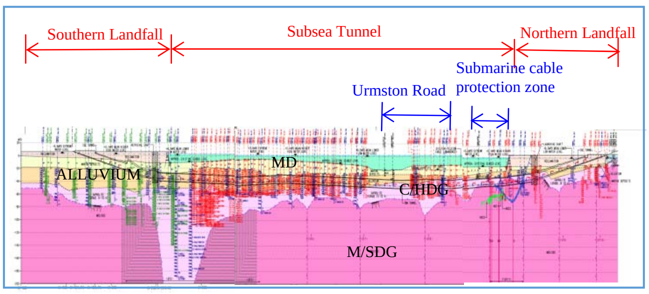

Figure 3 Inferred geological longitudinal section along tunnel alignment

3. SUBSEA TUNNELLING METHODS

3.1 Immersed Tunnel (IMT)

An immersed tunnel consists of a number of prefabricated tunnel elements that are first constructed in a fabrication yard. It can be made by concrete, steel or composite structure of steel and concrete called sandwich structure. IMT offer high flexibility in tunnel cross section design and normally it is in rectangular shape for highway tunnel.

The immersed tunnel elements will be sealed at both ends by installation of bulkhead. In addition, rubber gasket will be mounted on the collar plate at one end of tunnel element for flexible connection of the tunnel elements. After the tunnel elements are constructed, they are floated and towed to the site, installed one by one, and connected to one another under water. An immersed tunnel is generally installed in the trench that has been formed by dredging at the bottom of the sea. The space between the trench bottom and the invert of the tunnel is filled with sand foundation in later stage or the elements are set on the pre-formed gravel mat foundation on the trench. As construction proceeds, the tunnel is backfilled. The completed tunnel is covered with a protective layer over the roof.

3.2 Mechanized Tunnel Boring Machine (TBM)

The TBM is a machine used to excavate tunnels with a circular cross section through a variety of soil and rock strata. Modern TBMs typically consist of the rotating cutting wheel, called a cutter head, followed by a main bearing, a thrust system and trailing support mechanisms. It moves forward as it excavates for the tunnel by extending the pushing jacks at the back. When the advancement of the machine reaches distance of the length of a ring, the excavation stops and the pushing jacks are retrieved, a concrete circular ring in the form of a number of segments were then put together at the tail of the shield. The pushing arms are once again extended in full contact with the concrete ring just erected and excavation is resumed. The cycle of excavation and ring erection is repeated as the TBM is advanced to form the lining of the tunnel.

3.3 Key Factors in Choosing IMT or TBM Bored Tunnel Scheme

For planning of an immersed tunnel, the following major issues should be studied in order to ascertain the engineering feasibility and constructability of the project:

- Casting basin for tunnel element construction;
- Marine operation of immersed tunnel;
- Dredging of tunnel trench;
- Submarine utility;
- Weather condition;
- Environmental impacts; and
- Geological condition and long term settlement of immersed tunnel.

For a TBM bored tunnel, the following major issues should be studied to demonstrate the feasibility of tunnelling scheme:

- Ground condition determine type of TBM to be used;
- Launching shaft and retrieval shaft need to be planned;
- Sufficient cover shall be provided to ensure safe tunnel construction;
- Flotation during construction and operation;
- Tunnel face stability during tunnel excavation;
- Cross passages between TBM bored tunnels; and
- Hyperbaric intervention for cutterhead maintenance.

The designer should carefully investigate the specific constraints at the planning stage in order to determine the most appropriate tunnelling method with consideration of the constructability, quality of work, programme and cost of the project.

4. SUBSEA ROAD TUNNEL SCHEME OF TM-CLKL

4.1 Original IMT Scheme

Immersed tunnel is considered the most suitable form of harbour crossing in Victoria Harbour. One of the major reasons is due to the shallow tunnel cover required for immersed tunnel. Normally soil cover of 1-2m above the tunnel top is provided to protect the tunnel from dropping anchor and sunken ship. The shallow tunnel alignment allows the tunnel climbing up earlier at landfall sections on both sides of harbour to join the existing road networks along the shoreline. As a result, more gentle alignment gradients and shorter lengths of approach tunnels on both ends are required. In addition, IMT techniques are well established and involve less geotechnical risks compared with other types of tunnel construction methods.

Immersed tunnel was originally proposed for the TM-CLKL subsea tunnel based on the past successful experiences of cross harbour tunnels constructed in Hong Kong. However, dredging for the tunnel trench is required for immersed tunnel construction and it would cause significant impacts to the environment and marine ecology particularly that the project site area is within the active zone of Chinese White Dolphins. In addition, diversion of the submarine power cables is required and this would cause significant delay to the implementation of the project. With the critical environmental and programme considerations, the subsea tunnel scheme needs further review.

4.2 TBM Bored Tunnel Scheme

During the investigation study of the TM-CLKL project, option comparison between adoption of IMT method and TBM bored tunnel method was carried out. It was concluded that TBM bored tunnel scheme is much more appropriate than IMT scheme in view of the following key constraints / considerations:

- Utilities impacts associated with the need for submarine utilities diversion (existing 132kV cable and telecommunication cables connecting Tuen Mun and Chek Lap Kok Airport Island) by the IMT scheme;
- No need to reserve a land for casting basin. TBM lining manufacturing can be off site and even outside Hong Kong;
- No marine operation is required. It results in no marine traffic impact to the busiest multi-traffic fairway – Urmston Road. It also avoids impacts to HKIA operation and the constraints of marine restricted zone around the Airport Island, both of which may limit the marine operation of IMT construction;
- Environmental impacts associated with the IMT construction such as huge amount of dredging, dumping, backfilling and tunnel foundation works;
- Ecological impact associated with the potential disturbance to Chinese White Dolphins and other marine life due to dredging, dumping and backfilling operations of IMT construction; and
- Divers need to work on underwater joint construction up to 3.7 bar in IMT construction. The divers will be exposed to the strong current in Urmston Road while working with low visibility.

5. TECHNICAL CHALLENGE FOR THE SUBSEA TBM BORED TUNNEL SCHEME

With detailed study and assessment, large diameter TBM bored tunnels were eventually proposed to resolve the impacts associated with IMT scheme. On the other hand, the proposed TBM bored tunnel scheme needs to address technical challenges of being the biggest and deepest road tunnels to be constructed in Hong Kong. The main subsea tunnels will employ two large diameter (approx. 14m) TBMs designed to overcome mixed ground conditions at up to 60m below the sea level.

During the planning stage of the large tunnel diameter subsea TBM bored tunnel, the following key issues have been studied:

- Latest Development of TBM;
- Type of TBM and Selection;
- Tunnel Section Configuration;
- Tunnel Alignment;
- Geological Constraints for Proposed TBM Bored Tunnel;
- Tunnel Stability;
- Cutterhead Intervention;
- TBM Bored Tunnel Launching and Retrieval;
- Cross Passages between TBM Bored Tunnels; and
- Risks Management and Tunnel Health and Safety.

5.1 Development of TBM

It has been reported that a 19m diameter TBM was once ordered by a private developer in 2008 but project records at the time of tunnel options assessment in 2009 indicated that one of the largest TBM in operation is a 15.44m diameter TBM machine for the Chong Ming dual 3-lane road link project in Shanghai. The mixed shield slurry TBMs crossing the Yangtze Delta have successfully excavated the tunnels in "soft" ground and effectively maintaining stability of the excavated face under hydrostatic pressure up to 6 bars. With reference to the latest development of TBM technology and the successful records in the world, it is envisaged that the large-diameter TBM application in the TM-CLKL project would be another technical challenge.

5.2 Type of TBM and Selection

It is anticipated that the tunnels will pass through soft and mixed ground conditions with high hydrostatic pressures. Closed face TBM is therefore adopted. There are two types of mixed ground closed face TBM, namely earth-pressure-balanced (EPB) TBM and mixed shield slurry TBM. Recent tunnelling projects in Hong Kong involving excavation in soft and mixed ground conditions have been successfully completed using either EPB TBMs or mixed shield slurry TBMs.

<u>EPB TBM</u>

- Twin bored 8.7m ø KCRC Kwai Tsing rail tunnels; and
- Twin bored 8.7m ø KCRC Lok Ma Chau rail tunnels.

<u>Slurry Type TBM</u>

- Single bored 4.5m ø DSD Kai Tak Transfer drainage tunnel; and
- Twin bored 8.1m ø MTR Kowloon Southern Link rail tunnels.

The shallow overburden and high face pressure are the defining factors for selecting the closed face TBM that would be able to support the tunnel face at all times and be completely watertight. Besides, mixed ground condition ranging from marine deposit, sandy alluvial deposit, in-situ decomposed rock with corestones to hard rock will be encountered during the tunnel bore. Therefore mixed shield slurry TBM equipped with cutters discs and drag picks suitable for mixed ground condition is required for the TM-CLKL project. Besides, the face pressure can be sensitively controlled in the slurry type TBM to reduce the risks of blow-out and cave-in failures compared with EPB TBM. Therefore slurry type TBM is considered more appropriate.

5.3 Tunnel Section Configuration

Dual 2 traffic lanes are to be provided in the sub-sea tunnel for TM-CLKL. The tunnel configuration and alignments of the tunnel is designed to have trunk road standard in accordance with the Transport Planning & Design Manual (TPDM) published by Transport Department of HKSAR Government.

As the tunnel is circular in shape, the tunnel cross section has been optimized in order to accommodate traffic structure gauge, ventilation ducts and all services in the tunnel. It is proposed as twin bored TBM bored tunnels of approximately 12.4m internal diameter with external diameter of about 14.0m. The general arrangement of the proposed subsea TBM bored tunnel is shown in Figure 4.

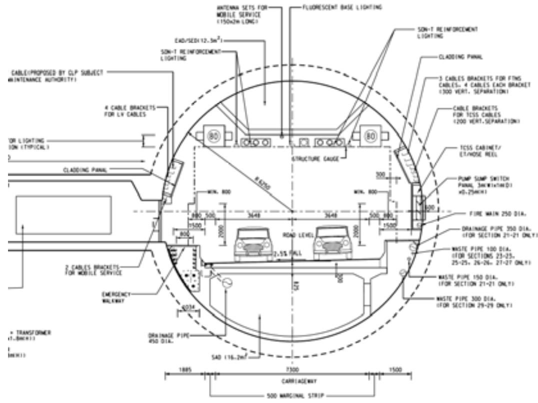

Figure 4 General Arrangement of TBM Bored Tunnel

5.4 Tunnel Alignment

The tunnel alignment is designed to avoid passing through difficult ground such as great variation / depression of seabed level, weak soil stratum (e.g. marine deposit) and area where high rockhead or corestone is anticipated. In addition, the tunnel alignment avoids passing through contaminated soil, planned dredging/filling area or other existing structure such as seawall structure.

The tunnel alignment is designed as shallow as possible in order to minimize the climbing up distance at landfall sections on both sides of the subsea tunnels. At the same time, the minimum soil cover above the TBM bored tunnels is designed against tunnel stability during excavation and operation. In addition, it is necessary to protect the tunnels from damage of dropping anchor or sunken ship.

Apart from the afore-mentioned considerations, the vertical alignment of TM-CLKL is controlled by the following constraints:

- Sufficient vertical clearance between the existing 132kV submarine cables;
- Sufficient soil cover should be provided at the deep draught channel at Urmston Road with seabed level at about -20mPD. Planned future widening and deepening of Urmston Road is considered in the alignment design; and
- Sufficient vertical clearance between the proposed tunnel crown and bottom of seawall at both ends of the subsea tunnels.

5.5 Geological Constraints for Proposed TBM Bored Tunnel

The proposed TBM bored tunnels will generally pass through a thick layer of alluvium with local presence of marine deposit at the southern section (1950m in length). Subsequently in the middle section (1700m in length), completely decomposed rock is expected to be encountered while the alluvium becomes thinner. At the northern section (850m in length) including the submarine cable protection zone (540m in length), the tunnel is likely to encounter rock where the rockhead profile intercepts the lower portion of the tunnel. Since permission to carry out drillhole within the submarine cable protection zone was not allowed in the design stage, the rockhead profile along this section was based on the interpreted rockhead levels from the geophysical survey data.

The risks from limited ground investigation data for development of accurate ground profile in the mixed ground area with sensitive submarine cables on top of the proposed TBM bored tunnels is one of the major concerns on the overall feasibility of subsea TBM bored tunnel scheme. The frequency of cutter tool wear and damage of cutter discs would increase when the TBMs excavate in the mixed ground condition. Therefore the need for cutterhead intervention under hyperbaric condition for replacement of worn or damaged cutter discs is anticipated to be more frequent in this section of TBM bore.

There is no previous example of similar TBM diameter in mixed ground condition under high pressure of over 5 bars. In addition, it will be the pioneer for large diameter (about 14m) subsea TBM bored road tunnel in mixed ground condition with hyperbaric invention with pressure of over 5 bar in Hong Kong. Therefore a better understanding of the geological profile and engineering properties of soil and rock is very important to the design of the bored tunnel. During the design stage, vertical marine drillholes, marine inclined drillholes and horizontal directional coring (HDC) were carried out to retrieve more information about the ground condition in this sensitive area.

5.6 Tunnel Stability

The stability of tunnel during construction stage and operation stage should be designed against different failure modes with adequate factor of safety. To ensure feasibility of tunnel scheme, the following failure modes were checked during the design stage:

- Floatation;
- Face stability during tunnel excavation; and
- Twin bored tunnel separation and interaction between twin bores.

5.6.1 Flotation

The bored tunnels were checked for the possibility of flotation due to differential water pressure. Since no relevant Hong Kong code for checking the flotation of bored tunnel was available, the method stipulated in Civil Design Criteria for Road & Rail Transit System from Land Transport Authority of Singapore was adopted. Sufficient ground cover above the tunnels is provided to ensure sufficient dead weight to prevent tunnel floating with due considerations of long-term scouring of the seabed and the future dredging of the Urmston Road.

5.6.2 Face Stability

Generally, the stability of the tunnel face during tunnel boring by TBM is maintained by the face pressure of the TBM. The mixed-shield slurry TBM is widely used for subsea bored tunnels because the use of the slurry system allows a much more precise control of the face pressure (+/- 0.05bar) than an EPB system (+/-0.20bar). This mitigates the risk of blow-out in sections with shallow cover. In addition, during routine cutterhead interventions, the slurry in the cutterhead can be drawn down to about 1m below the axis to allow cutters to be inspected and replaced. Because of the importance to ensure adequate face pressure provided by the TBM, proper face pressure control and determination of the minimum soil cover to prevent blow-out failure for a mixed shield slurry TBM is crucial.

In order to determine the face pressure to be provided by the TBM, three simplified failure mechanisms are presented in Figure 5. The lower bound face pressure should be provided to prevent face collapse (active failure) as shown in Figure 5(a). On the other hand, the face pressure should not exceed the upper bound passive failure as shown in Figure 5(b). Besides, if the vertical pressure applied by the TBM in the excavation chamber is equal to or greater than the overburden pressure as illustrated in Figure 5(c), the resultant stresses on top of the TBM can result in heave at the surface. In an extreme situation, a "blow-out" failure at tunnel crown can occur, with the subsequent loss of face pressure and collapse of the excavated face. This problem is particularly acute for subsea tunnels because the water level is always higher than the seabed level. The required slurry pressure is dominated by the water pressure. In order to have sufficient overburden pressure above the tunnel against the relatively high slurry pressure, the tunnel alignment was designed to provide sufficient soil cover with adequate factor of safety against failure.

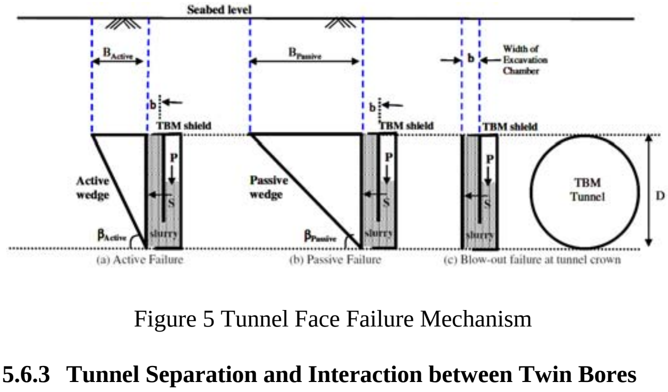

Figure 5 Tunnel Face Failure Mechanism

5.6.3 Tunnel Separation and Interaction between Twin Bores

Since the twin bored tunnels are constructed one by one, and so the separation of the twin tunnels should be sufficiently wide to minimize the interaction between the twin tunnels during and after construction. Generally a tunnel separation of one tunnel diameter is provided. However for sensitive ground condition such as in weak marine deposit, sensitive study was carried out to assess the impact of tunnel separation to determine the most feasible horizontal tunnel alignment.

5.7 Hyperbaric Cutterhead Intervention

Maintenance of the TBM cutterhead is required from time to time in particular for changing worn or damaged cutter discs when excavating in mixed and hard ground conditions. The Shanghai Chong Ming Tunnel was equipped with free air spokes within the cutterhead so that the damaged cutter tools could be changed under atmospheric conditions within the spokes. However it was only successfully applied in soft ground excavation of Chong Ming Tunnel and the feasibility of changing the cutter disc within the spoke for mixed ground excavation is still under development. Therefore, the possibility for entering the excavation chamber under hyperbaric condition cannot be ruled out. Regular inspection and maintenance of the cutter discs and TBM cutterhead will be required.

The cutterhead intervention works shall follow the relevant requirements under the Factories and Industrial Undertaking (F&IU) (Work in Compressed Air) Regulations, the Factories and Industrial Undertakings (Confined Spaces) Regulation and the Code of Practice for Safety and Health at Work in Confined Spaces issued by Labour Department of HKSAR Government.

In accordance with the F&IU (Work in Compressed Air) Regulations, except in the case of emergency, no person shall be employed in compressed air at a pressure exceeding 50 pounds per square inch (equivalent to 3.45 bar) without permission from the Commissioner for Labour. Based on the developed tunnel vertical alignment with due consideration of tunnel flotation and tunnel face stability issues, the maximum inspection pressure will be up to 6 bar. Therefore, an application for approval for working in compressed air higher than 3.45 bar would be required. A comprehensive study on working at a pressure exceeding 3.45 bar has been undertaken with a view to obtaining permission from the Labour Department.

Apart from the statutory requirements, possible health risks and hazards in hyperbaric works under high pressure were investigated. When tunnellers are working under higher than atmospheric pressure, additional oxygen and nitrogen gases will dissolve in their body tissues. The additional oxygen is consumed by the tissues, but the excess nitrogen must be removed from the blood during decompression. During or after decompression, this excess nitrogen gas can form bubbles in the tissues, these bubbles may then cause symptoms that are referred to as decompression sickness (“DCS” or “the bends”). Trapping of gas within the lungs during ascent, either because the lung is diseased or because of breath-holding, can cause bubbles to be forced into the bloodstream (“arterial gas embolism” or “AGE”), where they can block the flow of blood or damage the lining of blood vessels supplying critical organs such as the brain. Symptoms of DCS or AGE can include joint pain, numbness, tingling, skin rash, extreme fatigue, weakness of arms or legs, dizziness, loss of hearing, and in serious cases, complete paralysis or unconsciousness.

In order to reduce the risk of DCS or AGE, sufficient time shall be allowed for the compressed air absorbed in the blood or tissue fluids to come out of the body without forming gas bubbles inside the body. Generally decompression is carried out according to the published and approved decompression table. However the statutory decompression table adopted in Hong Kong for compressed air works higher than 3.45 bar is not available. With consultation with medical hyperbaric doctor and deep diving specialist, decompression table with pressure higher than 3.45 bar available in other countries were reviewed and found that it would be applicable.

As pressure increases the allowable working period decreases significantly under conventional condition and decompression would take a long time to complete. In commercial diving, mixed gases method was developed to avoid nitrogen narcosis, improve decompression, decrease gas density, lower thermal capacity, and prevent the high-pressure nervous syndrome. There are three mixtures of oxygen, nitrogen, and helium that are used today for deep and saturation diving: nitrox (nitrogen/oxygen with higher partial pressure of oxygen than air), heliox (helium/oxygen with varied portions of oxygen and helium in mixture), and trimix (helium/nitrogen/oxygen as in heliox with varied portions among the three gases). Nitrox is used at relatively shallow diving depth as the breathing gases to reduce decompression sickness, heliox is employed for deep diving, and trimix is used for dives to depths at which the high-pressure nervous syndrome may be expected and for short and relatively deep dives. For long term maintenance or repair works, saturation diving may need to be considered. Saturation diving refers to the situation whereby the diver's tissues have absorbed the maximum partial pressure of gas possible for that depth due to the diver being exposed to breathing gas at that pressure for prolonged periods. This is significant because once the tissues become saturated, the time to ascend from depth, to decompress safely, will not increase with further exposure. Under this condition, the diving works may be maintained for up to several weeks, and they are decompressed to surface pressure only once, at the end of their tour of duty. By limiting the number of decompressions in this way, the risk of decompression sickness is significantly reduced. This application has been adopted in Westerschelde Tunnels in Netherlands and is considered feasible to be adopted for TM-CLKL.

Methodology, risk assessment and management plan have been undertaken in the design stage. These have been further developed and established in detail to address the intervention strategy during the construction stage.

5.8 TBM Bored Tunnel Launching and Retrieval

Typically the works site to launch a slurry TBM includes spoil treatment facilities (i.e. slurry treatment plant – STP and spoil basins), segment storage area, workshops and space for the TBM ancillary equipment. With the two TBMs deployed simultaneously, the works site will need to be approximately doubled.

Delivery of the TBM and the precast concrete segmental lining panels would be made by sea transport. As the area in Tuen Mun is already developed with a matured road network it would be logical to establish the launching site in the Tuen Mun side where transportation of the supplies and materials can easily be made via land transportation. Spoil can be removed off-site either by trucks or by sea using barges.

Working shafts are required for TBM launching and retrieval at the ends of the tunnels. Since the tunnel level will be about 50m below future reclamation level, the depth of shaft will be in the range of 45-50m and circular shafts are adopted for better transfer of earth load. In order to allow launching and retrieval of the 14m diameter TBM, the internal diameter of the shafts is about 50m.

5.9 Cross Passage between TBM Bored Tunnels

The emergency evacuation of the public from a tunnel in the event of a fire incident to a place of safety can be achieved by cross passages between adjacent tunnels. Cross passage construction would be one of the high risk activities as it requires the segmental lining to be breached. Prior to breaching the tunnel lining the ground that will be occupied by the cross passage excavation has to be stabilised.

Since the cross passages were located under the sea, ground treatment work from top of these locations may not be easy and appropriate due to the issues of interruption of waterway, environmental and marine impacts. Ground treatment using ground freezing to be carried out from inside of the TBM bored tunnel had been considered. Another alternative of using mini-TBMs could be considered.

5.10 Risks Management and Tunnel Health and Safety

The successful construction of many TBM bored tunnels in Hong Kong and all over the world demonstrated that health and safety can be achieved for tunnel construction by TBM. However, as the TM-CLKL project is the first subsea TBM bored tunnel project and the longest road tunnel in Hong Kong, it is indeed that health and safety in the construction of TM-CLKL would be much more challenging than other tunnel projects.

Safe system of work including risk assessment, safe operation of TBM and emergency procedures should be provided and implemented by the contractor for the TBM tunnelling works.

The major high risk works of a subsea TBM bored tunnel include cutterhead intervention in hyperbaric condition, cross passage construction, TBM excavation in mixed ground condition, stability of tunnel face in sections with shallow ground cover and interface with the HKBCF seawall. A risk management plan and risk register was produced during the preliminary design stage. The risk register has been carried forward to the detailed design and construction stages of the project.

A risk register has been developed and presented in the Systematic Risk Management documents under the following categories of risks and mitigation measures:

- General Health, Safety and Environmental;
- Design Management;
- Programme and Costs; and
- Risks to third parties and existing facilities.

6. CONCLUSION

Since the first subsea tunnel across the Victoria Harbour in Hong Kong was constructed in 1972 using immersed tunnel method, four other subsea immersed tunnels were constructed across the Victoria Harbour between 1979 and 1997. The immersed tunnel technique is well established in Hong Kong and considered less risky when compared with other methods for subsea tunnel construction. However, with the site constraints of TM-CLKL, using a TBM method would have much more benefits over the IMT especially for excavation in the seabed, as it does not require dredging and marine access. It eliminates the impacts to the environment and marine ecology particularly in the active zone of Chinese White Dolphins. In addition, diversion of the submarine power cables is not required and this can ensure the project can be constructed according to the implementation programme.

Teams of hyperbaric doctors, deep diving specialists and TBM manufacturers and suppliers are required in order to address the technical challenges such as working in high pressure, difficult ground conditions and hyperbaric intervention.

The study concludes that TBM bored tunnel scheme is feasible under such site conditions and constraints and has been considered as the most appropriate scheme to be implemented for the TM-CLKL subsea crossing, while taking care of environmental concerns and interest of the general public.

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