Innovative Skidding Mega Truss Shoring System

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ABSTRACT

The construction of submerged tunnels at marine areas is a difficult challenge faced by both Contractor's and Designer's as the excavation and tunnel construction works will be carried out over water exposing workers to safety risks for marine works and the costly logistical planning required. To overcome this challenge, the proposed cut and cover tunnel with clutched pipe pile (CPP) wall cofferdam would use an innovative method where mega trusses are proposed as struts for the first and second shoring layers and also double function as support for the hanging kingposts. The trusses would be transported by barge in modules and assembled on the bulkhead temporary working platform as on-site assembly factory. Once mega truss is assembled, strand jack lifting towers will lift each mega truss onto the skidding rails installed along the top of the CPP cofferdam wall where hydraulic jacks will skid each truss in a sequence of small strokes along the rails until they reach their final position and this process is repeated for all trusses. The use of the mega truss skidding system increases the productivity and cost effectiveness of both the installation and dismantling of the ELS works in addition to reduction of the safety risks and complexity of erecting steel works above water.

Keywords: Skidding, ELS, Truss

1 Introduction

1.1 Project Background

In the Central Kowloon Route - Kai Tak West (CKR-KTW) project by the Highways Department Major Works Division under Contract no. HY/2014/07 and is located at Kai Tak West area. The main works are for the construction of a 900m length dual three lane carriageways by cut & cover method comprised of 125m long depressed road and 200m long underpass at the runway of former Kai Tak Airport, a 370m long submerged tunnel under Kowloon Bay and 160m long tunnel located at Ma Tau Kok Public Transport Interchange. Refer to Figure 1 below.

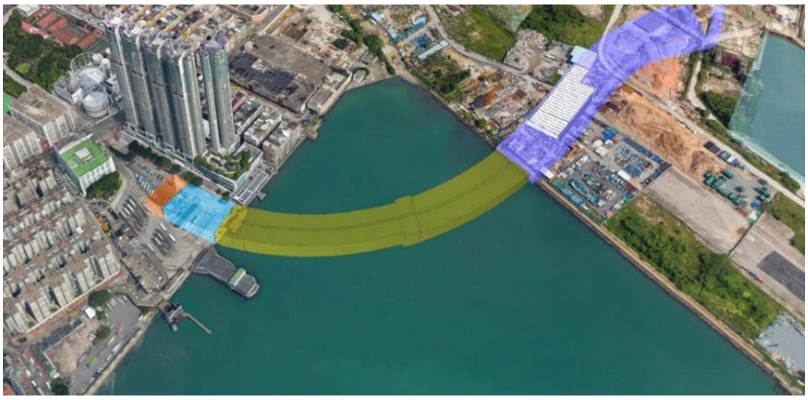

Figure 1: CKR-KTW Submerged Tunnel located at Kowloon Bay

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The construction of the 370m length by 60m width curved submerged tunnel at Kowloon Bay is the highlight of this project and a difficult challenge faced by the Contractor and his Designer for the temporary works required of the bulk excavation and tunnel construction works over water. The works are further made more difficult due to Kowloon Bay (KWB) being a typhoon shelter and marine passage for several stakeholders in the area requiring uninterrupted access through-out the Contract. To overcome this, the submerged tunnel was planned to be constructed in two stages and maintain a 60m wide navigation channel at all times as shown in Figure 2 below:

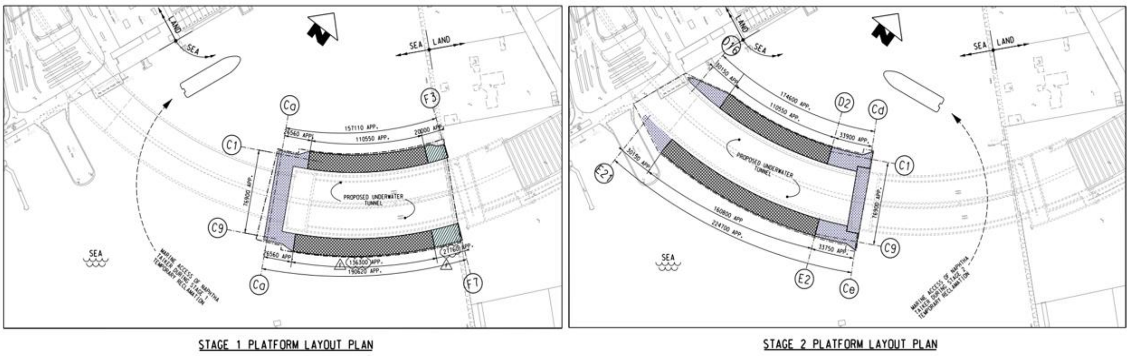

Figure 2: Provision of 60m wide Navigation Channel within KWB

1.2 Innovative Concept for Marine Cut and Cover Tunnel Construction

An innovative scheme was proposed for the cut and cover cofferdams using Clutched Pipe Pile (CPP) cofferdam wall where the mega trusses are proposed as struts for the first and second shoring layers. The mega trusses also provide the 3 nos. of hanging kingposts used for supporting the remaining typical struts below. This sliding strut system eliminates the necessity and difficulties of driving multiple King Post piles and erecting the struts above the water prior to dewatering works. The trusses would be transported by barge in modules and assembled on the bulkhead temporary working platform located at the midpoint of KWB as on-site assembly factory. Once truss is assembled, strand jack lifting towers will lift each mega truss onto the skidding rails installed along the top of the CPP cofferdam wall where hydraulic jacks would skid each truss in a sequence of small strokes along the rails until they reach their final position and the process is repeated for all trusses. The mega truss skidding struts were developed from scheme to detailed design completely in house by the Contractor's Designer. The Designer made use of the experience gained during the use of the mega trusses in previous project in Marina Bay, Singapore and further enhanced for this project by applying skidding struts to allow for easy strut installation over water and elimination of piling works for king posts. The mega truss shown in use at Singapore in Plate 1 below.

Plate 1: Mega-Truss concept as used for ELS works in Marina Bay, Singapore

2 Skidding Mega Truss Shoring System

2.1 Underwater Tunnel ELS Cofferdam

The temporary works for construction of the 370m length curved submerged tunnel commenced in August 2018 and is separated into two cut and cover tunnel stages named Underwater Tunnel (UWT) Stage 1 and UWT Stage 2 with the bulkhead wall located at midpoint of KWB. The cofferdams for UWT Stage 1 and Stage 2 are approximately 160m and 210m in length, respectively. The layout plan of mega trusses for UWT Stage 1 and 2 are shown in Figure 3 below.

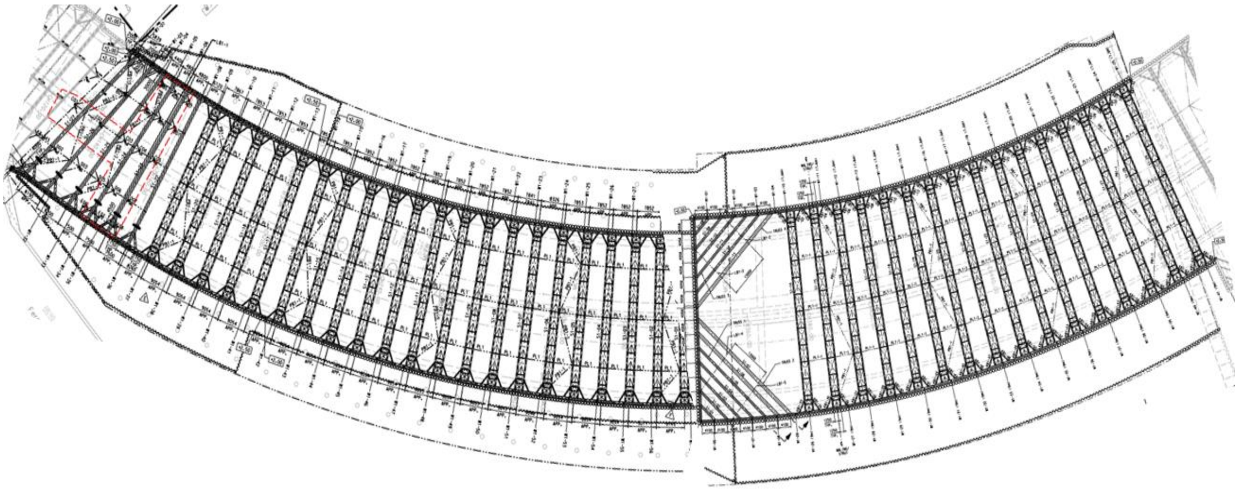

Figure 3: UWT Stage 1 and 2 Mega Truss Layout Plan

The cofferdam wall is a double wall system of 16m width with 813mm diameter x 25mm thick CPP as the inner ELS wall and FSP Type V sheet piles for the outer sea wall. Reclamation backfill is deposited in between the inner and outer walls with tie backs at +2.5 mPD with 6m c/c spacing. Temporary marine working platforms of 16m width were erected with top level of +6 mPD over the reclamation area and supported by 2 rows of staging piles driven by 80t vibro-hammer to the top level of the CDG layer below. The lateral shoring of the ELS works comprised of maximum 6 layers of modular type struts and walers to the final excavation level of -25 mPD. The mega trusses provide the top two layers of shoring for strut layers S1 and S2. The remaining strut layers below are typical modular struts supported by three rows of kingposts hanging from the mega truss above as shown in cross section of Figure 4 below.

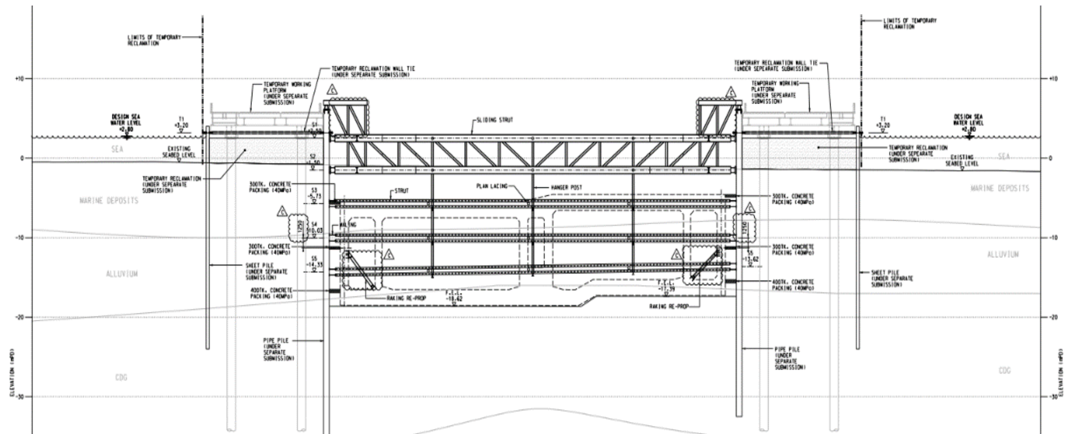

Figure 4: Typical Cross Section of UWT Stage 1 ELS Arrangement

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The mega trusses also allowed the earlier commencement of the pumping test as the ELS design required that the strut layers S1 and S2 be installed prior to the required pumping test in order to control the wall deflection to less than 1% of the excavation depth as required by the particular specifications of the Contract. The traditional method of driving kingposts and installing the strut layers S1 and S2 would have required an estimated 75% more time than the mega truss system.

2.2 Mega Truss / Skidding Struts

The design of the mega truss modules was based on two criteria's, first being that they would function as beam / strut combination capable of supporting vertical loads from the hanging kingpost to eliminate the need for piling rig and marine platforms of traditional king post founded in soil or rock and also the lateral shoring loads from ELS design for strut layers S1 and S2, secondly, the mega truss should be transportable by barge in modular segments onto the temporary cradle and assembled by bolt and nut into the full span for lifting by the strand jack towers onto the skidding rails. It was determined that each of the modules would be sized to be less than the SWL of 50t which is the lifting capacity of the crawler crane positioned on the temporary marine working platform at the bulkhead of UWT Stage 1 and 2 interface. The delivery of mega truss modules to assembly area is shown in Plate 2 below:

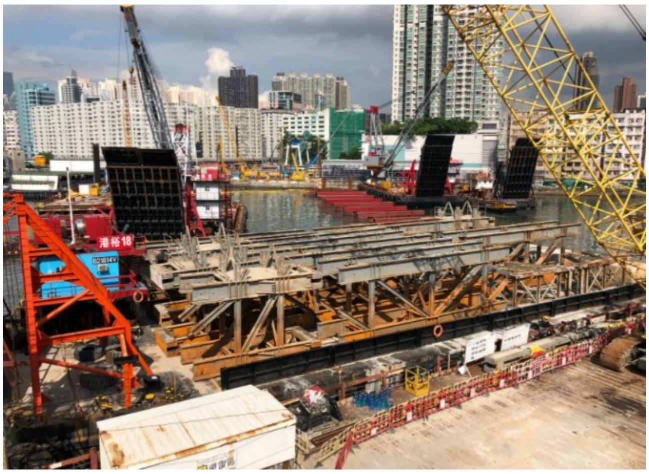

Plate 2: Mega Truss modules as arranged on transport barge

Therefore, each of the 9 nos. of modular segments was limited to be less than 30t with the completed mega truss having a gross weight of 160t and clear span of 57.7m. The mega truss cross sectional area is generally 3m width by 5m deep. The modular segments and weights are shown in Figure 5 below.

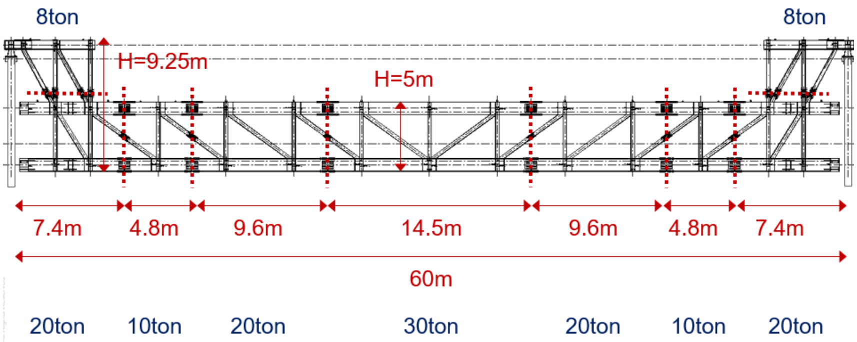

Figure 5: Modular Segments of Mega Truss (UWT Stage 1)

At either end of the mega truss are forks extending out 3m on each side of the strut and connected to 9m wide walers to spread the strut loads onto the CPP wall. The 9 nos. of modular segments are connected by nut and bolt on a temporary hanging cradle to avoid the necessity of carrying out hot works above water and benefit worker safety. The mega truss is pre-set at the required strut levels with the top chord for S1 at +2.5 mPD and bottom chord as S2 at -1.5 mPD. An upstand hanger frame connected at each end of the mega truss rests on the skidding rails installed at the top of CPP wall as shown in Figure 5 below. The 16 nos. of mega trusses spanning the 60m wide UWT Stage 1 cofferdam are designed as modular struts and reusable in the 50m wide UWT Stage 2 cofferdam which require 21 nos. of mega trusses for the lateral shoring works. The deletion of two 4.8m length modular segment from the UWT Stage 1 57.7m span mega truss will change the effective span from 57.7m to 48.1m and the removed modular segments can be used to build up three more nos. of mega trusses with 57.7m span allowing for high majority reuse rate in UWT Stage 2 for the mega trusses from UWT Stage 1.

2.3 Mega Truss Assembly Cradle Strand Jack Lifting Towers

The mega truss segment modules are transported by barge to the temporary marine platform located at the bulkhead of UWT Stage 1 and 2 at the midpoint of KWB where a 200t crawler crane on the marine platform lifts each segment from barge to the temporary cradle for assembly into the full span of mega truss. The platform geometry was set to maximize deck panel sizes to suit derrick lighter and also handling by the crawler cranes on the platform. This meant that the handling logistics required one lane for construction vehicle access to pass by the 200t crawler crane which drove the geometric design of the temporary marine working platforms to be 16m in width. There are 6 nos. of temporary cradles that are hung from the CPP bulkhead wall at the connection joints of each of the mega truss modular segments. Workers then fix the modular segments together by nut and bolt to form the final completed span of the mega truss strut. The marine working platform and temporary cradles are shown in Figure 6 below.

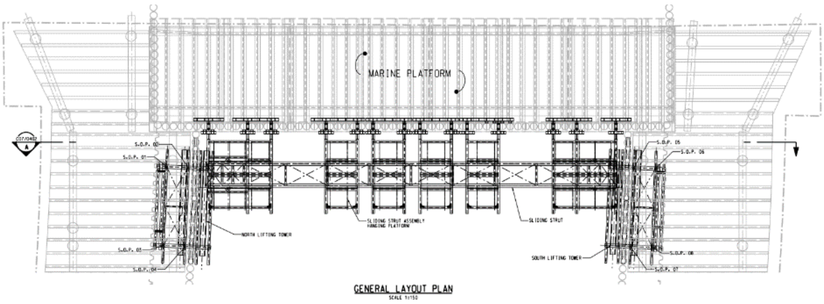

Figure 6: Mega Truss Assembly Yard - Temporary Cradle, Lifting Tower and Strand Jack Layout

Two numbers of strand jack lifting towers are used to lift the mega truss struts onto the skidding rail and they are designed to be reusable from for UWT Stage 1 to UWT Stage 2. Each lifting tower is approximately 17m in height by 4m wide by 13m long and positioned at either ends of the temporary cradle each with a lifting capacity of 200t. The Lifting Tower and Strand Jacks arrangement are shown in Figure 7 below.

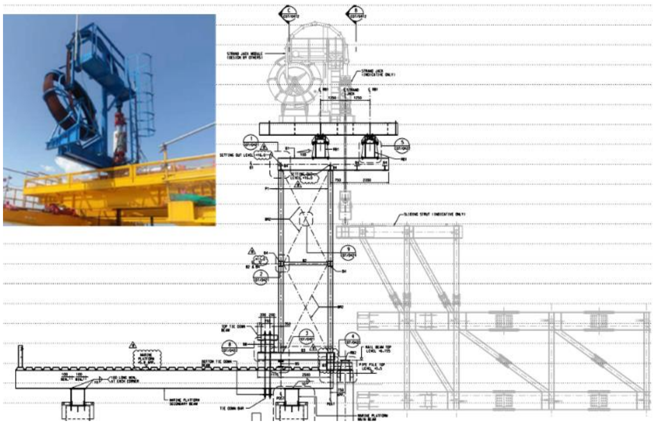

Figure 7: Lifting Tower and Strand Jacks Arrangement

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2.4 Mega Truss Skidding System

The skidding system is comprised of slotted skidding rail, slider and hydraulic jack system, mega truss skate and vertical jack system. The mega truss strut is lifted directly by the strand jack lifting tower onto the skidding rail. Rollers are provided on each side and a PTFE pad to reduce the friction of the 160t mega truss struts. Since the UWT ELS cofferdam is curved, the rollers allow the mega truss strut to maintain its alignment along the curved skidding rail while skidding with a tolerance for longitudinal movement. Next a fully retracted horizontal hydraulic cylinder jack is attached with lock pin inserted to the skidding rail slots and used to push or skid the mega truss simultaneously at both ends of the curved skidding rails. Workers at each end of the mega truss strut observe the skidding movement to ensure that both ends are skidding at the correct rate. Should one end skid too fast, the worker would cease skidding and allow the other end of the mega truss to catch up to the correct rate of advance. Both workers would be in communication with each other and another worker would observe the overall rate of skidding from the high point of strand jack lifting towers. The jacking system hydraulic power unit is placed directly onto each end of the mega trusses. Illustration of the skidding action of the mega truss is shown in Figure 8 below.

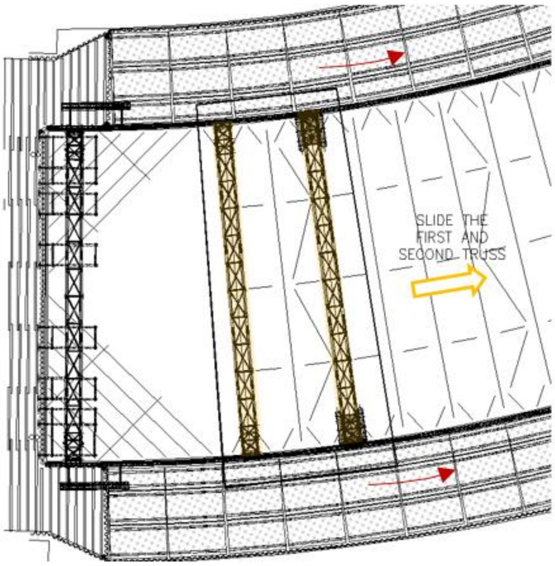

Figure 8: Skidding mega truss from UWT Stage 1 bulkhead towards the Kai Tak seawall

The aerial view showing all 16 nos. of skidding mega trusses in position as well as the progressive staged excavation and lateral shoring works up to strut layer S5 are shown in Plate 3 below.

Plate 3: Completed view of skidding mega trusses at UWT Stage 1

The skidding of one mega truss across a typical bay of 12m length requires approximately 1 hour. Once the mega trusses are skidded into positions, two nos. of locking pins are inserted with stoppers and welded to the mega strut to maintain its final position for the duration of the tunnel construction works. The process is repeated for the remaining mega trusses until all 16 nos. of mega trusses are in position. As the mega truss is designed to be reused, the removal of the mega trusses is done in reverse and the modification of the truss segment modules as described in *Section 2.2* above for reuse in ELS UWT Stage 2 is completed on land.

2.5 Design Considerations and Modelling

The design concepts of the skidding idea were drafted early on during the tender design stage which the detailed design drawings of the skidding mega trusses were based upon. The early concept ideas are shown in Figure 9 below.

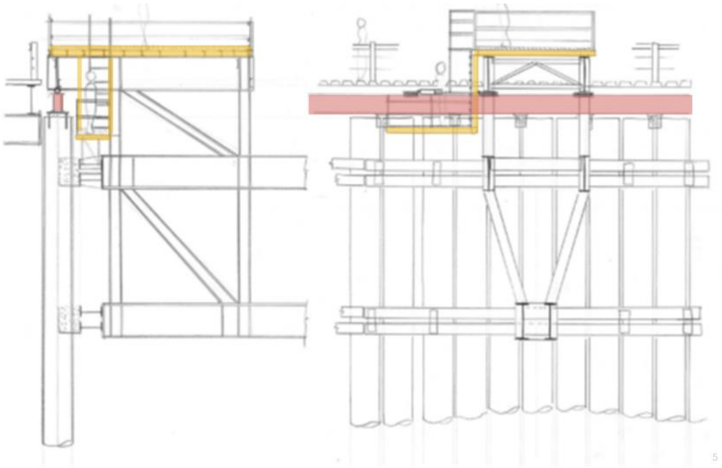

Figure 9: Early Conceptual Design on the Development of Mega Truss Skidding System

From the preliminary conceptual design, the berthing or accidental impact of ship vessels was a major consideration for the skidding truss system. In order to mitigate this impact, the 16m width of temporary marine working platforms and the reclamation backfill were tied back together at +2.5 mPD to form the double wall cofferdam and provide significant mass to mitigate berthing from the marine working barges or accidental impact collision of marine vessels operating in the KWB typhoon shelter area. The tie between outer and inner walls was envisaged as a fuse, acting only in one direction or tension without transferring direct compression loads from berthing vessels or accidental collisions to the ELS struts. The use of OASYS GSA structural computer modelling was carried out to simulate the collision from marine vessel to the temporary marine platform and impact to the skidding rails as shown in Figure 10 below.

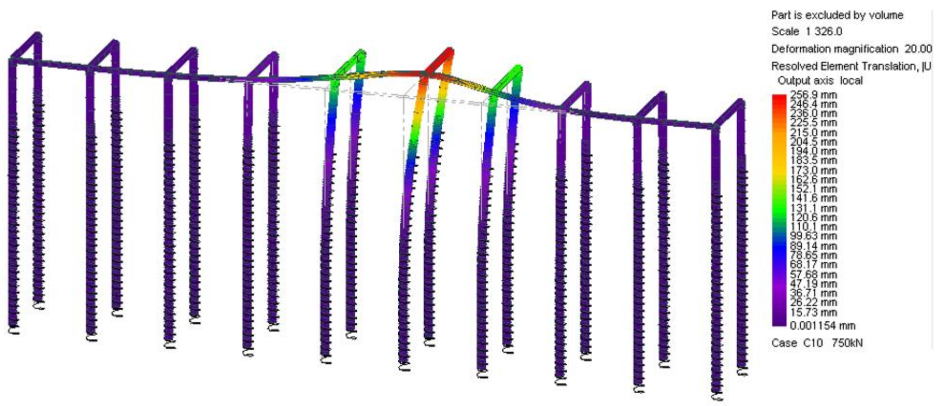

Figure 10: OASYS GSA computer modelling of accidental collision on temporary marine working platform

Since the CPP wall effectively functions as both a retaining wall and vertical support for the mega trusses above, the CPP wall was modelled as a retaining wall. The vertical load applied at the top was checked against the structural and geotechnical capacity of the CPP. This was modelled along with the double tie back wall and marine working platforms directly in the PLAXIS computer simulation. Additionally, the predicted maximum wall deflection at the top after would need to be known to allow suitable tolerance for the skidding system upon the time for the removal of struts. The PLAXIS model geometry is shown in Figure 11 below.

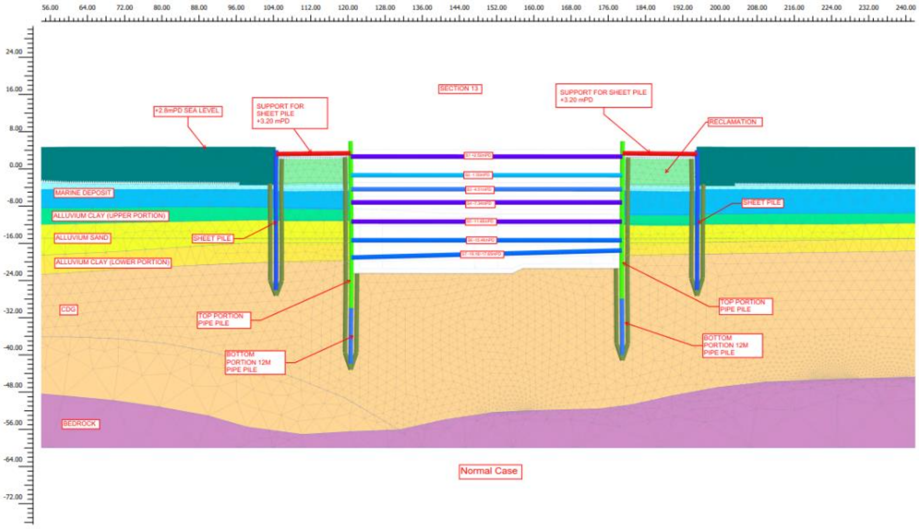

Figure 11: PLAXIS modelling of ELS and Mega Truss Strut

Consideration was also made for removal of the mega truss was made for the deflection of the CPP wall after completion of tunnel structure and backfilling works by including a 1m segment allowed for sacrificial cut at localized strut extension of S1 / S2 levels and walers. The ELS design also required that strut layers S1 and S2 be installed prior to pumping test and dewatering works for installation of strut S3 layers and below in order to control the cofferdam wall deflection to within the PS requirement of 1% of the excavation depth. Without the use of the skidding mega truss method, the construction programme would have been severely adversely impacted by the traditional method of vertical member installation and subsequent staged bulk excavation and dewatering works sequence. The removal of CPP in UWT Stage 1 is shown in Plate 4 below.

Plate 4: CPP Removal at UWT Stage 1

2.6 Precautionary Measures

The ELS UWT design adopted seawater level of +2.8 mPD based on the historical seawater levels for 1 in 10-year return periods. However, as a precautionary measure the ELS design also considered the Hong Kong Observatory (HKO) records for the highest historical seawater levels recorded even including the extreme storm of Typhoon Mangkhut in September 2018 where the highest seawater levels recorded up to +4 mPD. Therefore, the CPP top level of +6 mPD was adopted so that along with the outer sheet pile wall, the marine platform top level and 16m width provided margin to safely prevent seawater overtopping the cofferdam wall and flooding the UWT ELS works by standing waves up to two times the wave height due to wave interference. The design of the cofferdam wall and platform to mitigate the risk of flooding is shown in Figure 12 below.

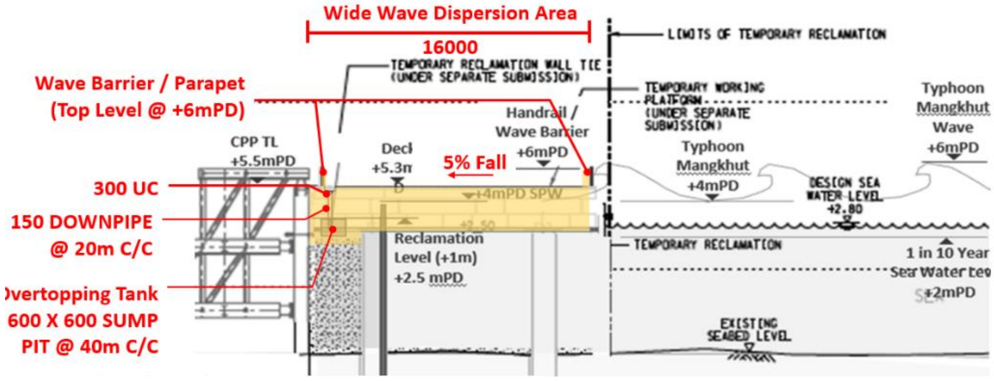

Figure 12: Precautionary Measures for Flood Risk Mitigation

2.7 Potential Limitations

The main limitation of the skidding mega truss system is due to the width of the ELS cofferdam. As the ELS span increases, the free span of the simply supported mega trusses also increase, which proportionally increases the bulk and weight of the mega trusses and at some point, it becomes structurally unfeasible and uneconomical to construct and erect such a large span.

The potential limitations and solutions for the skidding mega truss system are listed below:

- Large Span (50-60m) that is required for the mega trusses are heavier in steel tonnage for the ELS compared to traditional king post design. However, king posts would have meant additional platforms / piling cost which meant that even though the mega trusses had greater steel tonnage, they would still be faster and less costly.
- Shallow seawater obstructs the mega truss skidding since the truss structural depth of 5m requires sufficient draft for clearance between the truss soffit and the sea bed level. As the water depth is shallower nearby the shore line, some dredging of seabed within the cofferdam to below the soffit of mega truss is required.
- Transportation of the bulky and heavy mega truss modules makes delivery to the assembly area difficult. As there is no marine or land access for mega truss delivery at both ends of the cofferdam-seawall interface, an island platform at the bulk head is required for the loading and unloading of truss modules from barges. Therefore, the mega truss modules are fabricated in our strut factory in parallel with the installation works for the ELS cofferdam wall and transported to site when needed to reduce the storage area for mega trusses on site.
- Skidding Rail placement on top of the CPP wall meant that the wall alignment for individual piles that were out of tolerance wasn’t critical. We pit the vertical load down the centre of the wall and the truss had to be designed for that tolerance as well as the lateral movement from deflection of the ELS cofferdam wall.

3 Conclusions

The Employer envisaged scheme was a full reclamation, D-walls and constructed as a land operation with king posts. The Contractor's solution was quite a big departure in thinking and had many interacting benefits to simplify the construction. The use of this innovative construction method facilitated increase productivity by eliminating King Post piling works and safety to workers compared to the traditional method of ELS works at marine area and risk associated with working above water. The system benefits the environment by being reusable and reduces the quantity of marine piling works as well as the reclamation fill needed as working platform at excavation area.

4 Declarations

4.1 Acknowledgements

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4.2 Publisher's Note

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