Innovative and Practicable Designs in Construction

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Introduction

Infrastructure developments are escalating at an unprecedented speed in recent years in Asia. The continuous urbanization results in the ever increasing need for housing and transportation. Land becomes scarce and these infrastructure developments are planned in closer proximity to the existing structures, sometimes even underneath or above another. This has imposed a unique set of constraints in each case, on both the design and construction. The engineers shall not only design it as a 'wished-in-place' structure, but also be familiar with construction techniques and able to apply a suitable method, sometimes a unique one, to overcome those constraints.

In doing so, innovative thinking is needed and innovative ideas are explored and developed into a workable solution. In many instances, these innovations in construction are led by the contractors and their designers.

This paper aims to present the specific constraints the contractors have encountered in the form of three case studies - two projects in Hong Kong and one project in Singapore, and how innovative ideas have been developed into practicable solutions that are both time- and cost-effective.

- Case Study 1: Singapore – A Steel Footbridge
- Case Study 2: Hong Kong – A Cut-and-cover Tunnel Crossing Underneath an Existing Tunnel – Alternative Design of Foundation by Re-using Existing Barrettes
- Case Study 3: Hong Kong – Happy Valley Underground Stormwater Storage Scheme – Use of Drainage Blanket

Conclusion

Innovative and practicable solutions have been developed to overcome the unique constraints in each of the three projects presented. The contract arrangement has allowed the contractors and their designers to use innovation in design, leading to time and cost saving for the client whilst reducing construction risks and minimizing nuisance to the neighbourhood and community affected.

References

The Singapore Engineer – Launching of Whampoa Footbridge, 2003, P.Q. Yu & C.S. Fan

Innovation in Geotechnical Engineering in Hong Kong – A Personal View, J.W. Pappin

https://www.neccontract.com/NEC-in-Action/Case-Studies/Happy-Valley-underground-stormwater-storage-scheme

Innovative Foundation Design for Happy Valley Underground Stormwater Storage Scheme, Hong Kong, G.S.K. Chou, K.W.N. Ko

http://issmge2014.ust.hk/~issmge/jun2015/4.Major_project.pdf

Case Study 1: Singapore

A Steel Footbridge

A 58m span steel footbridge was successfully installed over the Kallang River, Singapore, on 1 July 2003, see below picture. A custom made barge was used to float the bridge across the river prior to installation onto the pile caps at the river bank that are supported by vertical and raking piles. A number of design and site constraints have been overcome by the project team for achieving the success of the project.

Figure 1.1 A 58m Span Steel Footbridge Across Kallang River, Singapore

The decking is a steel truss structure that is pre-cambered to allow for deflection as well as drainage collection at the ends. The deck truss is supported by the pile caps at both ends and two transverse beams at approximately one third positions, which in turn are supported by the 'W' shaped bracing hung from the large diameter steel pipe arches.

The original design is that both the decking and arches are supported on the pile caps with separate, anchored end plates. To construct the footbridge according to the original design it would inevitably require falsework over the river. However, there are a number of constraints to erect falsework over the river:

- Kallang River is connected to sea – large tidal fluctuation makes floating platform infeasible
- Shallow riverbed – piling plant access from sea not possible
- Authority approval – environmental concerns, falsework over the river is not preferred

Construction methodology is then sought towards no falsework method. One idea is to build and assemble the bridge on ground and then lift it over across the river. This will require design modifications to the original design, which assumes the decking and pipe arches are connected separately to the pile caps in the ‘wish-in-place’ structure analysis. This is done by inserting a rigid tie beam at either end to tie them together, which has been designed for significant torsional moments. This method would require a lifting capacity of nearly 160Ton at over 30m radius, which is far beyond the capacity of any commercially available mobile cranes.

The direction is then sought towards lifting it over a barge and pulled across the river. However, due to the shallow riverbed as well as its trapezoidal geometry, no commercially available barge is suitable for the task. It has then been decided that a special barge is to be designed and used for the launching. The riverbed profile is surveyed for the geometry design, and a 15m long, 7.8m wide and 1.85m deep trapezoidal shaped barge with a carrying capacity of 140Ton has been designed and fabricated using in-house left over materials. It has been found that a minimum tide level of +2.0m is required so there is sufficient water float and the barge can get close enough to the river bank, which would leave about 4 hours working time in a monthly high tide conditions.

In addition, launching analysis has been undertaken at each stage of construction to check member capacity. The barge is positioned at approximately one quarter position and the reaction from analysis is 94Ton. Temporary bracing members are added at the barge support location and the design iteration process undertaken until the structure is found to be satisfactory and the residual forces will not deteriorate permanent stage performance.

Assembling

Assembly supported on barge

Alignment

Figure 1.2 Erection Sequence (a) Assembling, (b) Loading on barge and (c) Alignment and Fixing on Foundation

The project has been completed in 6 months of contract award, within the construction programme and on budget. The author is the Project Engineer responsible for all temporary works design and staged construction analysis with the contractor, TTJ Design and Engineering Pte Ltd.

Case Study 2: Hong Kong

A Cut-and-cover Tunnel Crossing Underneath an Existing Tunnel – Alternative Design of Foundation by Re-using Existing Barrettes

In a highly urbanised city like Hong Kong, infrastructure is planned further down below ground and quite often a new tunnel constructed underneath an existing one. In this project, a new cut-and-cover tunnel is designed to pass underneath an existing tunnel that is supported by rock socketed barrettes at approximately 15m spacing. The new tunnel is designed to be directly underneath with a small gap at the interface, between 300 - 500mm, which is grouted with structural grouting to allow load transfer. The soffit of the new tunnel is somewhat 30m below ground level. In accordance with the Alternative Design clause in the contract, the contractor and the designer have re-designed the tunnel foundation by re-using the existing barrettes, eliminating the need of new H-piles that would have been installed underneath the existing tunnel.

The original design approach is straightforward: the new tunnel is to be supported by bored pile foundation and at the section under the existing tunnel by new pre-bored H piles constructed using low headroom equipment. The new H-piles will also support the existing tunnel above through the structural grout at the interface in the permanent condition. The new tunnel slabs will be first constructed with box outs around the existing barrettes, and until the new tunnel box is completed and an alternative load transfer path is established through structural grouting at the interface, the existing barrettes will but cut and abandoned. After that the box outs will be completed.

The load transfer mechanism above is simple and the proposed construction sequence is straightforward. The problem is with the construction of the H piles underneath the existing tunnel with a short headroom. The extensive use of site welding in the confined space for the H pile splices is imposing a serious health and safety risk to the workers. In addition, the H-pile construction with mobilization of piling plants underneath the existing tunnel 30m below ground is on the programme critical path. A solution is then sought towards eliminating the H-piles, by re-using of the existing barrettes foundation.

It has been found through an initial study that the existing barrettes are inadequate in supporting both the new and existing tunnels, as well as the soil and surcharge above. In addition, due to lack of buoyancy during the temporary construction (dewatering) stage, the total loads in the temporary condition are found to be even higher than those in the permanent condition.

One possible approach to this is to make use of the ground bearing underneath the new tunnel, however this is likely going to lead to question of compatibility issue due to the differences in stiffness of different types of foundation system. The highly variable soil depth above the rock head will make this even more complicated. Given the stringent checking and approval procedures in Hong Kong, this approach has not been pursued.

Instead, a line of new piled foundation, consisting of large diameter bored piles, positioned at the edge of the existing tunnel either side is proposed. These new bored piles are considered relatively easy to handle – no additional mobilization is required and all works can be done at the ground level. Further analysis has however shown that the barrettes would be overstressed even at the construction stage should the barrettes were connected to the tunnel base slab during the construction of the new tunnel, even though there will still be spare capacity within the new bored piles along the perimeter.

To overcome this, a new approach is considered, by 'preloading' the new bored piles that are under-utilized using jacking method during construction, therefore relieving pressure in the barrettes in the permanent condition. The procedure is as follows: The new tunnel box is constructed with box-outs at the barrettes location, without physical connection. A series of jacks are then installed at the six tunnel wall interception points, next to the two lines of new bored piles. The jacking is carried out sequentially in plan, and jacking loads are increased progressively, so that the loading is applied in a gradual and even manner. The total loads applied through the jacking is limited to 30 – 40% of the weight above at the time of jacking, therefore only partially relieving the compressive pressure in the barrettes. The shear connection between the barrettes and the tunnel base slab is then undertaken and the interface between the tunnels is grouted. Once an alternative load path is established, the section of barrettes inside the new tunnel is cut and the box-outs cast.

Analysis iteration has been carried out in detail to refine the jacking sequence and jack loads, so that the bored pile capacity is well utilized and enough pressure is relieved in the barrettes so that they will not be overstressed in the permanent condition. There will be some loads transferred to the ground bearing during jacking, which are found to be relatively small compared with the bearing capacity tested. Settlements of the tunnels have been monitored closely during the jacking and found to be negligible. In the permanent condition, the ground bearing has not been considered and both the existing barrettes and new bored piles are within its geotechnical capacity.

This method of relieving the pressure in the main foundation by ‘preloading’ the adjacent foundation that are under-utilized has been adopted previously in the ICC project in Hong Kong.

The new design not only makes use of the existing barrettes capacity, hence avoiding waste of resources, removes the health and safety risk to the workers due to excessive site welding in a confined environment, it has also been proved to be a time and cost effective solution that is practicable.

This project has been completed with success in 2015.

The author is the Project Manager responsible for all temporary works design for the deep excavation and alternative design of the tunnel foundation. The project team is the winner of the companywide URS Award of Excellence in the innovation category.

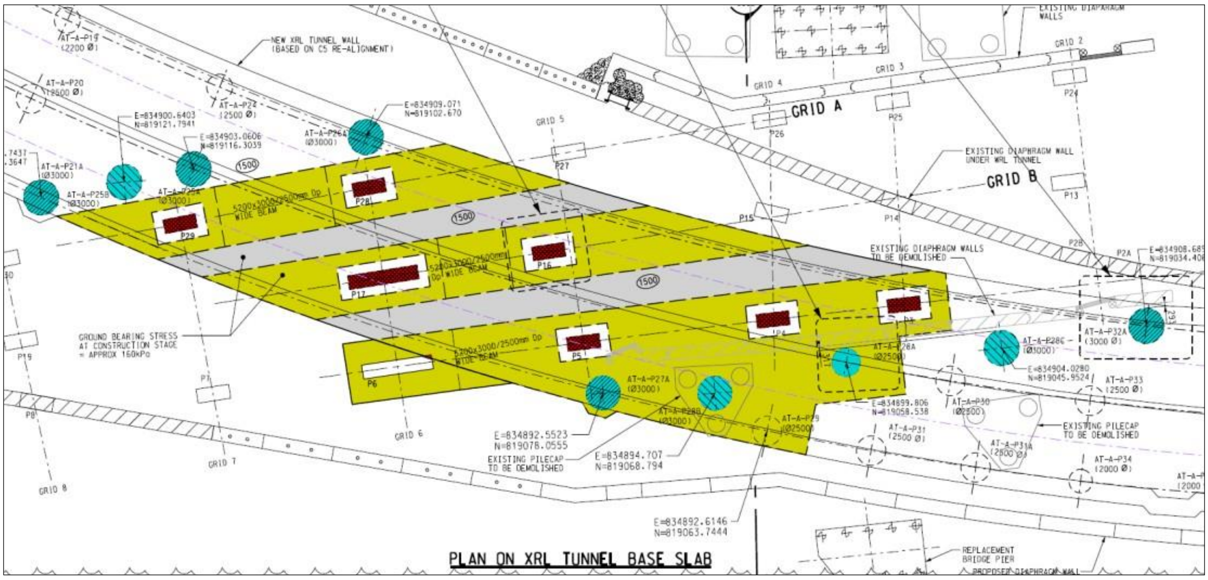

Figure 2.1a Plan Cross Section of Tunnel Construction Underneath Existing Tunnel

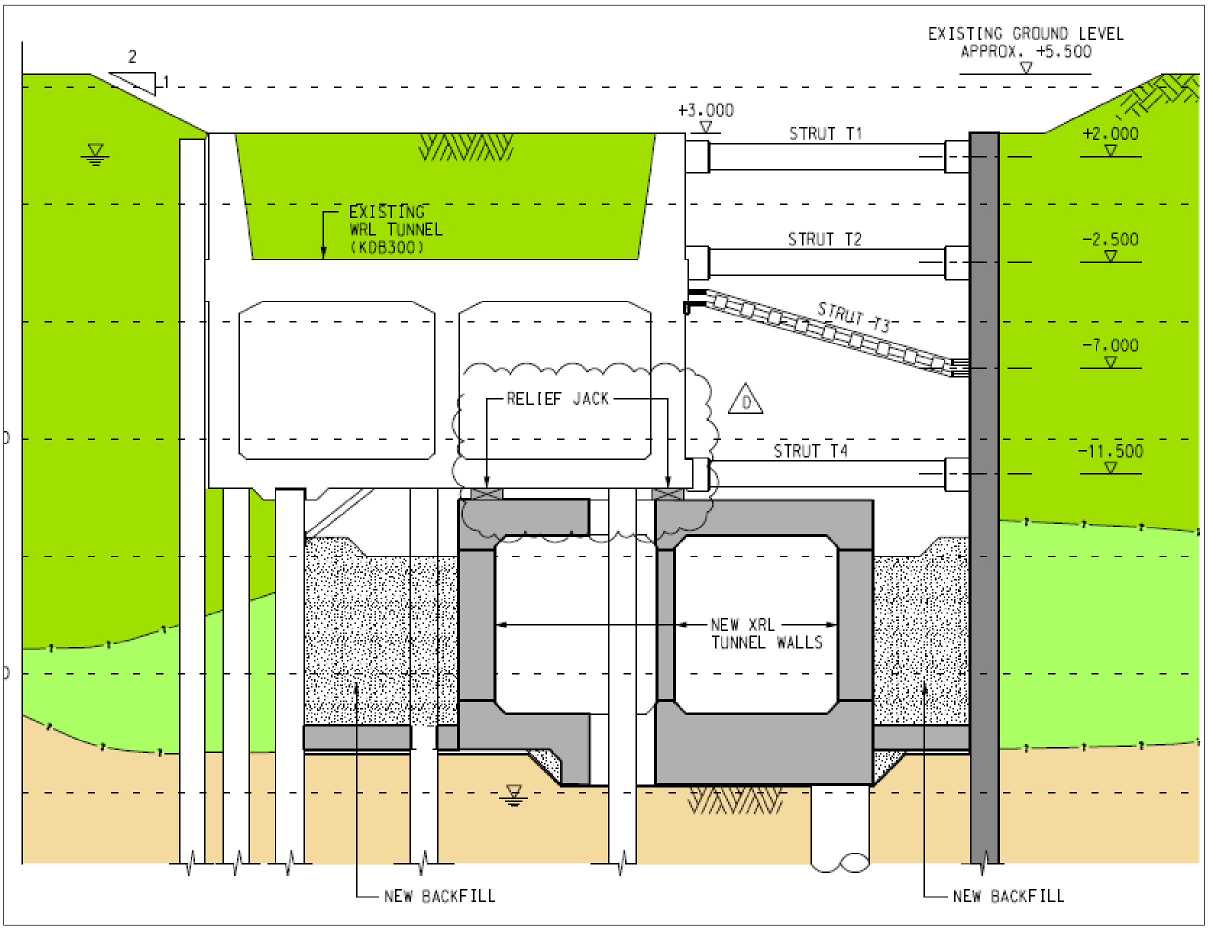

Figure 2.1b *Cross Section of Tunnel Construction Underneath Existing Tunnel*

Figure 2.2 *Aerial Photograph of Construction*

Case Study 3: Hong Kong

Happy Valley Underground Stormwater Storage Scheme – Use of Drainage Blanket

This is another successful application of innovative designs initiated by the contractor in Hong Kong. The project is to construct an underground storage tank that is able to store a minimum 60,000m^3 (or 24 standard swimming pool) of stormwater temporarily, hence alleviating pressure on the drainage system downstream. The site is located at the iconic Happy Valley Recreation Ground right in the middle of the horse racing course and underneath the existing sports fields. The proposed construction is to use a cut-and-cover method, however given its unique location as a prime residential and leisure area, the construction techniques as well as equipment used shall be chosen so as to minimize obstruction to horse racing and other sports activities as well as nuisance to the public and residents in terms of noise and vibration generated. In addition, all construction access is through a dedicated tunnel underneath the existing racing course. The contractor Chun Wo and its designer have developed an alternative means of flotation resistance by using a drainage blanket underneath the base slab, replacing the massive tension piles in the original design.

The original design is a relatively shallow underground box on piled foundation, with 1m soil cover above the roof slab. The existing ground level is at +5m and the base slab soffit at -0.5m. Due to the large empty space needed to store stormwater and a relatively shallow soil cover, the box tends to move upwards as the groundwater table is near the ground level. This has dictated some 500 numbers of pre-bored H-piles socketed into bedrock as tension anchor to prevent the box from floating due to the uplifting water pressure underneath the base slab. The H-piles are 40 – 60m in length, which will be site welded during construction for every 12m. It is required that the piling rigs are dismantled and lowered so as to offer a no obstruction viewing of the horse racing twice weekly.

All of the above has imposed challenges to the construction team, and an alternative way of preventing the box from floating is sought. Various ways have been considered, including a thickened wall / slab design, which will require significant change to the structure geometry such as a 3.5m thick base slab. The solution that is chosen in the end is to keep the box geometry however lower the anticipated groundwater table to +3m by incorporating a layer of 600mm thick drainage blanket underneath the base slab, which will be separated from the soil underneath by a non-woven geotextile. A network of sunken sumps and submersible pumps will be used to collect the water to be drained out. In addition, a cut-off wall will be provided along the perimeter of external wall to prevent lowering of adjacent groundwater table. The cut-off wall is using the temporary sheet pile wall that will be needed to enable temporary excavation, hence with no significant additional cost except verifying the wall toe would be deep enough to provide an effective cut-off. As a fail-safe measure, additional 32 numbers of relief wells have been incorporated through the base slab, which can be used to prevent excessive unfavourable groundwater pressure built up underneath the base slab.

The proposal has been favourably accepted by the owner. This innovative design has saved some HK$ 70million cost (about 10% of the original contract) and 6 months in programme.

It is noted this contract was awarded on NEC3 Engineering and Construction Contract Option C (cost saving incentive and fair risk sharing), whereby a pain/gain share mechanism was implemented to set common goals for the employer and contractor at the beginning. This has ensured that all parties collaborated closely to optimise design, progress, and ultimately reduce the cost, says DSD chief engineer Mr Wai-hung Luk.

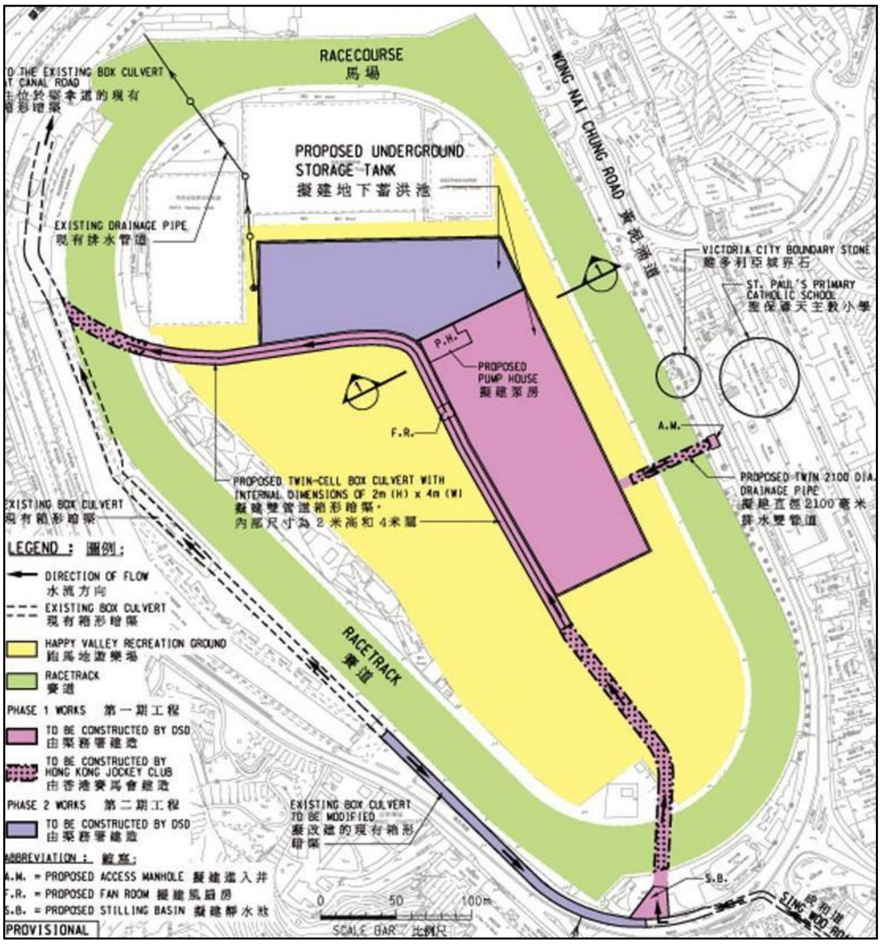

Figure 3.1 Location Plan

Figure 3.2 Completed Stormwater Storage Tank

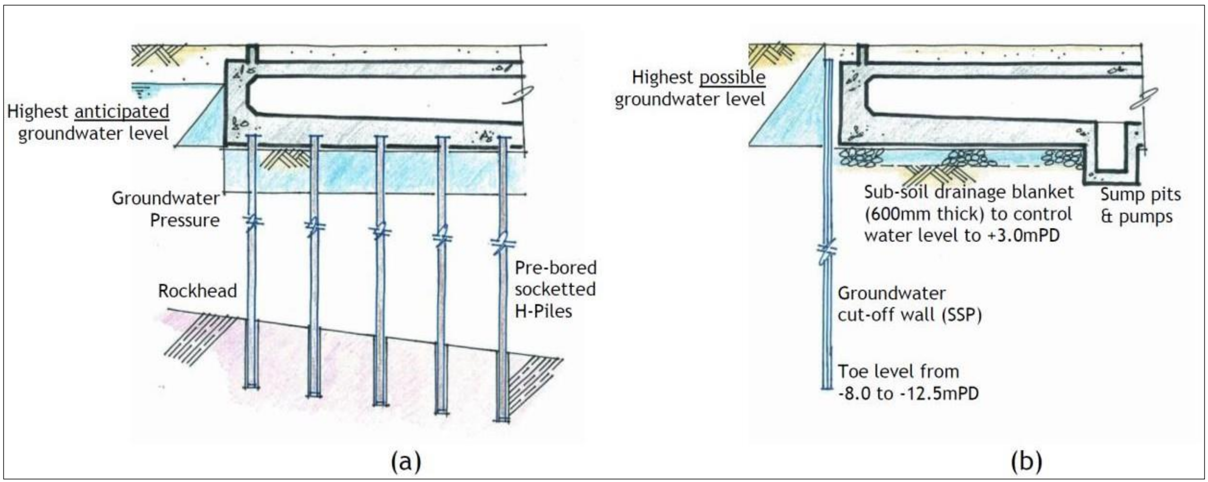

Figure 3.3 Comparison of (a) Conforming Scheme and (b) CSD Scheme