Top-Down Construction Method: A Case Study For Underpass Structure in Qatar

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Abstract

The Cut and Cover construction method has been applied to build several underpass structures within the expressway programme of the Highway Projects Department, Public Works Authority, Qatar. Booming in the construction industry contributes to increasing existing traffic in Qatar. This subsequently failed existing road junctions and required updating the road network parallel to the traffic studied. Underpasses and bridges were planned across many locations in Qatar to increase the level of service at road junctions, enhance the traffic capacity, reduce traffic congestion, and improve the free flow of traffic. This paper discusses the design and construction challenges of the underpass structure constructed by top-down construction method located on D ring Road in Doha, Qatar. The top-down construction method has been suggested by the construction contractor as an alternative to the conventional cut-and-cover construction method to minimize the traffic disruption and meet updated temporary traffic management (TTMs) due to underpass construction works, restore traffic at the junction on top of the underpass prior to the completion of construction works and overall optimize the construction duration. A numerical modelling research was carried out to study the change in arrangements. The site-specific challenges, such as modification in the structural arrangement of the underpass, change in ground conditions, lateral displacement of pile walls and dewatering challenges, are discussed in this paper.

Keywords: Top-Down construction; Underpass construction; Construction method; Deep excavation; Structure in Qatar

1 Introduction

The top-down construction method is preferred for constructing substructures in urban areas where tieback installation is not feasible in the deep excavation and when the aboveground area, such as roads above the substructure, is to be utilized during the construction. This approach allows simultaneous underground and aboveground structure construction.

In a conventional cut-and-cover method, after the construction of the diaphragm wall, excavation proceeds for a certain depth and an anchoring system (one or more layers) are installed to support the diaphragm walls and the excavation proceeds, followed by construction of the underground structure. This process takes more time, and the whole area can only be utilized once the structure is completed. In roadway underground structures, this approach causes much inconvenience to the public as the road cannot be utilized, and traffic must be diverted for a longer duration. Lengthy occupation of road sites with noise disturbances and disruption to access is a prime disadvantage of the cut-and-cover method in busy urban areas (Puller, 2003). This paper presents a case study of an underpass constructed by top-down methodology on D-Ring Road, Doha, Qatar. In this case study, the design approach followed for the top-down construction, the construction sequence adopted, the challenges encountered, advantages and limitations of this approach are discussed.

The D-Ring Road in Doha connects many crowded areas such as Freej Hilal, Al Nuaija, Old Airport and Doha Expressway. D-Ring Road improvements were planned to avoid traffic congestion and reduce travel time. As part of this project, a 420m long underpass with 3 lanes in each direction, with a capacity of 12,000 vehicles per hour, was proposed to provide uninterrupted traffic movement. Underpass construction was planned as a combination of conventional cut-and-cover and top-down construction approach in the design stage. However, during construction, the construction contractor preferred to execute the construction implementing fully the top-down construction approach to minimize traffic disruption and optimize the construction duration (Hossein et al., 2018).

2 Literature Review

Puller (2003) stated that peripheral sheeting/walling, ground and groundwater conditions, geographical location, skills, and preferences of local contractors influence the substructure construction method (cut-and-cover or top-down). The top-down construction will likely minimize wall movements, soil deformation, and settlements. When the excavation depth increases, excavation becomes more complex, leading to top-down techniques which allow simultaneous substructure and superstructure construction.

Whittle et al. (1993) demonstrated the importance of finite-element analysis for top-down modelling construction for reliable and consistent predictions of soil deformations, nevertheless, emphasizes the need for adequate characterization of engineering properties for the entire soil profile.

Marchant et al. (1994) stated that the top-down construction approach was driven by economics from the main contractors' point of view. Moreover, adopting the top-down method can have a far-reaching impact on the design, and implications are also site-specific, per consultants' point of view. It emphasized the significance of involving the contractor at an early stage to enhance the efficiency of the design and construction process.

The top-down approach is well suited for most situations of the urban construction environment. However, it demands rigorous quality adherence, thorough planning, managerial expertise, and a detailed understanding of construction sequences for inclusion in the design and analyses (Basarkar et al. 2010).

Wong et al. (2019) studied the effectiveness of the top-down construction method in Malaysia. They concluded that adopting the top-down construction approach is most suitable and efficient in urban areas and busy traffic locations. The study highlighted the necessity of highly experienced contractors and special machinery for executing top-down construction. Further, the study identified that confined working environments and machine idling are limitations of this approach.

3 Top-down Construction

3.1 Construction Methodology

A top-down approach is instrumental in construction of the underpass. Piles and the top deck slab are first constructed to allow traffic at the ground level, then excavation to the bottom, where the underpass foundation slab and side walls are constructed.

At the site, the following construction sequence was followed, as shown in Figure 1.

- Construction of Contiguous/Tangent-pile Walls and then pile cap construction on both sides. Construction of temporary piles in the middle for the deep sections.
- Construction of approach slab.
- Erection of concrete girders (post-tensioning) and casting of deck slab.
- Proceeding the excavation (with dewatering) to the foundation level in stages using temporary struts supports. Access for the removal of soil was provided.
- Construction of base slab, shotcrete on the pile walls, pouring mass concrete as a counterweight against uplift.
- Construction of underpass box wall.

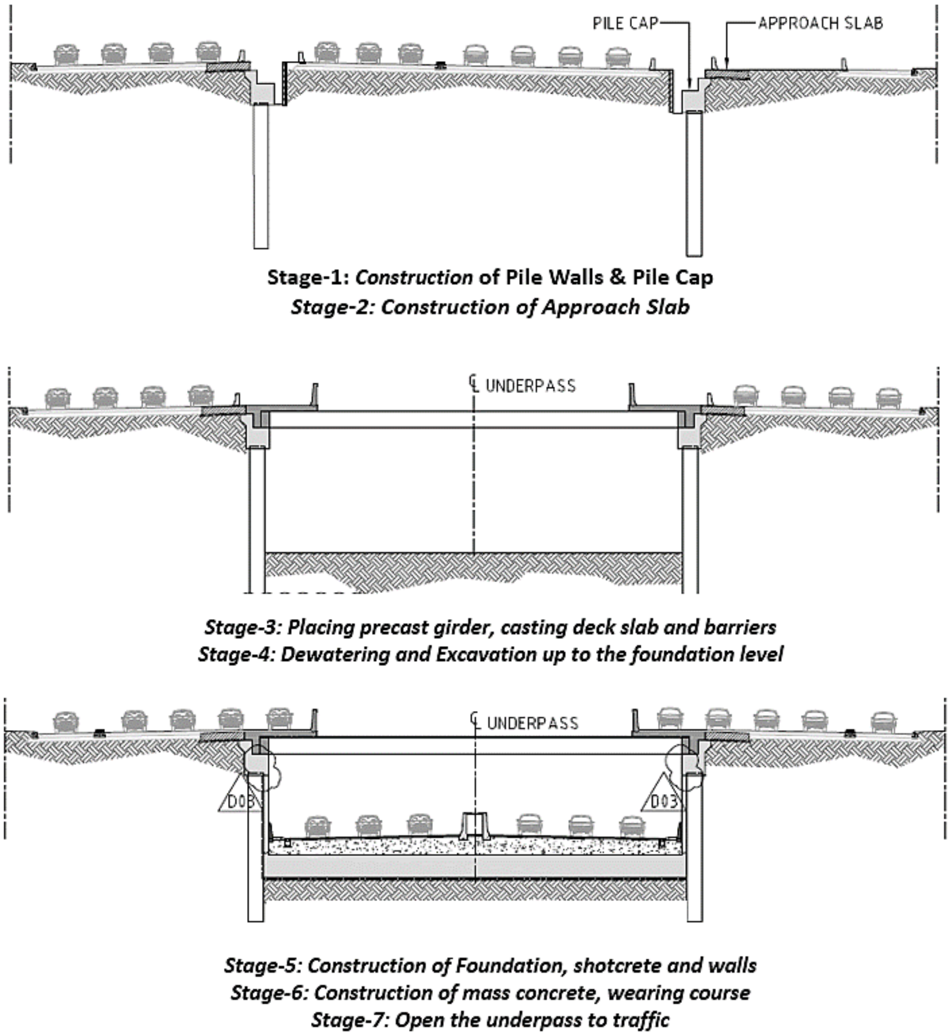

Fig. 1: Construction Stages

Some of the site construction photos showing various stages of construction are shown below in Figure 2.

Boring of Piles

Constuction of Approach Slab

Deck slab reinforcement fixing

Excavation below Deck Slab

Excavation work

Application of Shotcrete at inner face of piles

Formwork installation for wall

Casting Central wall in between temporary piles

Fig. 2: Site Construction Photographs

3.2 Design Approach

The pile wall-ground interaction analysis was carried out using the finite element program Plaxis 2D and forces, displacement, and pile-wall stiffness were assessed. The contractor's geotechnical consultant performed the analysis following each section's Construction Industry Research and Information Association (CIRIA) C760 Guidance on Embedded Retaining Wall Design (Gaba et al.,

2017) of the underpass. In the analysis, each construction stage excavation condition, groundwater level, excavation support system, and loadings were modelled, and the analysis was carried out accordingly. The pile-wall flexural inertia for short-term (temporary condition) and long-term (permanent case) conditions of 0.7EoI and 0.50EoI (where E is the modulus, and I is the moment of inertia) were used. The resultant forces were used in the structural design.

4 Ground and Groundwater Conditions

4.1 Ground Conditions

The subsurface at the proposed underpass location consists of residual soil cover up to about 0.45m to 3.0m below the ground level, comprising *SILTY SAND* with occasional limestone fragments, followed by moderately weak *SIMSIMA LIMESTONE* up to about 10.0 -12.0m depth. *MIDRA SHALE* was encountered below Simsima limestone with a thickness varying from 1.4m to 4.4m which is underlain by a weak to moderately strong *RUS formation* up to the maximum drilled depth of 30m below the ground level. No cavities were found.

4.2 Groundwater Conditions

The groundwater level measured in the piezometers varied between 3.75m and 6.50m below the existing ground level, i.e., between Elevation +3.28m and +7.11m Qatar Highway National Datum (QNHD). The ground surface elevation at the project varied between elevation +13.0m and +15.0m QNHD.

5 Design and Construction Challenges

5.1 Change in Ground conditions

After completing the detailed design and before the underpass construction, wet utility pipeline construction was carried out by another contractor as part of a different project. Due to this, on one side of the underpass close to the pile-wall location, the existing natural formation was excavated and backfilled with soil fill material to about 8.0-10.0m depth (Table 1).

Table 1: Change in Subsoil Conditions

Subsoil Conditions	
During Detailed Design	**After Detailed Design (Before Construction)**
0.0-3.0/4.0m Residual Soil 3.0/4.0-20m and below Rock Formation	0.0-8.0/10.0m Backfilled soils in medium-dense condition 8.0/10.0m – 20.0m and below the Rock Formation

Initially, the pile wall was designed considering frictional resistance from rock formation encountered at about 3.0m below existing ground level. However, as rock formation was excavated and backfilled with soil, the pile wall was redesigned for the latest ground formation, and pile-wall length was increased at these locations.

As the piles must resist the lateral earth pressures and vertical loading, any reduction in pile capacity might have endangered the entire top-down construction approach. The additional ground investigation helped identify the fill areas. Accordingly, the piles at this alignment of the underpass were redesigned by sufficiently extending into the rock formation below the base slab level.

5.2 Modification in Structural Arrangement

Two rows of temporary piles were necessary to be constructed for the deep sections to allow casting the final intermediate wall. Then temporary piles were removed at a level below the base slab. After the installation of side piles and excavation of soils for the construction of the underpass, it was observed that at deeper sections of the underpass where the box structure was proposed, and the exposed tangent piles at some locations exceeded the pile wall alignment tolerances. Revised wall thicknesses were structurally assessed to ensure the safety of construction. This issue has forced the contractor to make some minor modifications to the final structural configurations of the underpass. The final structural arrangement of the underpass structure is shown below in Figure 3.

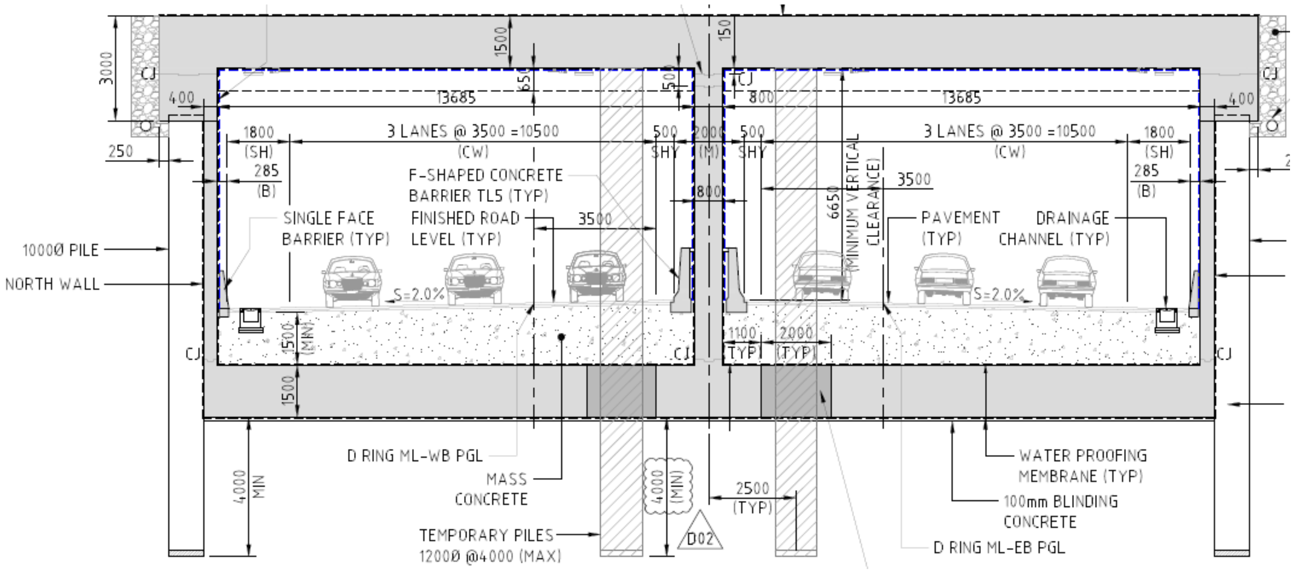

Fig. 3: Final Arrangement of Underpass Structure

5.3 Dewatering

The WellPoint Dewatering Method was adopted at the project site to lower the groundwater during excavation and underpass construction. The dewatering groundwater level was maintained at 1.0m below the excavation level. The existing WellPoint system could not achieve the required dewatering at deeper underpass sections. Hence, additional French drains 1.0m wide and 1.0m thick on both sides of the pile walls and 0.60m x 0.60m in the middle of the underpass at the base level were installed along the underpass alignment, as shown in Figure 4 below.

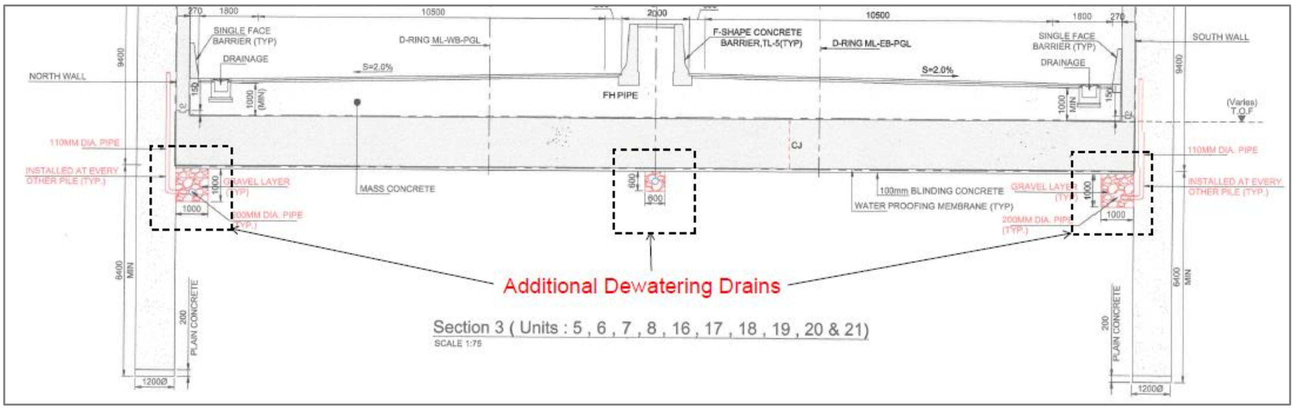

Fig. 4: Additional Dewatering Drains

As the new drain system requires an additional 1m, the pile wall design was checked by performing soil-structure interaction analysis using Plaxis 2D for the additional excavation. Initially, the detailed design of the pile wall design was performed considering additional excavation of 0.50m depth considering possible over-excavation meeting CIRIA C760 Standard (Gaba et al., 2017) requirements. Hence, the net increase in excavation depth was about 0.50m only, and the increase in forces in the pile walls due to this additional excavation is marginal. As dewatering was under progress for some construction activities, the final deflection of walls for the static water level condition is not available.

6 Discussion and Conclusion

The Top-down Construction Method was very useful for temporary traffic management in this project with less traffic disruption. Compared to the conventional Cut & Cover Approach Method, this approach reduced construction duration, and the contractor could complete the construction works on time. Further, this case study reiterates the importance of precise location and structure-specific geotechnical investigation for the design of various structural elements of the underpass. Post geotechnical investigation, nearby below-ground construction activities that could alter the ground conditions must be reported to the designer. The design of deep pile-wall sections shall allow sufficient tolerances considering possible deviations in the verticality of piles, and underpass box structure geometry shall be designed accordingly. Implementing this method in locations with high water table, increases the complexity of the construction and complicates configurations to ensure that specifications for waterproofing details are met.

7 Acknowledgements

UCC Infraroad Limak JV company W.L.L is the construction Contractor, PARSONS International is the Design Consultant, and the Supervision Consultant of this project is WSP International, Qatar, acting also as Independent Checker for the detailed design. ACTS, Qatar, acted as a geotechnical consultant for the contractor and was responsible for the geotechnical design for the Top-down Construction Shoring System. The opinions expressed in this paper are those of the authors and do not necessarily reflect those of the organizations mentioned above and Public Works Authority.

References

Basarkar S. S. et al. (2010). ‘Emerging Trend in Deep Basement Construction: Top-Down Technique’, *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE),* ISSN: 2278-1684, PP: 01-11.

Gaba, A. et al. (2017). ‘CIRIA C760 Guidance on Embedded Retaining Wall Design’, CIRIA, London.

Gui, Y. et al. (2020). Study on deformation law of deep foundation pit with the top-down method and its influence on adjacent subway tunnel. *Advances in Civil Engineering*.

Hossein, Z. S & Mirmohamadi S. & Mostafa (2018). ‘Top-Down Construction Method: A Case Study of Commercial Building’, 11th International Congress on Civil Engineering May 2018, University of Tehran, Iran.

Marchant, S., Wren, G. & Lamb, R. (1994). ‘Top-down construction and its implications’, Proceedings of the Institution of Civil Engineers - *Geotechnical Engineering,107*(2), pp. 123-124.

Puller, M. (2003). *Deep excavations – a practical manual* (2nd Edition), Thomas Telford Ltd., London.

Whittle, A. J., Hashash, Y. M., & Whitman, R. V. (1994). ‘Analysis of deep excavation in Boston’. *Journal of Geotechnical Engineering*, *120*(10), 1911-1912.

Wong, J. Y. et al. (2019). ‘Effectiveness of top-down construction method in Malaysia’. *International Journal of Innovative Technology and Exploring Engineering, 8*(6), 386-392.

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