Box Jacking Method Implementation in Rock for Mesaimeer Pedestrian Underpass Structure in Qatar

Firas Alkadour
Public Works Authority (Ashghal), Doha, Qatar
falkadour@ashghal.gov.qa

Anbalagan Chelliah
Public Works Authority (Ashghal), Doha, Qatar
anchelliah@ashghal.gov.qa

Theodoros Tzaveas
Public Works Authority (Ashghal), Doha, Qatar
ttzaveas@ashghal.gov.qa

Ali Kara
Public Works Authority (Ashghal), Doha, Qatar
akara@ashghal.gov.qa

Abstract

Mesaimeer pedestrian underpass is proposed under the live traffic of Sabah Al Ahmad Road, Doha, Qatar which consists of a four dual lane carriageway, in addition to diverge lanes, service road lanes and right turn lanes by box jacking/pushing method for a total distance of 80.6 m. Due to the necessity of maintaining undisturbed traffic and to avoid disruption of the existing utilities crossing over the underpass alignment, the use of conventional Cut and Cover method is not feasible. Accordingly, trenchless construction method by box jacking/pushing is to be implemented in weathered limestone rock overlaid by fill soil. The method of construction of box jacking includes constructing shaft as launching pit for jacking operation, aligning the precast concrete box into position, excavating the soil/rock at the face of the precast concrete box, then pushing the box into the excavated length, and repeating the process. This paper includes overview of the project and its challenges intending to bring greater familiarity with the box jacking process in rock formation. The design and anticipated construction challenges are discussed from both structural and geotechnical perspectives. The challenges faced include box segment protection details, waterproofing details, construction and expansion joint details, high jacking loads due to rock formation, excavation advancement rate, necessity of grouting at box over-head and impact on existing utilities. Both structural and geotechnical analysis/design are assessed by numerical finite element modelling (FEM). Further, instrumentation and monitoring measures are planned to monitor various utilities and assess the impact during construction.

Keywords: Box Jacking in rock; Underpass construction; Trenchless construction; Structure in Qatar

1 Introduction

Mesaimeer pedestrian underpass is proposed under the live traffic of Sabah Al Ahmad Road, Doha, Qatar which consists of a four dual lane carriageway, in addition to diverge lanes, service road lanes and right turn lane. The underpass is located perpendicular to Sabah Al Ahmad Road and adjacent to Al Ghariya Street, to facilitate and provide safe connections for the pedestrian movement between two urban areas, Al Waab and Fereej Al Soudan as shown in Figure 1.

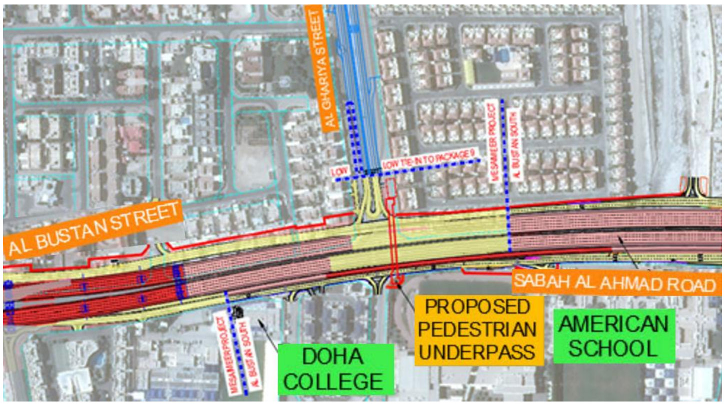


Fig. 1: Project Location

Due to the necessity of maintaining undisturbed traffic and avoid disruption of the existing utilities crossing over the underpass alignment, the use of conventional Cut and Cover method is not feasible. Accordingly, trenchless construction method by box jacking/pushing is to be implemented in weathered limestone rock overlaid by fill soil. Considering the geological conditions in Qatar, construction methodology implemented worldwide needs to be modified. Generally, box is pushed into ground and simultaneously excavation takes place. However, due to the rock formation, excavation must be done ahead of box pushing, which makes it a unique case. Further, the groundwater table is above the underpass top slab level, which would require waterproofing measures and water-tight joints at construction and expansion joints. Konstantis and Massinas (2020) discussed the challenges faced during construction of Doha Metro, Gold Link project by the box jacking method. However, construction sequence presented was not detailed. In addition, the authors did not discuss the waterproofing protection measures and joint details, and the ground improvement works were not presented.

This paper includes overview of the project and its challenges intending to bring greater familiarity with the box jacking process in rock formation. The proposed construction sequence is described and the design and anticipated construction challenges are discussed from both structural and geotechnical perspectives. Structural challenges include box segment protection details, waterproofing details, construction and expansion joint details, high jacking load due to rock formation and detailed design of jacked concrete segments. On the other hand, geotechnical challenges include excavation advancement rate, necessity of grouting at box over-head and impact on existing utilities.

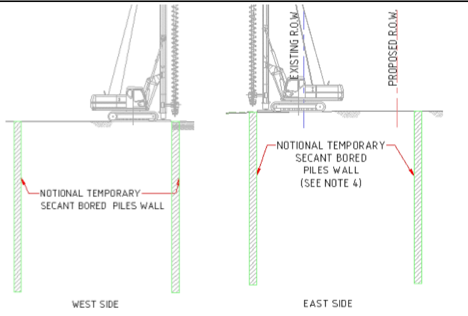
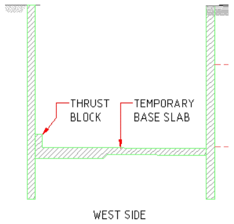
2 General Arrangement

The section of the underpass is a single cell box section with clear width and height of 6.20 m and 4.60 m, respectively. The overall length of the jacked underpass is 80.6 m with variable fill height above the box segments ranging from 4.3 m to 5.0 m. At both ends of the underpass, the pedestrian movement is facilitated with stairs and lifts. The underpass comprises of nine segments, each with length of 9.0 m. The joint types between the segments are either construction joints or expansion joints. The thicknesses of top slab, walls and base slab are 600 mm, 800 mm and 800 mm, respectively. The segments will be cast in excavated pits, which will later be jacked into their final position.

3 Proposed Construction Sequence

The general construction sequence for the jacked tunnel will be as presented in Table 1.

Table 1: Construction Sequence

<table>
<tr><th>Stages</th><th>Steps</th><th>Figures</th></tr>
<tr><td>1</td><td>a) Setting up and install temporary piles.
b) Perform ground improvement to strengthen the fill material within the utility trench.
c) Install ground and structure monitoring geotechnical instruments and take base readings.</td><td>
</td></tr>
<tr><td>2</td><td>a) Excavate the access shafts on both sides of tunnel.
b) Drilling of pilot hole horizontally below tunnel crown level to confirm the geological profile (soil/rock) to be encountered at tunnel face and perform laboratory tests to determine the ground properties.
c) Install horizontal inclinometer and take the base reading.
d) Cast smooth concrete slab and cast thrust block for pipe jacking.</td><td>
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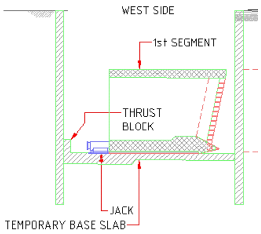
<tr><td>3</td><td>a) Cast in situ the first box segment within the access shaft.
b) Install jacks and prepare for box jacking.</td><td>
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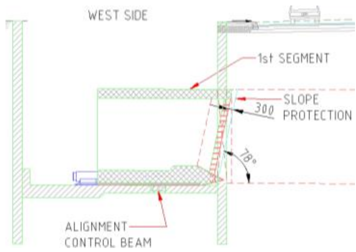
<tr><td>4</td><td>a) Break in the tunnel portal.
b) Excavate maximum of 300 mm and jack the first box segment immediately. The contractor shall verify the tunnel portal stability and provide any strengthening measures as required.
c) Perform geological mapping of the full tunnel face.
d) Monitor the installed instruments during the excavation and box jacking. The contractor shall immediately report the monitoring results to the engineer prior to future excavation.</td><td>
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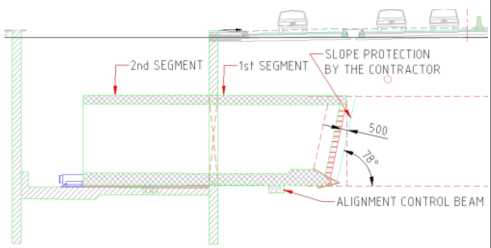
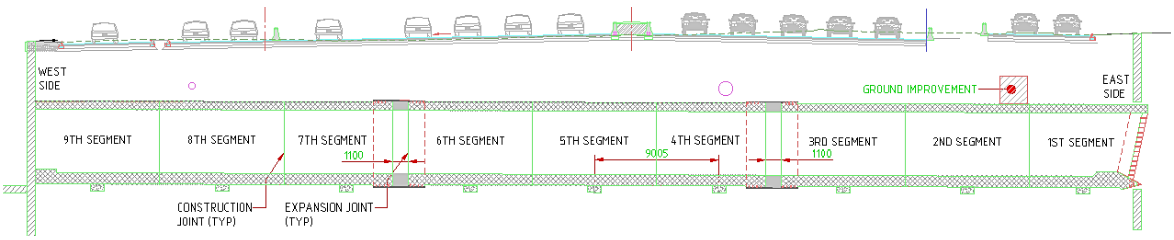
<tr><td>5</td><td>a) Excavate ahead of the first jacked box segment to maximum of 500 mm and jack the first box further.
b) Jack the first box segment up to the last 1m, to allow the construction of the second box segment with the relevant construction joint with advancement rate of 500 mm maximum.
c) Continue geological mapping after each excavation round, monitor the ground and structure instruments during the excavation and jacking and review the monitoring results.
d) Adjust the excavation advancement rate based on the monitoring results to maximum rate of 1000 mm.</td><td>
</td></tr>
<tr><td>6</td><td colspan="2">a) Continue jacking the box sections one by one.
b) Cast alignment control beams as necessary along the box jacking alignment.
c) Cast the gaps at intermediate jacking location.
d) After box pushing is completed, voids will be filled with grout using preinstalled grout holes at segments.

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4 Structural Challenges

4.1 Box Segment Protection Shield

At the front face of the first segment, a protection shield is provided to protect the reinforced concrete from any damages that might occur during excavation such as falling rocks as shown in Figure 2. The steel sheets which are fixed to the concrete by threaded bars can be easily removed to allow for installation of shear dowels at the Expansion Joint between first segment and east cast in situ shaft.

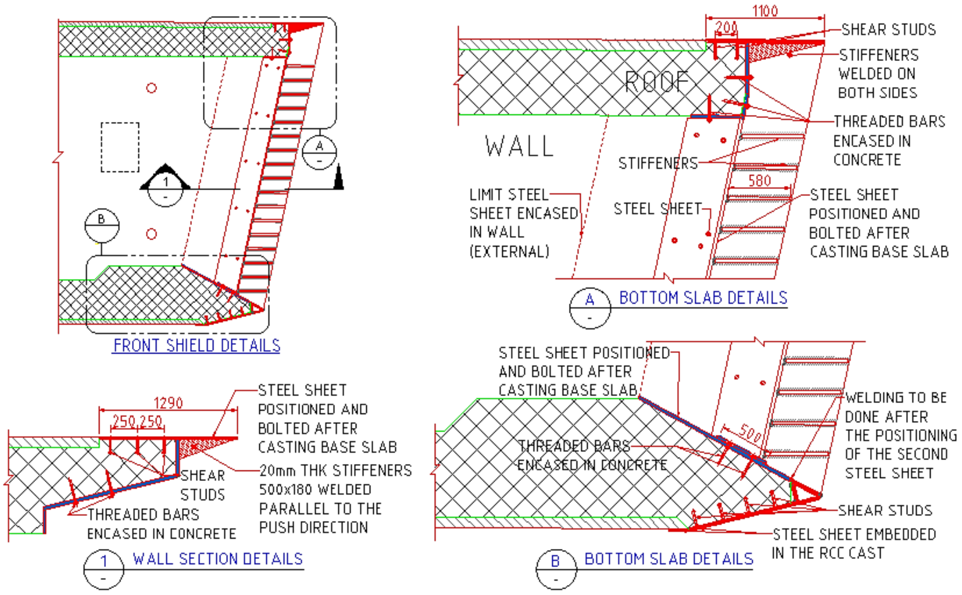

Fig. 2: Protection Shield details

4.2 Waterproofing Details

Ashghal specification for waterproofing of cut and cover tunnel and underpass highway structures which are designed to exclude groundwater are specified under Interim Advice Note No. 004 (IAN 004), Rev. A1 (Ashghal, 2013). The external faces of concrete shall be protected by waterproofing membrane. However, the waterproofing member is subject to damage during box jacking. Therefore, surrounding concrete protection of 100 mm thickness with steel mesh is proposed all around the box section to protect the waterproofing from any damage during construction and jacking as shown in Figure 3.

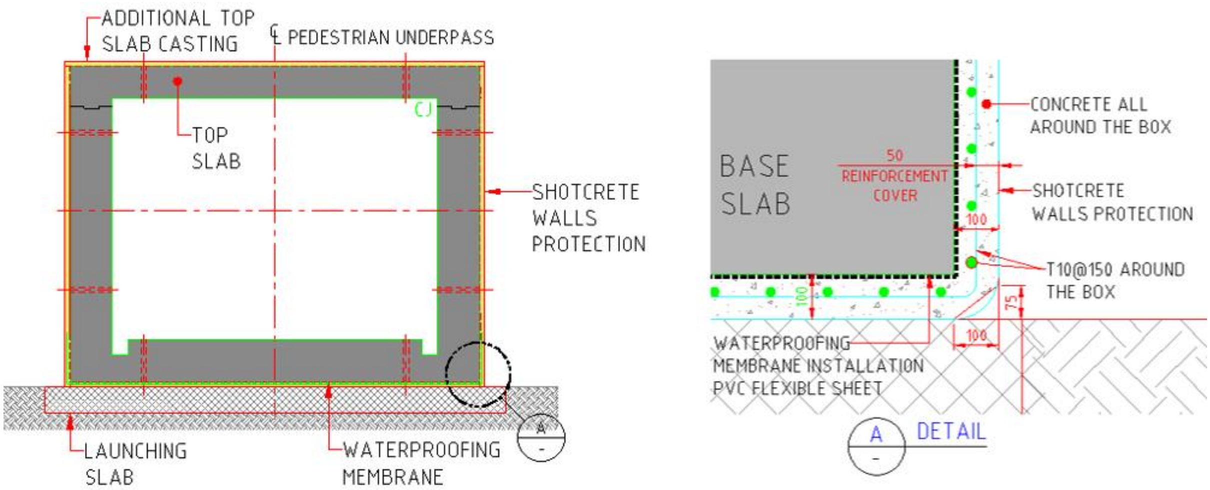

Fig. 3: Waterproofing Membrane Protection

4.3 Construction and Expansion Joint Details

As per Public Works Authority (PWA), IAN 004, Rev.A1 (Ashghal, 2013), waterstops shall be provided at both internal and external locations of the concrete structure.

4.3.1 Construction Joints

Following the construction sequence described under Section 3, segments are to be jacked to last 1m (i.e., projection of 1m from the tunnel portal) to allow the construction of the following box segment. Construction joint details are shown in Figure 4.

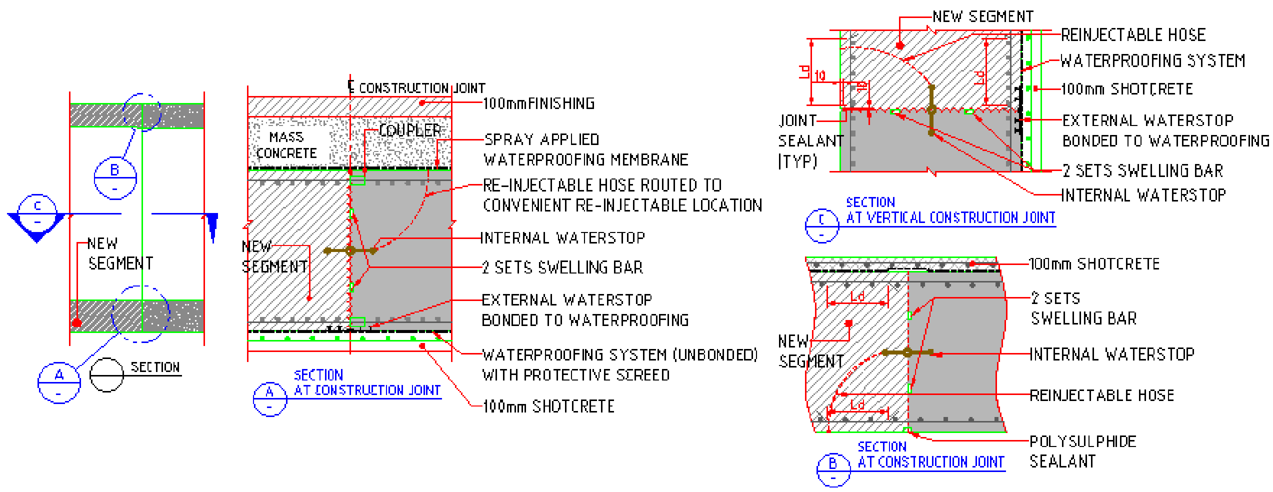

Fig. 4: Construction Joint Details

4.3.2 Expansion Joints

Two intermediate jacks are provided prior to box segments 3 and 6 to allow pushing of segments 1 to 3, 4 to 6 and 7 to 9 individually. Further details on box jacking arrangement are provided under Section 4.4. After completing jacking operation and removing the intermediate jacks, the gap is filled by stich concrete with Krystol Internal Membrane (KIM) Crystalline admixtures. Stainless steel plates are anchored into the segments by shear studs to prevent any misalignment in the segments by restraining them. Expansion joint detail at base slab is shown in Figure 5.

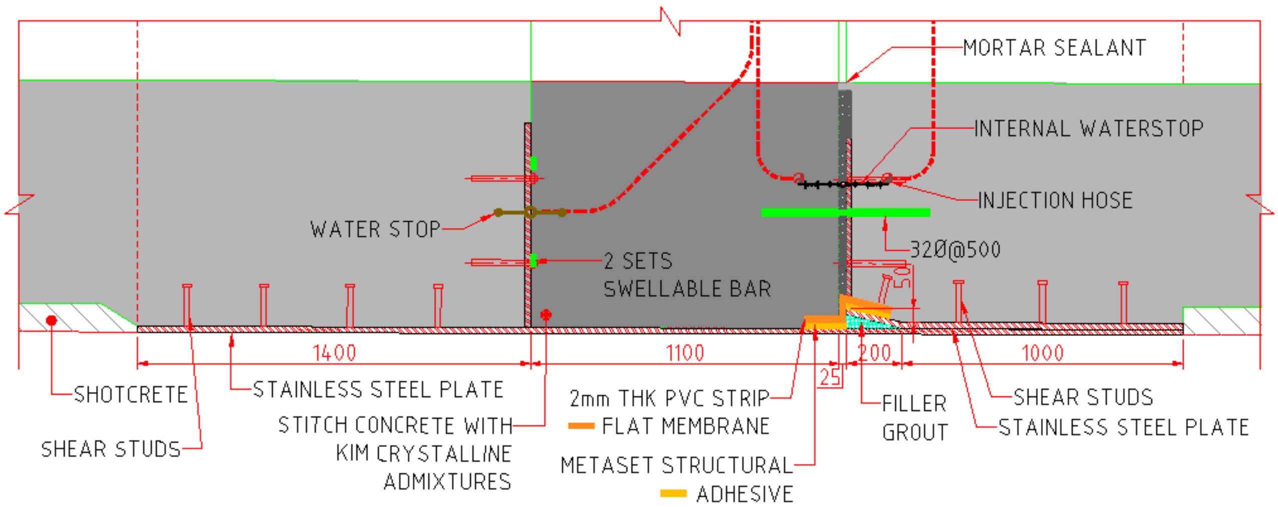

Fig. 5: Expansion Joint Detail at Base Slab

4.4 Box Jacking Loads and Arrangement

Based on the box-jacking specialist's experience in Qatar, the friction coefficient of 0.5 was appropriate for the estimation of jacking forces. This was considered in Doha, Metro, Gold Line Project (Konstantis & Massinas, 2020). However, friction coefficient of 0.8 is considered in this project for estimating the required jacking forces. Considering the higher friction coefficient at design stage will capture the worst-case scenario during box pushing and minimize the risk of segments being jammed during the pushing operations. The contractor shall validate the assumed value by measuring the actual coefficient of static friction between the concrete and the ground during construction. Furthermore, jacking force calculations are conservatively done considering the frictional resistance of the ground applied at the total perimeter of the box segment (i.e., roof, walls, and base slab).

Moreover, intermediate jacking locations are provided after every three segments (i.e., prior to box segments 3 and 6) leading to maximum jacking length of 21.0 m. Thus, the size of jacks is optimized and the impact of the jacks on the permanent structure is minimized. Based on the above considerations, the estimated required jacking force is 7,072 tons and this force shall be provided by seventeen jacks of 500 tons capacity each. Box jacking arrangement is shown in Figure 6.

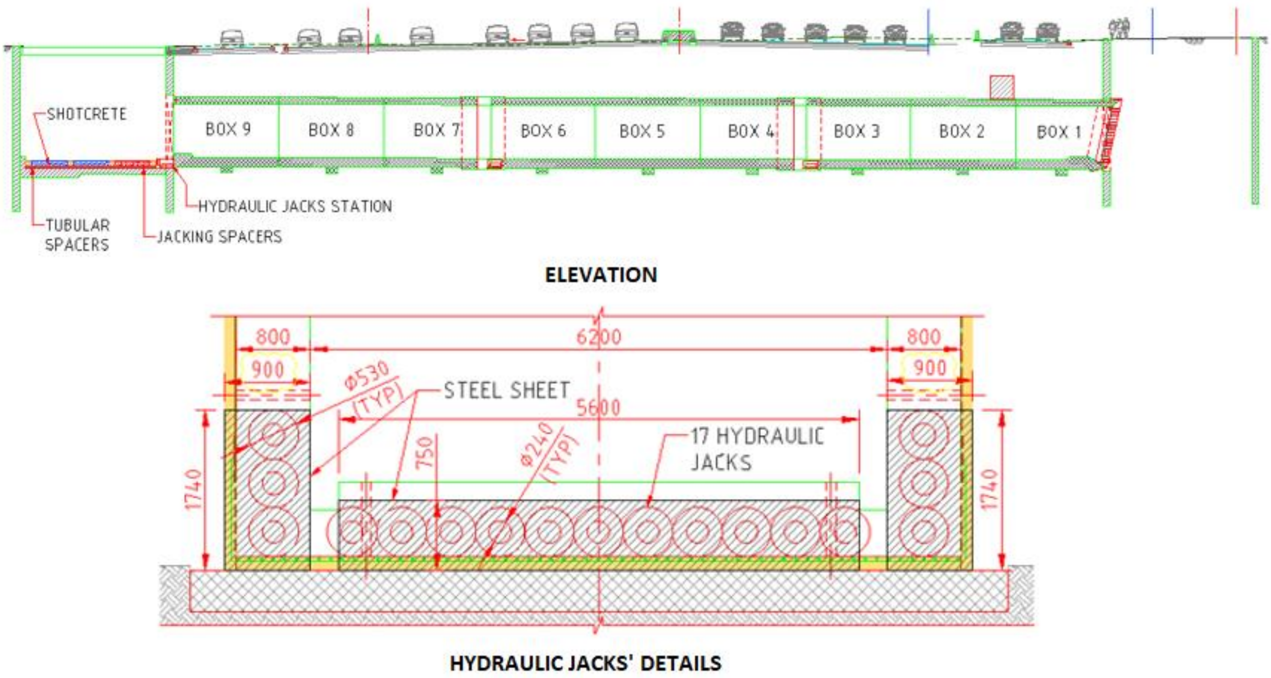

Fig. 6: Box Jacking Arrangement

4.5 Detailed Design of Jacked box RC Segments

The design criteria for highway structures are specified under Ashghal Interim Advice Note No. 009, Revision No. A2 (Ashghal, 2016) which requires the design to be carried out as per BS-5400-4 (BSI, 1990) and BD 31-01 (Highway Agency, 2001).

The global analysis of the structure was performed by finite element model (FEM) using CSiBridge software and the design was carried to cover both construction and permanent conditions. Top slab, walls, and foundations for box segments were modelled as frame elements in 2D model. Further, to capture the jacking force effect, the underpass was modelled as shell elements in 3D model. The earth pressure coefficients were based on the backfill properties specified in the Geotechnical Interpretative Report (GIR). The design considered upper and lower bound approach for the geotechnical parameters to cover all critical cases listed below:

- Case of no lateral ground loads due to over excavation.
- Case of full lateral loads considering the highest anticipated at rest coefficient (ko) value of 0.7 as per the GIR.
- Case of full lateral loads due to grouting. (ko) of 1.0 is conservatively considered.
- Case of no vertical overburden due to over-excavation.

In addition, the design forces resulting from the soil-structure analysis performed using finite element analysis software (PLAXIS 3D) were also taken into consideration in the structural design. The reinforced concrete sections were designed for the most stringent forces.

5 Geotechnical Challenges

5.1 Ground and Groundwater Conditions

The subsurface condition at this site consists of a made ground/fill layer to a maximum depth of 3.5 m to 4.50 m below the existing ground level, followed by weathered Simsima Limestone (WSL) extending to depths varying between 4.0 m to 7.4 m below existing ground level. The weathering condition of WSL improved with depth as moderately to slightly weathered Simsima limestone. The Simsima/Dukhan Limestone is underlain by the Midra Shale formation extending to a maximum depth of 19.7 m to 22.9 m below ground.

At some sections of the underpass, due to existing utilities (like the Treated Sewage Effluent pipeline), filled up soils encountered at varying depths. A geophysical investigation performed along the underpass alignment showed potential variations in the compactness of overburden soil and the strength of the WSL formation.

The groundwater level was encountered at a level between 5.16 m and 5.64 m Qatar National Height Datum (QNHD) where the structural slab level of the underpass's top slab varies between 4.858 m to 5.030 m QNHD.

5.2 Geotechnical Analysis

The geotechnical analysis was performed by the Design Consultant using Plaxis 3D Finite Element Analysis. In the analysis, the overburdened fill soil depth was taken as 4.7 m followed by 4.0 m thick weathered limestone formation. As per this consideration, a 0.50 m thick WSL formation will exist on top of the underpass concrete box. In the analysis, it is considered that WSL formation will have minimum Cohesion of 50 kPa and Friction angle of 30 degrees.

A systematic excavation with advancement rate of 0.30 m to maximum of 1.0 m was considered. A face angle of 78 degrees was also considered at every advancement of the cutter during excavation. It is assumed that tunnel excavation will be carried out in dry conditions after lowering the groundwater level by dewatering. With the above assumptions, the analysis was carried out and the resultant forces and displacement were estimated.

5.3 Variation in WSL formation

Currently, it is assumed that a minimum of 0.50 m thick WSL formation will exist on top of the tunnel concrete box and this formation will have minimum cohesion of 50 kPa and angle of internal friction of 30 degrees. As geotechnical boreholes were drilled only on the road edges and geophysical investigation along the underpass alignment showed varying velocity in the WSL formation, any variations will seriously impact the ground improvement cost and overall construction duration. Hence, before construction, it was recommended to perform horizontal drilling of borehole along the underpass alignment at the tunnel crown level and assess WSL formation existence and strength of the formation by performing relevant field and laboratory testing. Based on the findings, the excavation with or without improvement shall be finalized.

5.4 Impact on Existing Utilities and Road Pavement

Above the proposed pedestrian underpass box crown level, many existing pipelines are present at varying depths. The current analysis proved that the deflections are within the allowable limits of new construction limits. However, as these pipelines have already experienced the surcharge loading and some settlements might have already occurred, it was recommended to carry out deflection and condition assessment survey of the pipe by performing CCTV survey or other approved method before commencing and after finishing the tunnel excavation work. Further, instrumentation and monitoring were recommended during and after construction works to assess and decide on ground improvement requirement. It was also emphasized to coordinate with respective owners of these utility assets and get their approval before commencing these works. Localised ground improvement at the existing utility locations might be required to avoid any further settlement of these utilities.

5.5 Ground Improvement

Ground improvement was recommended at existing deep utilities’ locations constructed by cut and cover method and at locations where WSL formation is weak at the underpass crown level. Upon exploring multiple ground improvement options, most conservative approach is to grout the entire length of the ground formation at the underpass crown level (like umbrella pattern). However, due to the high cost, an optimal approach was explored, and it was decided to identify the weak zones and perform ground improvement only at these locations. Horizontal borehole at underpass crown level before excavation was recommended to assess the ground improvement requirement. The location, extent and type of ground improvement will be finalized based on pilot horizontal borehole study at underpass crown level. The improved ground shall have minimum uniaxial compressive strength (UCS) of 500 kPa. It is expected that drilling and grouting execution in steps of 2.0 m to 3.0 m length in front of the segment opening is done to maintain 0.50 m height of grouting zone. The successful Tenderer/Contractor will design and execute the ground improvement works.

6 Conclusion

Mesaimeer pedestrian underpass is proposed under live traffic by box jacking method in rock. First, the proposed construction sequence was presented. In addition, details for tanking membrane, construction joint and expansion joint were provided for watertight structure considering the high groundwater table. Further, jacking force was calculated assuming a higher friction coefficient of 0.8 and frictional resistance of the ground applied to the total perimeter of the box segment. Moreover, structural analysis was carried out by FEM models using CSiBridge software covering both construction and permanent conditions and considering upper and lower bound approach for the geotechnical parameters. Furthermore, the geotechnical analysis was carried out assuming the presence of a WSL formation having a minimum thickness of 0.50 m with a cohesion of 50 kPa and an angle of internal friction of 30 degrees along the entire alignment of the underpass. Given the potential variations in ground formation, suitable mitigation measures such as ground improvement works were recommended in the event of weak formation at the underpass crown level.

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