DESIGN OF TEMPLETON OVERPASS FOR THE CANADA LINE

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ABSTRACT

The Canada Line is a 19 km rapid transit line connecting Downtown Vancouver with Richmond and the Vancouver International Airport (YVR). The airport section of the Canada Line includes a 1.8 km at-grade guideway. The at-grade guideway is designed to accommodate future airplane taxi way requirements in accordance with YVR's future plan. Templeton Street is a major road servicing YVR and connects the North Service Road with Grant McConachie Way. It plays an important role in YVR's transportation planning; a bus route and a bicycle route are also included in the Templeton Street design. And it crosses the existing Templeton Street at about 100 meters west of Templeton Station.

A grade separated structure is required to allow the train to travel at-grade and vehicular traffic to cross over the Canada Line uninterrupted. After comparing various design and construction options for the overpass, the decision was made to design a 60 m long cast-in-place concrete box structure with approach ramps. This paper presents various options considered for the overpass, the preliminary design and detailed design of the overpass structures. The soil condition surrounding the Templeton Overpass consists of highly compressible soft clayed silt. The large amounts of fill placed for the approach ramp and the off ramp to Grant McConachie Way causes short term and long term soil settlement. The effects of the long term settlement on the structural design, roadwork and Canada Line track, and strategy to accommodate the settlement in the structural and trackwork design are discussed in this paper. A brief discussion of the construction aspects will also be included. The construction of the concrete overpass was completed in July 2007 and the overpass and the connecting road were opened to traffic in October 2007.

1.0 Introduction

The Canada Line is a 19 km rapid transit line connecting Downtown Vancouver with Richmond and the Vancouver International Airport (YVR). It includes three sections, which are the Vancouver section, Richmond section and Airport section. The Vancouver section consists of an underground tunnel from Waterfront station in Downtown Vancouver to the north of Marine Drive station. The Richmond section is an elevated guideway from Marine Drive station through Bridgeport station to Richmond Center. The Airport section is comprised of an elevated and at-grade guideway from Bridgeport Station to the Airport.

The design and construction of the Canada Line in the airport section needed to consider YVR's ground transportation plan, land use plan and the airport's existing and future development requirements. According to YVR's 2027 master plan, a north-south taxi way will be built in the year 2014 to cross the Canada Line (1). To accommodate this taxi way, the Canada Line needed to be built at grade and the future taxi way will be elevated to cross the Canada Line. The at-grade guideway starts right off the Middle Arm Bridge and ends before the airport terminal building. It has a total length of 1,800 meters. The at-grade guideway intersects Templeton Street about 100 meters west of Templeton station. This street plays an important role in YVR's ground transportation plan; it is a major road servicing YVR and it connects the North Service Road with Grant McConachie Way.

A grade separated overpass structure is required to allow the train to travel at-grade and vehicular traffic to cross over the Canada Line uninterrupted. A 60 m long cast-in-place concrete box structure with large amounts of fill was designed and constructed for the overpass. This paper will present the schemes and options developed in the preliminary design, detailed structural design of the overpass structure, soil settlement and its effects on the structural and trackwork design and measures undertaken in the design to accommodate the long term soil settlement. The construction aspects will be briefly described as well.

2.0 Background

According to YVR's ground transportation plan, there are two stages of traffic requirements for the Templeton Street. In stage 1, the new elevated road will cross the Canada Line and intersect the existing Grant McConachie Way with a signalized at-grade intersection (see Figure 1). Stage 1 requires a road width of 17.8 m which consists of two 3.5 m lanes, separated by a median, and 2.5 m shoulders with roadside barriers. In the ultimate stage, a future interchange, west of the stage 1 road, will be built at the intersection of Templeton Street and Grant McConachie Way. The new interchange will require the stage 1 Templeton Street to be shifted to the west and a new Templeton Street southwest off ramp will be built. The ultimate stage road will include 5 traffic lanes and a bicycle lane.

The new overpass is required to provide adequate clearance for the Canada Line train. It should also be designed to accommodate both stage 1 and ultimate stage Templeton Street road geometry requirements.

The entire Airport section of the Canada Line is situated on Sea Island land, which consists of highly compressible soft clayey silt. These clayey silts exist below a depth of about 20 m and are relatively uniform. This layer extends to a depth of about 100 m (2). Deep seated consolidation of the clayey silt will cause long term settlement. The geotechnical consultant, EBA engineering, was retained to provide assistance and advice on the soil settlement. They conducted analysis and provided soil settlement curves. According to EBA's recommendations, short term settlement was accounted for by the preloading, however, the long term settlement had to be accounted for in the overpass design.

3.0 Preliminary Design

The new overpass structure had to meet the following functional requirements:

- the different stage geometry requirements for Templeton Street
- the new interchange at the intersection of Templeton Street and Grant McConachie Way
- the Canada Line train operation

Various schemes were developed in the early stages, including a one span or multi-span precast girder bridge supported on piles, and a concrete box structure (tunnel) with approach ramps. A pile supported bridge would have the advantage of reducing the soil settlement and minimizes its effects on the Canada Line train operation. However, the bridge would have to be long enough to reduce the approach fill height and soil settlement. According to EBA's analysis, a maximum fill height of 3 m is allowed for the bridge embankment fill. A 100 m long bridge would be required in order to keep the fill height below 3 m and the cost to build such a long bridge would be high. Moreover, it would be difficult to design the bridge structure to accommodate both the stage 1 and ultimate stage road geometry requirements. Substantial reconstruction of the structure for the ultimate stage road would be required and most of the initial structure would have to be demolished. The cost to demolish and reconstruct the bridge would be very high and a bridge option was therefore not developed any further.

A box structure (tunnel) with mineral approach fill or light weight fill (LWF) was also considered. The box structure would provide the train with a continuous smooth at-grade running surface, while allowing vehicular traffic to cross over the Canada Line without interruption. It provides an economical and efficient structural scheme. The tunnel and the associated approach fill would provide flexibility for the future road geometry requirements. LWF was considered because it has the potential to reduce long term settlement by about 50%. However, it was decided that the significant cost increase related to LWF use and the time delays, because of limited supply, did not justify the reduced settlements (2).The concept of building a concrete cast-in-place tunnel with mineral approach fill was endorsed and supported by YVR. This solution is compatible with YVR's normal transportation plan.

The selected scheme includes design and construction of a 60 m long cast-in-place concrete box structure (tunnel) with approach ramps. The 60 m length provides adequate width for both the stage 1 road over the east side of the tunnel and the ultimate stage road, which will cross over the majority of the tunnel. The inside box dimensions of the tunnel were determined based on the train static and dynamic envelops. A minimum clear height of 4.0 m over the top of rail and a clear width of 8.56 m for the double track was required.

Preliminary design was undertaken to determine the structural dimensions. A simple 2-D frame model was developed to calculate the design forces in the various structural components. The roof slab has a thickness of 0.6 m. The base slab thickness was determined based on the flexural bending of the slab due to the forces imposed from the soil bearing pressure. A thickness of 0.6 m was obtained for the base slab. The tunnel wall is subject to the soil lateral pressure from the fill acting on the wall and it also needs to take the forces from the frame action. The wall thickness was designed to be 0.6 m as well. The tunnel structure is also subject to twisting forces due to the soil settlement and the seismic dynamic soil pressure. The slab and wall thickness are designed to be slightly larger to account for any additional forces resulting from the twisting of the structure due to the soil settlement.

In the preliminary design, it was acknowledged that the long term settlement will have a significant impact on the structural behavior, roadwork and train operation. Thus, the methodology and measures taken to ensure the structural performance of the tunnel to meet the Canada Line train operation requirements was the key to the next stage design.

4.0 Detailed Design

The preliminary design of the overpass structure, the roadwork of Templeton Street and trackwork began in April 2006 and was completed in June 2006. The design was submitted to YVR for review. The detailed design was completed in October 2006.

A detailed analysis was undertaken for the concrete tunnel. A refined 2-D model was developed with various load cases and load combinations. The loading included dead load from tunnel self-weight, soil weight, highway truck live load over the roof slab, train live load at the base slab, soil lateral pressure, live load surcharge, earthquake load and impact of differential settlement. Design forces were calculated for the structure. The structural slab thickness was confirmed. Reinforcement arrangement and details were also determined at this stage. The general arrangement of the Templeton Overpass is presented in Figure 6 and 7.

But the key focus at this stage of the design was determining how to design the 60 m long box structure to accommodate the long term settlement while maintaining the Canada Line train operation without interruption.

As described in section 2.0, long term settlement is expected due to the existence of high fill. Various settlement profiles were developed by the geotechnical engineer. It was obvious that a rigid continuous box structure cannot accommodate the predicted soil settlement profile. The box is so rigid that it would tend to support itself and not follow the settled profile. But the soil pressure that would develop at the end supports would be very large and localized soil failure would occur. The structure would adjust to the settled soil profile and new support locations would develop causing more localized soil failure until a balance point between the soil and the structure is found. In order for the rigid structure to deform to the soil settlement profile excessive concrete cracking and spalling would also need to occur. The methodology and measures undertaken for the structural and trackwork design to allow the structure and trackwork to accommodate the settlement profile are presented in the following section.

5.0 Soil settlement and its effects on the structural design, roadwork and train operation

The soil settlement caused by the large amounts of fill has significant effects on the structural, road work, and trackwork design. The following sub sections describe the findings of the soil settlement report, and the measures adopted in the structural and trackwork design.

5.1 Soil Settlement Report

EBA, the geotechnical consultant, completed a number of settlement analyses of the tunnel and approach fills as the overpass design concept evolved. In the final configuration large amounts of fill were required to accommodate the stage 1 and future stage road geometry for Templeton Street. Additional fill to the north of the guideway was also added in order to offset distortional settlements of the track. Based on the final required fills the maximum long-term settlement (LTS) will be about 630 mm and the longitudinal settlement along the tunnel will not be symmetric about the centre of the tunnel. Settlement at the west entrance will be greater than at the east entrance. Also, about 100 mm of transverse settlement will occur due to the absence of fill south of the alignment because of the future Grant McConachie abutment and off ramp. This transverse differential settlement will vary along the longitudinal axis and reverse direction at the center of the tunnel, subsequently causing twisting of the guideway slab and the tunnel structure (2).

5.2 Impacts to the structure and measures taken to accommodate the settlement

Due to the transverse soil settlement and the effects of the LTS the tunnel width and height had to be increased to ensure the required clearances for the train would be maintained. The clear width of the tunnel was increased by 0.34 m to 8.9 m and the clear height was increased by 0.5 m to 4.715 m. Also, a transition slab with a 300 mm wide seat was designed over the tunnel base slab to support the guideway slab at both the west and east entrances to allow the guideway slab to settle uniformly with the tunnel base slab. Adequate dowel reinforcement was incorporated to ensure the slabs will be tied together, and no abrupt deformation will occur at the tunnel entrances.

In order to allow the tunnel structure to conform to the estimated settled soil profile, a flexible tunnel structure was designed with a joint between each 7.5 m long segment. Each segment is a rigid closed concrete box, measuring approximately 10.1 m wide and 6.0 m high. To provide a smooth surface for the train, the base slab is continuous with two layers of continuous reinforcement. The wall and roof slab are discontinued only at the joint location with a physical gap of 36 mm. The gap will accommodate vertical settlement on the tunnel structure by closing the gap at the top and allowing the structure to rotate around the base slab top surface. In this way, the effect of soil settlement on the tunnel will be concentrated at the joint location. Since each segment is strong enough to span 7.5 m and support all related loads inside and over the tunnel, the tunnel structure will deform and the concrete box will be able to accommodate the predicted settlement (3). Finite Element Analysis was carried out to verify and confirm this design concept and to ensure the joint gap size is adequate. A model plot of the deformed rigid and flexible tunnel due to soil settlement is shown in Figure 9 and 10. The analysis confirmed that the joint was adequate and the soil settlement can be accommodated.

5.3 Impacts to the trackwork and measures taken to accommodate the settlement

Using the full 50-year ultimate settlement the track profile was raised to offset the 100% settlement numbers included in EBA's report. The design criteria was to raise the profile to such a level that low spots will fall outside the tunnel in order to ensure that no standing water will exist inside the tunnel structure. A positive drainage will be maintained. The transverse settlement of the tunnel also meant that one rail of each track may need to be shimmed by 17 mm in order to maintain a level track. Depending on the nature and severity of the settlement, plinths may also be needed to raise the rails while minimizing grinding of the concrete slab (3).

6.0 Construction

The construction of the Templeton Overpass commenced in early 2006. The proposed area was preloaded according to the geotechnical requirements. Preload commenced in the beginning of May 2006 and was completed three months later. The settlement was monitored to obtain the settlement survey data.

After six months of preloading, the soil was removed to make space for the tunnel base slab construction. The base slab concrete was poured in January 2007. Figure 2 shows a picture of the base slab construction with the Gomaco machine. Next, the wall and roof slab were constructed. Each 7.5 m long tunnel segment including two walls and a roof slab was poured alternatively; segment 1, 3, 5 and 7 were poured first, and followed by the construction of segment 2, 4, 6 and 8. Figure 3 shows the segments under construction. A waterproofing membrane was applied at each segment joint to avoid water leakage. Construction of the tunnel and overpassing roadway was completed in July 2007 and the completed tunnel can be seen in Figure 4. The area was opened to traffic in October 2007.

7.0 Conclusion

The Templeton Overpass structure was the first segment of the Canada Line construction to be completed. The test and commissioning of the line, including train test run, commenced in late 2007. The train operation inside the tunnel and the vehicular traffic above the Canada Line are running fairly smoothly, as can be seen in Figure 5. Recent survey data shows that the soil settlement is ongoing at a slightly faster rate than predicted by the geotechnical engineer, but the settlement is uniform, causing the whole structure to settle uniformly. Figure 8 is a plot illustrating the predicted and actual settlements of the structure. Negligible twisting of the tunnel is observed, the survey shows a lateral relative settlement between two rails of only 1 to 2 mm. The tunnel structure is performing as expected in accordance with the design.

REFERENCES

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2.EBA Engineering Consultants Ltd., Final Geotechnical Report Design Through Construction Elevated and At-Grade Guideway South Vancouver, Richmond and Airport (YVR) The Canada Line, September 2007.

3.SNC-Lavalin Inc. Templeton Overpass - Soil Settlement, Design Criteria and Strategy and Effects on the Operation, February 2007.

4. SNC-Lavalin Inc., Detailed Design Drawings of Grant McConachie Way/Templeton Overpass, October 2006.

FIGURES

Figure 1. Aerial view of Templeton Overpass site showing stage 1 Templeton Street

Figure 2. Pouring concrete for tunnel transition slab with Gomaco machine

Figure 3. Tunnel under construction

Figure 4. Completed Templeton Overpass

Figure 5. Canada Line train traveling through Templeton Overpass

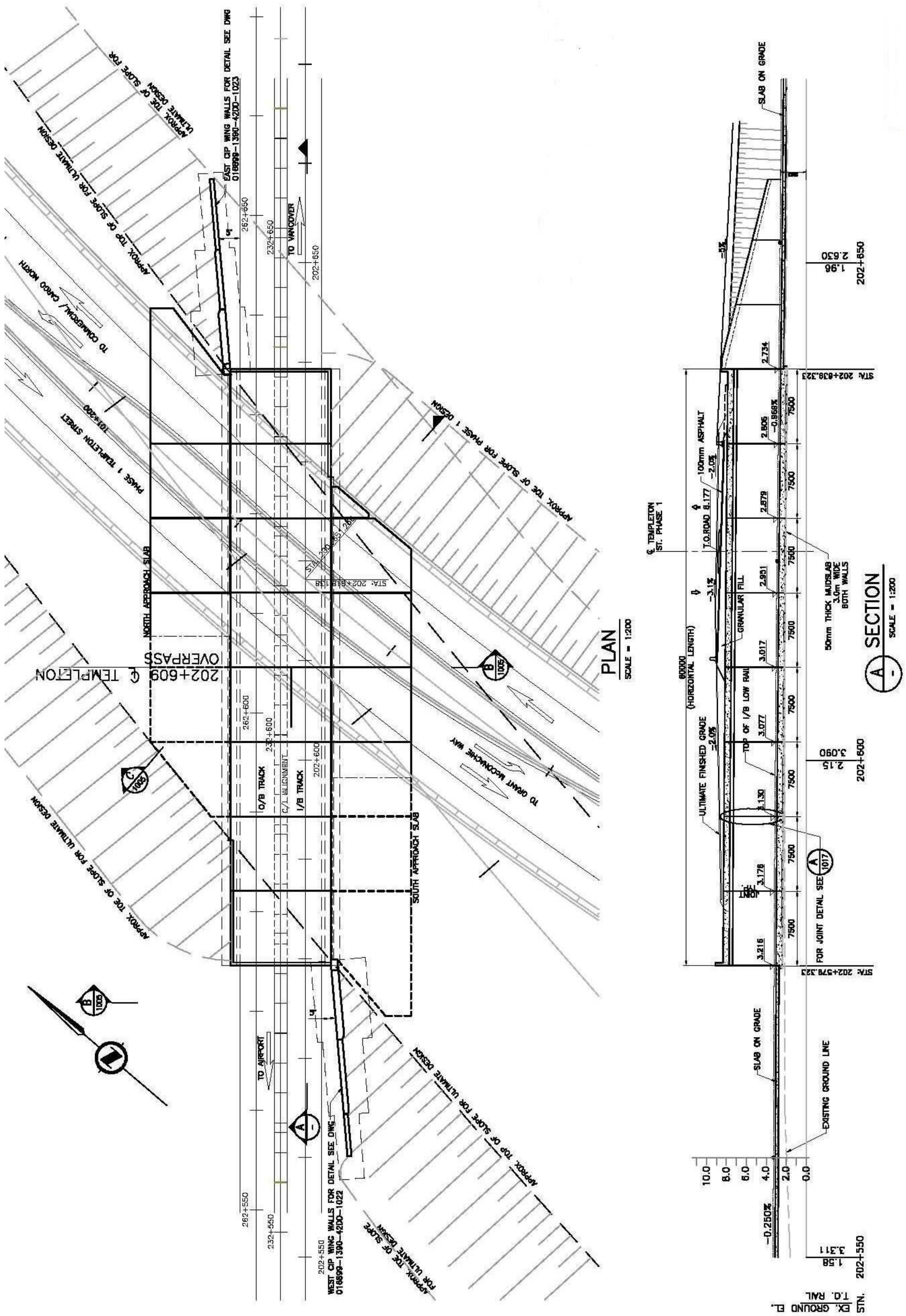

Figure 6. Templeton Overpass General Arrangement - plan and elevation (4)

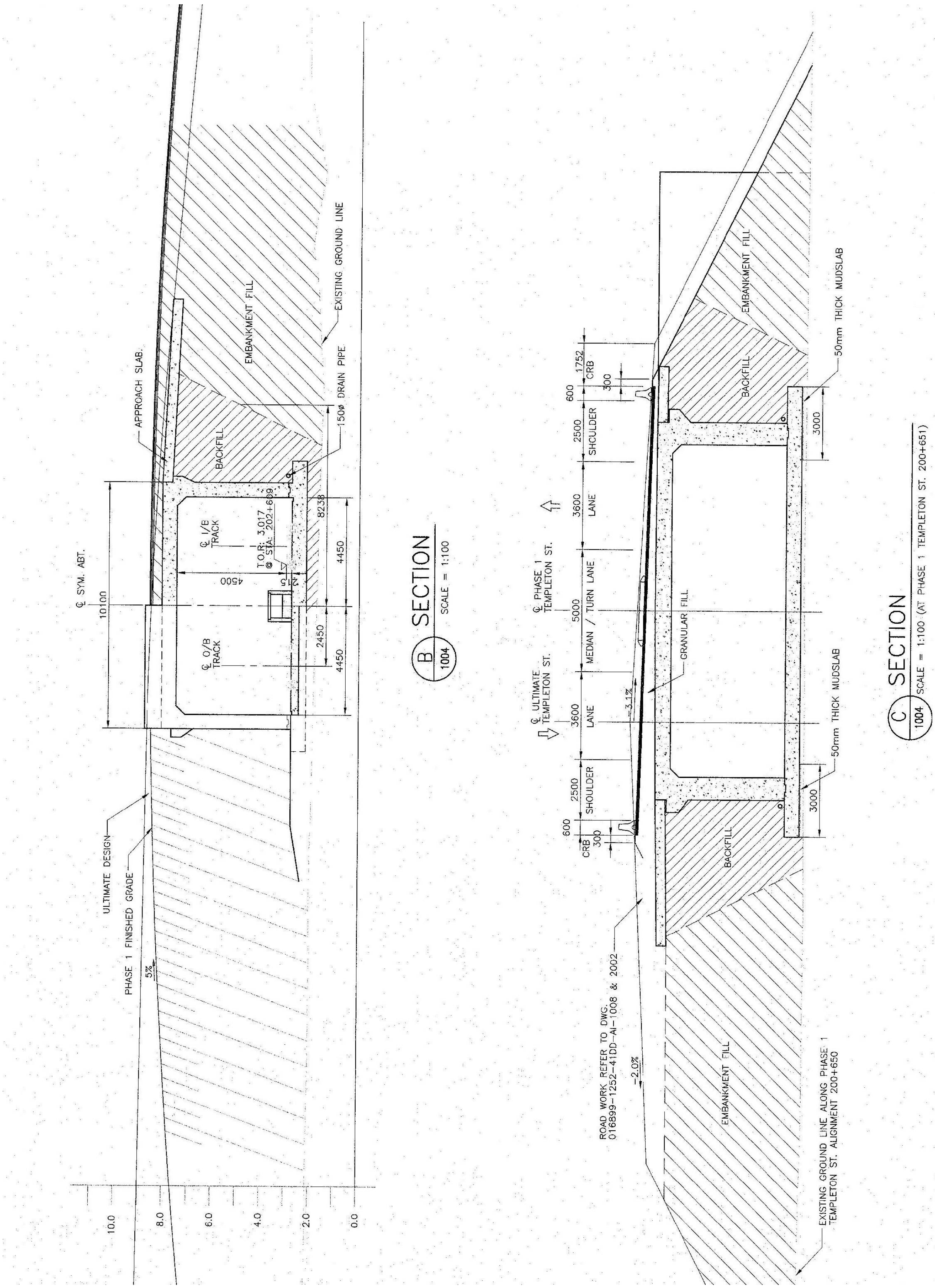

Figure 7. Templeton Overpass General Arrangement – Sections (4)

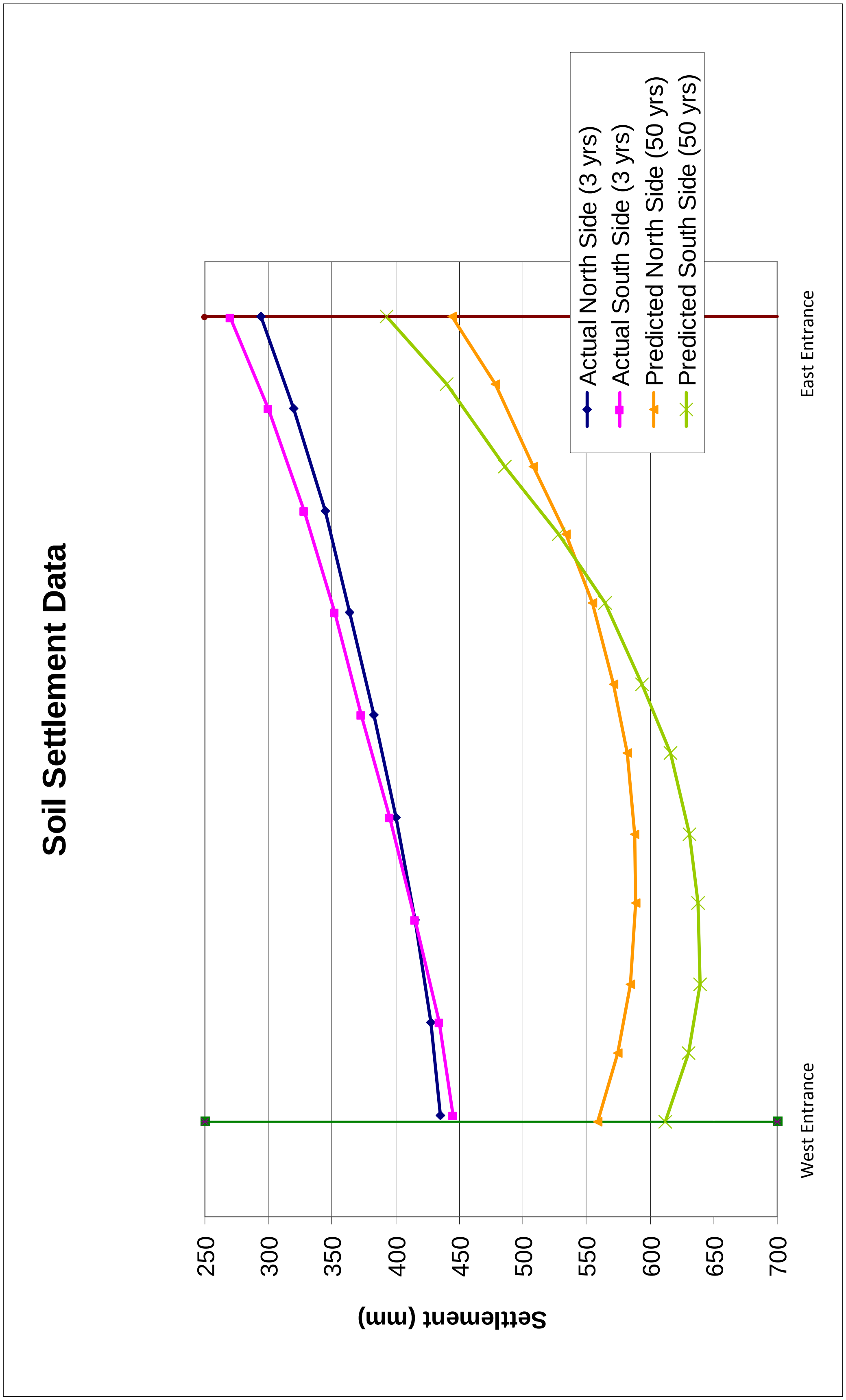

Figure 8. Predicted and actual soil settlement of tunnel (2)

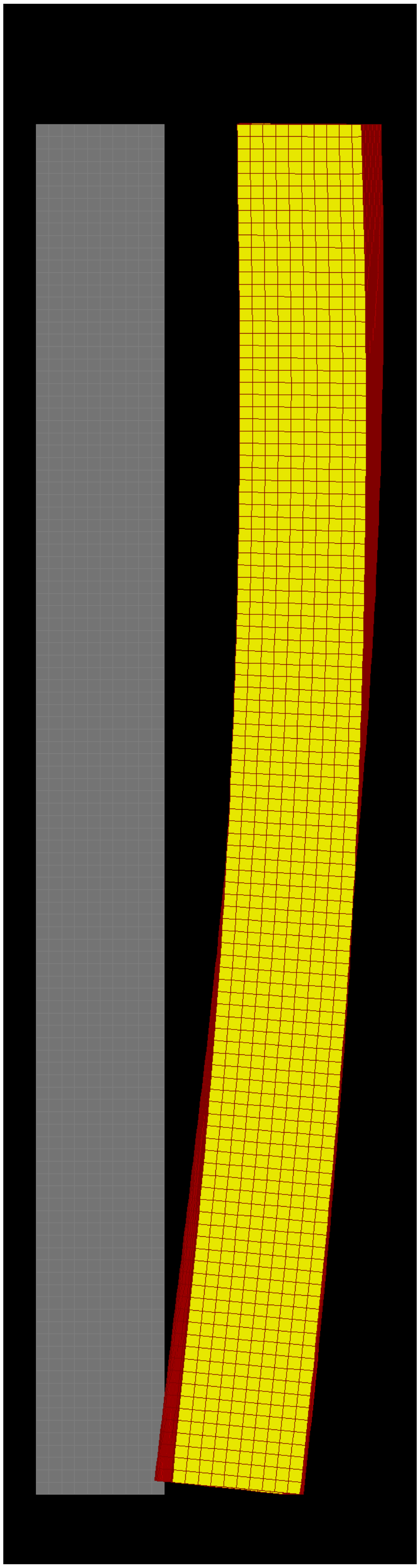

Figure 9. Settlement of rigid tunnel structure

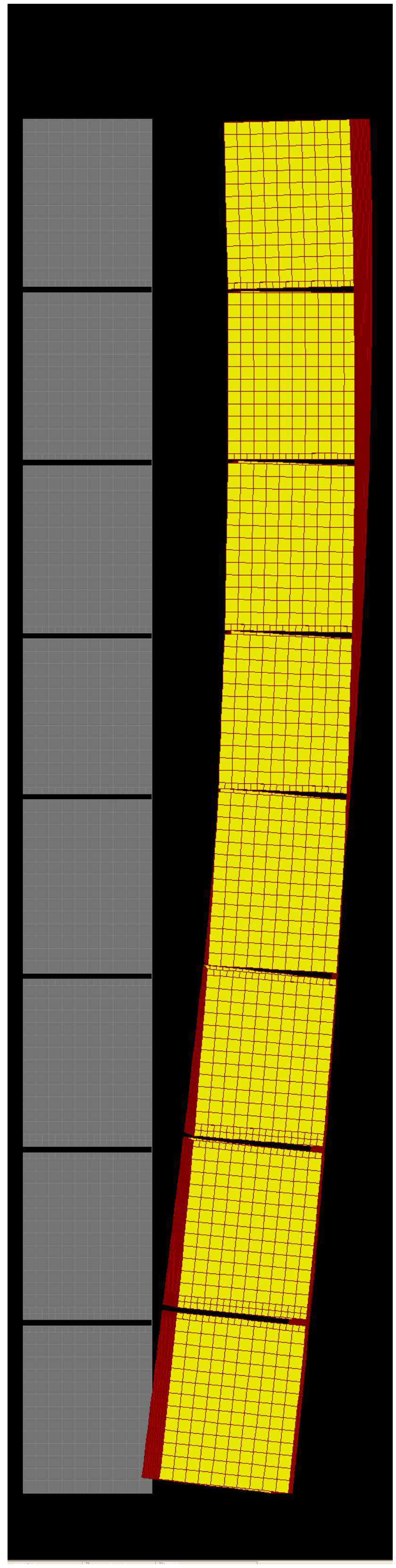

Figure 10. Settlement of flexible tunnel structure