

Calgary Airport Trail Tunnel

Azita Azarnejad, Bridge Operations Lead, CH2M HILL
Andrew Boucher, Senior Project Manager, CH2M HILL
Joost Bolderheij, Principal Manager, CH2M HILL

Paper prepared for presentation
at the Bridges: Better, Faster, Safer Session

of the 2013 Annual Conference of the
Transportation Association of Canada
Winnipeg, Manitoba

Abstract

The Calgary Airport Trail Tunnel is a 620 meter (m) long, six-lane, two-cell roadway tunnel constructed under the Calgary International Airport's new parallel runway and three associated taxiways. The tunnel is owned by The City of Calgary (The City) and is on land that is leased from the Calgary Airport Authority (YYC). It is part of a 1.4 kilometre (km) section of roadway being constructed for better network connectivity in the vicinity the airport. This project is related to the massive expansion project underway at the airport, including the terminal expansion and the new parallel runway. The tunnel is a cast-in-place, conventionally reinforced concrete rigid frame structure on spread footings with two spans of 17 m each. A cut-and-cover construction method was used and the design is based on a drained system. Life safety was an important element of to the design and included smoke and noxious gas exhaust and fire and smoke detection systems.

The paper includes an overall explanation of the project with a layout of the tunnel, a cross-section, construction process, schedule, and roles and responsibilities. It discusses structural aspects such as design codes, structural analysis, aircraft loading, types of joints, durability considerations, waterproofing, and fire protection. Some of the project challenges are also highlighted, including the tight schedule, which was the main challenge for this project, loading considerations from the construction staging, assessment of the effects of conduits in the tunnel walls, cooling of the concrete, and assessment of temperature range in the tunnel.

Text

Introduction

The Calgary International Airport (YYC) currently serves over 12 million passengers and 230,000 aircraft movements annually. The Runway Development Program (RDP), part of the Airport Development Program (ADP), includes the construction of a 4,367 m (14,000 feet) long, 61 m (200 feet) wide runway. In addition to increasing the capacity of the airport with these new developments, the new runway will allow landing of the world's largest aircraft (the Airbus A380 and the Boeing 747-800) and will facilitate an increase in international air traffic to the airport.

The runway project necessitated the closure of Barlow Trail between McKnight Boulevard and Airport Trail. This section of Barlow Trail was one of the main access roads to the airport. Metis Trail was developed to replace Barlow Trail as a north/south route and did not have a direct access to the airport. The Airport Trail Tunnel will run under the new runway and will extend Airport Trail from Barlow Trail to 36 Street NE. This extension of Airport Trail would not only provide a new access to the airport, but will also be one of the main east/west connectors in Calgary, eventually connecting to Metis Trail and the Calgary Ring Road. The City plans to have an express bus route connecting the Calgary Transit system to the airport through the tunnel in the near future and the tunnel cross-section is sufficient to accommodate light rail transit (LRT) in the future. The Calgary Airport Authority (also referred to by Calgary's international airport code of YYC) is one of the largest employers in Calgary. The tunnel will provide a new access for employees as well as the residents of future developments north and east of the airport.

The airport tunnel has been considered in The City's planning since 1995. YYC's construction schedule of the new runway accelerated this plan. It is much easier and less expensive to construct a "cut-and-cover" tunnel rather than boring a tunnel under an active runway. In November 2010, Calgary City Council (Council) approved a study on the tunnel to provide a cost estimate to construct a tunnel under the new runway. The estimated cost for the construction of this tunnel was \$294.8 million, which was approved by Council in February 2011. Although the tunnel is owned by The City, it is located in/on lands leased/maintained by the Calgary Airport Authority and owned by the Government of Canada. The agreement with the Calgary Airport Authority for the land sub-lease was completed late in June 2011. Construction started in July 2011 with bulk excavation. The tunnel is expected to be open for public use in May 2014.

General Description

Figure 1 shows the tunnel plan-layout under the new runway and three parallel taxiways. Figure 2 depicts the lane arrangements for opening day and for potential future LRT. Figure 3 is a rendering of the completed structure, as viewed from outside the west portal.

The construction is managed by PCL-Parsons-Dufferin (PPD) joint venture, who is also the construction manager for the runway project. CH2M HILL and Associated Engineering (AE) are the consulting team with CH2M HILL in the leading role. Structural Engineering for the tunnel and site residence services including contract administration and quality assurance is provided by CH2M HILL and AE provides engineering for roadway, drainage, electrical, and mechanical as well as structural engineering for storm-water tanks. Thurber Engineering is the geotechnical sub-consultant. The project is broken down into 15 work packages and

construction progresses as each work package is completed. This allows portions of the construction to proceed before design is completed, and to start production on long-lead items such as fans, and electrical equipment.

The tunnel structure is a cast-in-place, conventionally reinforced concrete rigid frame on spread footings constructed with a cut-and-cover construction method. Figure 4 shows a typical cross section of the structure, and Figure 5 is an elevation of the portal walls (concrete retaining walls) at the ends of the tunnel. For construction, the tunnel was divided into 50 casting segments along the length. The walls and roof were cast in monolithic 12.5 m sections using a steel formwork system of lead and infill segments. Odd numbered segments (called lead segments) were cast first and then the infill segments were cast later. Casting started from the middle of tunnel, progressing to both ends. Four sets of steel forms were used and an engineered tent was fabricated for heating and hording (or shading and blocking wind) and curing the concrete (see Figure 6). The main structure was constructed from February 2012 to October 2012 (footings were constructed from November 2011, to August 2012). A total of 65,000 cubic metres of concrete was cast using 12,000 tonnes of reinforcing steel for the tunnel structure. A storm sewer system and watermain were installed below the tunnel to provide storm water drainage and firefighting water. Figure 7 shows a picture during construction in May 2012, indicating the white hoarding tents, and lead formwork in place.

Life safety played a major role in design, including smoke and noxious gas exhaust, as well as fire and smoke detection systems. Design was according to NFPA 502: Standard for Road Tunnels, Bridges, and Other Limited Access Highways” [1]. There are 32 100 horsepower (HP) jet fans located throughout the tunnel (with four sets of four fans in each cell of the tunnel) serving the dual purposes of normal ventilation and air movement. Fans are triggered to operate in the tunnel using an aspirating gas and smoke detector system that uses a common sample pipe work. In the event of a fire, all the fans on both sides will operate in the same direction to transport a layer of smoke away from the fire to allow firefighters to get close as possible to the scene. The fan units are 5.6 m long by 1.12m in diameter and weigh approximately 570 kg each. They are designed to work at temperatures up to 250°C (482°F) for 1 hour.

The emergency system consists of networked fire alarm system with manual pull stations located at each portal, each hose station and each inter-tunnel door. Fire extinguishers are co-located with the hose stations every 75 m on both carriageways. A linear fibre optic heat detector and a VESDA (Very Early Smoke Detection Apparatus) smoke and gas detection system monitor every section of the tunnel and are connected to the fire alarm panels in each control building (located at the east and west portals). There is a public address system and emergency phone system in the tunnel and a radio repeater system for first responders (emergency personnel). Dry standpipes in both carriageways provide fire department hose connections every 75 m. Standpipes are charged with water that will be pumped in from hydrants located outside each portal.

Lighting in the tunnel is by 1,380 holophane metal halide Predator fixtures. More light is required in the daytime than at night because of the transition drivers experience from bright daylight to the relative darkness of the tunnel. Therefore, extra lights have been provided at the entrances to the tunnel. Some fixtures are dedicated unswitched emergency lighting, although all lighting power is backed up by uninterrupted power supply (UPS). As emergency generators would have involved significant maintenance and capital costs, power from two separate substations on two different sections of The City's electrical supply grid provide power redundancy. If one electrical source fails, 100 percent of the tunnel power requirements will be supplied by the second source, through an automatic transfer of power. There is a 400 kilowatt (kW) UPS system in each control building to supply essential power to lights, life safety, and controls during a power transfer.

Structural Aspects

Structural Analysis and Design

The main structure consists of a cast-in-place reinforced concrete rigid frame on spread footing with two spans of 17 m each and a total length of 620 m (see Figure 4). Soil structure at site consisted of 2.5 to 4 m of clay till overlying bed rock (claystone, siltstone, and sandstone). The top of the structure was mainly below the top of the bed rock level. The tunnel was designed with a drainage system at the footing elevation to remove groundwater pressure. Depending on the location along the length of the tunnel, backfill was either a free-draining, graded granular material, or native material with a 1 m free draining gravel layer “chimney” next to the structure. Drainage pipes next to the footings, both inside and outside of the walls, collect ground water into the storm tank located outside of the west tunnel portal. The structure, however, is capable of resisting 7 m of water as an extreme load case.

To minimize any possibility of differential settlement of tunnel backfill, sections under the paved portion of runway have a continuous full load carrying structural approach slab supported on piles. Sections under taxiways, shoulder portions of runway, and service roads have a pinned, slab-on-grade approach slab supported on full height granular fill. Tunnel portals at both ends consist of cast-in-place reinforced concrete retaining walls (see Figure 5).

Structural analysis and design of the tunnel was based on the Canadian Highway Bridge Design Code (CHBDC) CAN/CSA S6-06 [2] and in accordance with The City’s Design Guidelines for Bridges and Structures [3]. Other references used for aircraft loading included Appendix 3 of USDOT FAA Airport Pavement Design and Evaluation, Advisory Circular No. 150/5320-6E [4] (referred to as AC150), (Design of Structures for Heavy Airplanes) and Section 5.10 of ACI 343-R95 [5] (Airport Runway Bridge Loads). Aircraft loads for the tunnel included both the general gear configurations of AC150 with a wheel load of 34,000 kg, as well as specific loading corresponding to some of the heaviest existing aircrafts such as Airbus A380 (602,000 kg), Boeing 777-300ER (352,441 kg), and Antonov 225 (600,500 kg). Aircraft loading was applied to the whole length of tunnel to consider the possibility of any future developments.

Structural analysis was performed using different models and different levels of detailing. The main analysis model consisted of a 2D linear finite element model using frame elements. Refined 2D and 3D models with frame or shell elements were used to check the effects of block outs, openings in the walls and conduits.

Joints

Construction joints in sections were only between the walls and the footings at 150 mm above the top of the footing. The first 150 millimeters (mm) of wall was required to be cast with the footings to facilitate wall form installation. An external water stop was installed covering both the construction joint and the wall-footing corner (in case of any cracking from applied moments). Walls and roof slab were poured monolithically, which helped prevent differential shrinkage between the wall and roof slab. In the sections with continuous roof slab, a construction joint was required between the approach slab and main structure.

Longitudinal construction joints were located at 12.5 m intervals based on form length. These joints were also considered control joints and were designed as a weaker section to absorb cracking but to keep continuity for load sharing. These sections had reglets with sealants and only half of the longitudinal reinforcement was continued between segments at construction joints.

Some of the longitudinal construction joints were designed as movement joints. Located at multiples of three or four construction joints (37.5 or 50 m), these were selected to be in

locations of cross section change or in sections with larger depth of fill where the load sharing for aircraft loading was not as significant.

There was a complete separation of structure across the movement joints, except for sleeved glass fibre reinforced polymer (GFRP) dowel (see Figures 8 and 9). This allows for longitudinal movements from temperature or shrinkage, as well as relief of any accumulated forces or stresses from lateral or vertical ground movements (although this not expected from the bedrock foundation and surrounding soils). There were not any formed gaps at these locations, just a bond breaker to allow for movements. The footings were poured monolithically between the movement joints and did not have longitudinal construction joints.

Durability

Durability of the structure and life cycle cost analysis was a major consideration in this project. High performance concrete and galvanized steel were used in the splash zones of portal walls and in the first two segments of the tunnel in from the portals at each end. It is expected that with the drainage systems, the inside of the tunnel will be mainly dry. As mentioned, GFRP bars were used as dowels in movement joints. Galvanized steel was also used for shear dowels between the footings and bed rock, where required. All of the spaces between the bed rock excavations and footings, including the vertical sections of the footings in portals, were filled with lean concrete.

The structure design was mainly governed by crack control requirements. In general, no structural cracks were observed during the construction. There were some differential shrinkage cracks between the walls and footings. Actions were taken to minimize the cracks, including adding horizontal reinforcing steel at lower portions of the wall and using different mix design with a lower rate of strength gain (higher fly ash to cement ratio). Adding steel changed the crack patterns but did not change crack widths. Changing the mix design, however, reduced the crack width. All of the cracks 0.4 mm wide or greater were repaired with pressure injection of epoxy, as per the specifications. The inside faces of the tunnel walls, as well as the outside faces of the portal walls are being covered with an elastomeric coating. The selected coating is capable of bridging existing cracks and allows for crack width increase, should it occur. The underside of roof slabs are covered by a layer of fire protection. The applied fire protection system is a cementitious type and contains corrosion inhibitor that helps protect the roof slab from corrosion.

Outside of the walls and the top of the roof slabs were all protected by waterproofing. A performance-based specification was used for this project that would allow for competition of different types of waterproofing systems. The selected system consisted of a volclay sheet and a protection layer both mechanically attached to the concrete (see Figure 10). This system had the advantage of not being sensitive to temperature, humidity, or the curing state of the concrete and therefore could be applied shortly after removing the forms. This was an important factor in meeting the tight schedule. All of the exterior movement joints were covered by an external waterstop that allowed for the anticipated movements of the joints.

Fire Protection

Fire protection of tunnels has gained a lot of attention in the past decade because of a number of disastrous fires in the tunnels in different parts of the world. During a fire in a tunnel, when concrete is heated, water vapour is formed. The rise in vapour pressure can generate high stresses inside the concrete leading to separation at the surface, sometimes with loud noises. This is referred to as explosive spalling. The objective of fire protection in tunnels is to prevent explosive spalling and limit the temperatures at the concrete surface and at reinforcing steel for a given duration (2 hours in this case). Options for fire protection in tunnels include additional cover, adding fibres (polypropylene) to the concrete mix, which

in case of fire melt and provide escape routes for vapour, and using fire barriers in form of panels or spray.

A performance-based specification was prepared for the fire barrier according to NFPA requirements. The main requirement was for the fire barrier to limit the temperature of concrete surface and steel reinforcement to 380°C and 250°C, respectively, during a 2-hour test of exposure to fire based on RWS time-temperature curve (representative of a petroleum-based fire). The RWS time-temperature curve is one of the most severe time-temperature curves and has higher temperatures and higher rates of temperature rise than the curves commonly used for testing the fire barriers in buildings. This curve has been obtained from experiments with burning vehicles in tunnels and is believed to be the most representative of temperature rise in tunnels during fire (see NFPA 502 [1]). There are also other requirements for the material of the fire barriers, including being non-combustible and having a minimum melting temperature of 1,350°C.

Project Challenges

Tight Schedule

Meeting the tight schedule was one of the main challenges of the project and affected many decisions made during the design and construction process. The budget for the tunnel was approved by Council in February 2011. In late June 2011 a lease agreement was agreed upon between The Airport Authority and The City. Construction (excavation) started immediately in July 2011. The design and construction team had to meet deadlines for August 31 and October 31, 2012, for handing over significant portions of the tunnel including backfill (to 600 mm above the tunnel) to the Airport Authority. Because of uncertainties regarding whether the project would proceed, full design and construction planning could not start earlier. Not all of the information was available when the design started and design was an ongoing process as the construction was going ahead. The construction plan and staging that was developed with the aim of meeting the given deadlines while staying within budget was the origin of other challenges, some of them described here.

Loads from Construction Staging

At the initial stages of design, construction staging, and process of form removal was not known to the design team. The dead load of the structure was assumed to be carried vertically in a 2D manner. Later, the construction procedure to cast every other segment, using lead and infill method, was developed. There were some discussions about the possibility of leaving the forms in place or re-shoring the lead sections while the infill sections were cast. Neither of these was possible because of cost, schedule, and practical aspects. The design team studied the effect of the construction process on the structural loading. A 3D analysis, including the time staging process, showed that some of the dead load of the slab of each infill section is carried by the existing slabs of the adjacent lead sections. According to the analysis, the additional load to lead segments could be as high as 50 percent of the existing load caused by self weight in the lead segments. Although it was argued that this effect might reduce over time from further deflections and load redistributions, it was decided to add steel at critical points to reduce crack width.

Conduits and Embedded Items in the Structure

The structure had many embedded items such as conduits and electrical boxes, as well as many block-outs for fire equipment, and openings for fire exit doors between the cells. The number, dimension, and location of these items or openings became known gradually, as the design went ahead in different disciplines. The effect of main conduits and openings were studied by preparing detailed finite element models of the structure. Also reinforcement mock-ups were fabricated to examine the details of the reinforcement around the embedded

items to avoid congestion of reinforcing steel. Reinforcement locations were rearranged based on review of these mock-ups.

Another challenge that was met late in the stages of construction was the detail at the end segments where the conduits exit the walls to enter the control rooms. At this location the conduits had to be located very close to each other (see Figure 11). These locations were studied both by detailed finite element models and strut-and-tie method. To provide sufficient structural capacity; concrete strength was increased, conduit locations were adjusted to leave room for compressive struts, and shear ties and vertical reinforcement was added to strengthen the section.

Cooling the Concrete

The project schedule to meet turnover dates with the runway project was based on stripping the forms for each segment after 3 days of curing. This could meet the curing requirement of the specifications, but the requirement to achieve 70 percent of the specified 28-day strength before removing the forms was also a challenge. To achieve this strength in 3 days, the initial concrete mix design was made for a high initial strength gain. This would result in both higher initial shrinkage and higher heat of hydration. The maximum temperature specified during hydration was 60°C. Maximum temperature measured in the walls (1 m thick) was within the limit, but the maximum temperature measured in the slab (1.25 m thick), even on cold days, was in just above 70°C.

After many discussions, the maximum temperature was relaxed to 65°C, but other actions had to be taken to achieve this temperature. One of these actions was to alter the mix design. A new mix design with higher fly ash and lower cement content was used. The new mix design was both helpful in reducing the heat of hydration and reducing shrinkage cracking. Replacing water with ice was also used but it reduced the production time significantly, if too much ice was added to each batch. To make sure that the desired temperature would be achieved in the hot days of summer, it was decided to use liquid nitrogen injection. Liquid nitrogen does not have adverse effects to the concrete, but it has initial costs associated with setting up a platform, a tank, and a frame for the injection lance (see Figure 12). Considering the size of the project and the desired quality, the additional cost was considered acceptable. Liquid nitrogen was helpful in keeping the temperature below the limit. The only challenge was adjusting the lance for different sizes of concrete trucks. In some cases, the liquid nitrogen was aimed at the body of the drum rather than the concrete and caused cracking of the mixing fins in some of the drums.

Monitoring Temperatures and Movements

As mentioned earlier, the tunnel was designed according to the Canadian Highway Bridge Design Code. The design temperature range given in the code for Calgary is from -34 to 38°C. The question came up during the design stage if the tunnel, which is a buried structure, will actually be subjected to this temperature range. The design team could not find any references that would address the temperature ranges inside tunnels.

Another issue raised during the design stage was the necessity for movement joints. Although some references recommend joints as close as 9 m apart, there are tunnels that are constructed without any joints. To find answers to these questions for future designs, it was discussed with The City and it was agreed to put temperature and movement monitors in the tunnel. Wireless sensors were installed (buried) in concrete that would measure temperatures at two surfaces and mid-depth at 40 locations. Also, surface mounted sensors will be installed to monitor the movements at two movement joints.

Conclusions

Currently the main tunnel structure and the portals are completed. Runway project turnover deadlines for August 31 and October 31, 2012, were successfully met on time and on budget and the portions of the structure under the runway and taxiways were handed over to the Airport Authority to continue their construction of the RDP. The tunnel is scheduled to open to traffic on May 2014.

This success was only possible because of close collaboration between the design and construction teams and the owner. All of the parties involved met weekly to discuss all the issues regarding design and construction and solve problems. The project had many challenges but all of those were discussed and actions were taken to overcome them. When the deadlines were set they seemed unrealistic and completing and backfilling the main structure of a 620 m tunnel in less than 10 months seemed unachievable. It has been a great achievement for all of those involved in this project and an accomplishment to be proud of.

Acknowledgements

Contributions:

- The City of Calgary: owner
- CH2M HILL: project management, structural engineering, and site resident engineering services
- Associated Engineering: roads, drainage, mechanical, and electrical engineering
- PPD (PCL, Parsons, Dufferin) Joint Venture: construction management
- Thurber: geotechnical engineering

Special thanks to Cathy Zou, Magda Sorial, Ken McWhinnie, Ayman Elmahdy, and Steve Murphy for their efforts on structural design and drafting, and Ovid Stroescu, Anthony Speelman, and Nathan Murdoch for their help as site resident engineers.

References

- 1 - National Fire Protection Association. 2011. NFPA 502, Standard for Road Tunnels, Bridges, and Other Limited Access Highways, 2011, NFPA, An International Codes and Standards Organization, 1 Batterymarch Park, Quincy, MA 02169-7471, USA.
- 2 - Canadian Standards Association. 2006. Canadian Highway Bridge Design Code S6 06 (CAN/CSA S6-06), Canadian Standards Association, 5060 Spectrum Way, Mississauga, Ontario, L4W 5N6 ON, Canada.
- 3 – The City of Calgary Transportation Infrastructure. 2007. The City of Calgary Design Guidelines for Bridges and Structures, Third Edition, Revision 5. The City of Calgary Transportation Infrastructure, The City of Calgary, Transportation Infrastructure, # 800, 125-9 Ave SE, Calgary, AB T2G 0P6 Canada.
- 4 – US Department of Transportation, Federal Aviation Administration. 2009. Airport Pavement Design and Evaluation, Advisory Circular No. 150/5320 6E, AAS-100, Office of Airport Safety and Standards – Airport Engineering Division, USDOT FAA, 800 Independence Avenue, SW, Washington, DC, 20591, USA.
- 5 – American Concrete Institute. 1995. ACI 343-R, Analysis and Design of Reinforced Concrete Bridge Structure, ACI, 38800 Country Club Drive, Farmington Hills, MI, 48331, USA.

Figures

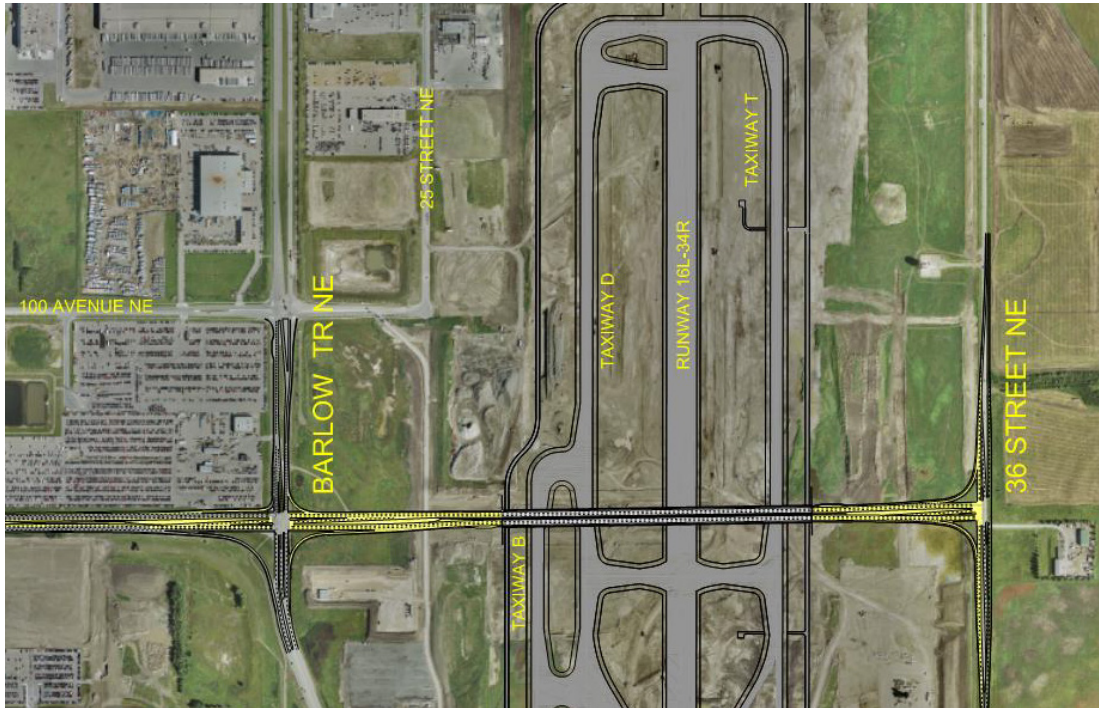


FIGURE 1 – TUNNEL LAYOUT UNDER THE AIRPORT RUNWAY AND TAXIWAYS

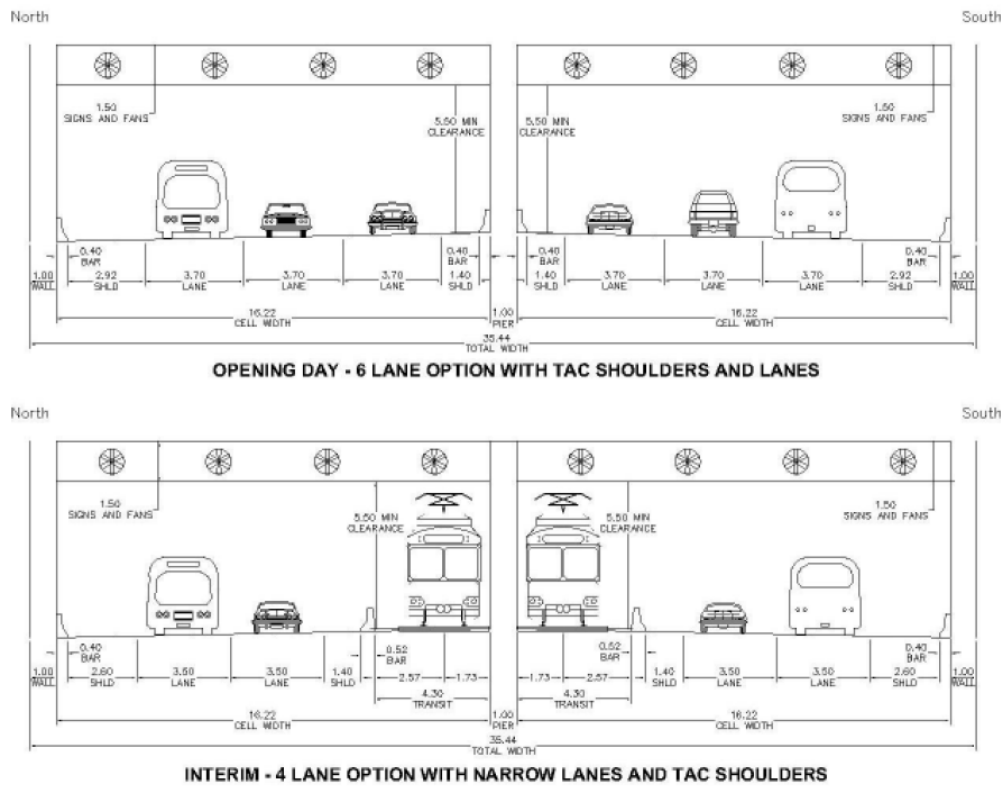


FIGURE 2 – LANE ARRANGEMENTS



FIGURE 3 – RENDERING OF COMPLETED STRUCTURE

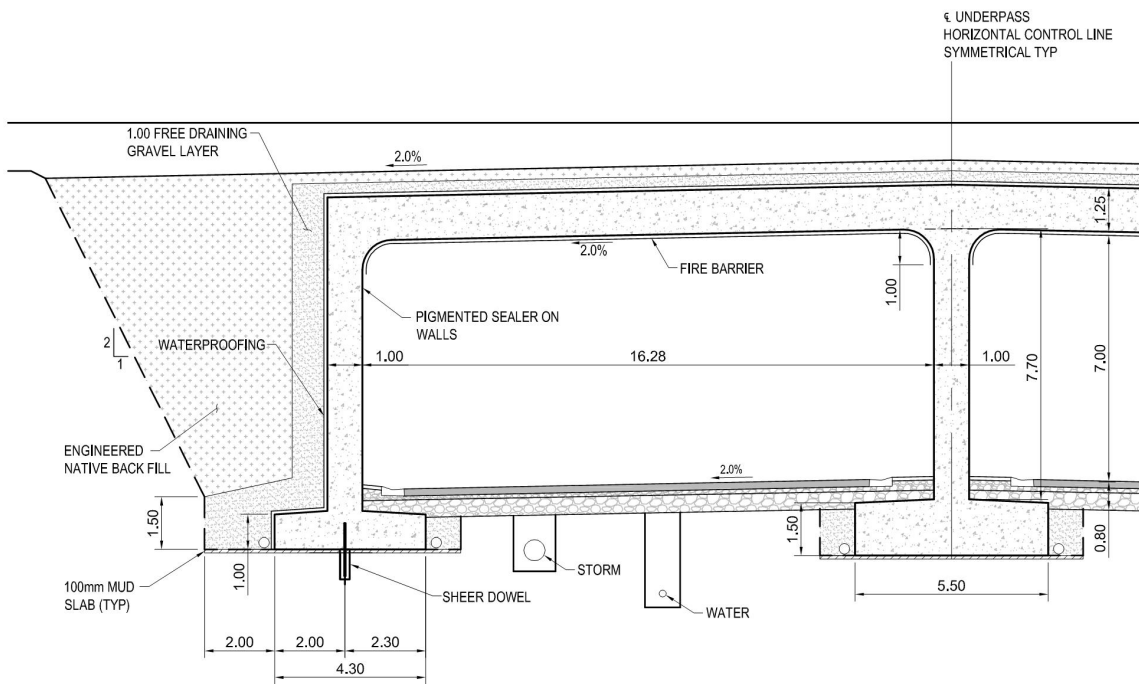


FIGURE 4 – TYPICAL SECTION OF TUNNEL WITHOUT APPROACH SLAB

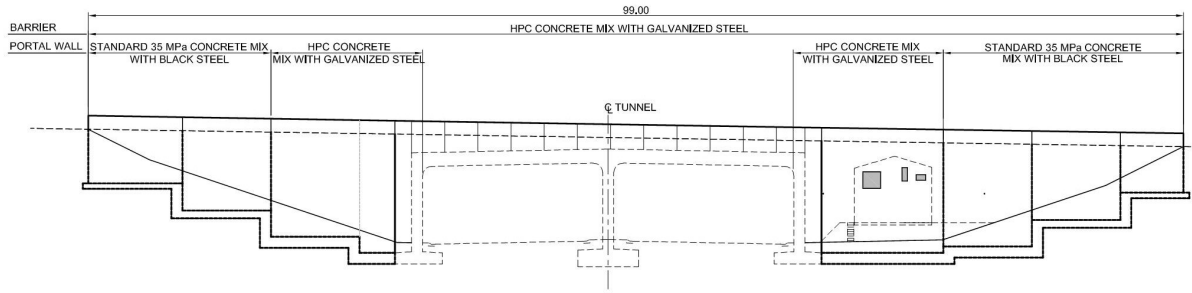


FIGURE 5 – TUNNEL PORTALS



FIGURE 6 - METAL FORMS AND HORDING TENT USED FOR TUNNEL CONSTRUCTION



FIGURE 7 – TUNNEL DURING CONSTRUCTION, MAY 2012, LOOKING NORTH

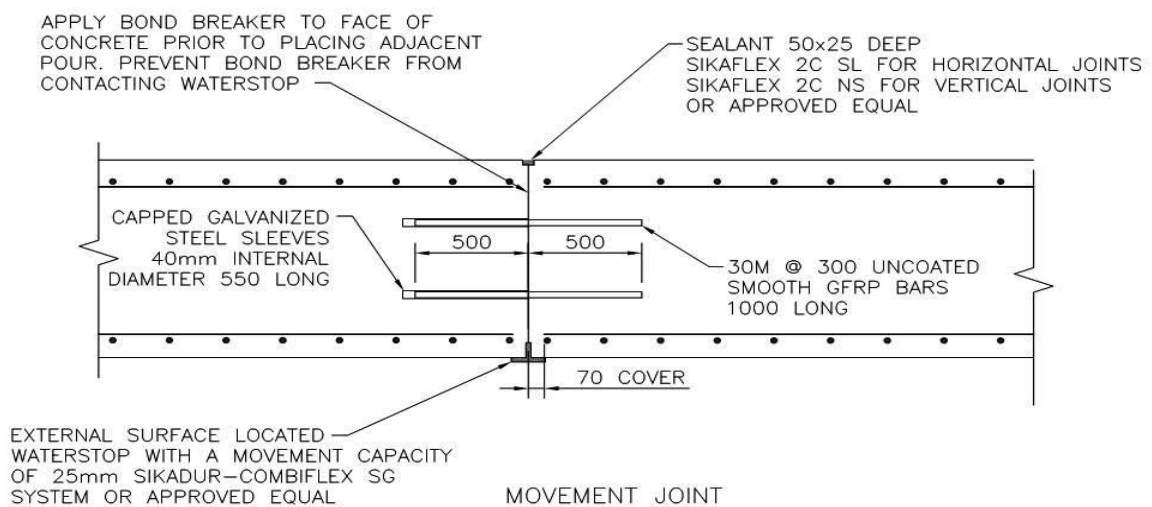


FIGURE 8 – MOVEMENT JOINT



FIGURE 9 – CONSTRUCTED MOVEMENT JOINT



FIGURE 10 – TUNNEL WATERPROOFING SYSTEM



FIGURE 11 – CONDUITS IN TUNNEL WALLS



FIGURE 12 – LIQUID NITROGEN INJECTION