

CALGARY

WEST LRT EXTENSION, DESIGN-BUILD



ASSOCIATION OF CONSULTING
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Canadian Consulting Engineering Awards 2013
Submission Category: Transportation



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CALGARY

WEST LRT EXTENSION, DESIGN-BUILD



Balanced Cantilever Structure

PROJECT INTRODUCTION

MMM Group Limited (MMM), Read Jones Christoffersen Ltd. (RJC), and SNC-Lavalin Group Inc. (SNC) provided engineering services on the Calgary West LRT project, a \$750 million expansion of the City of Calgary's C-Train network. The project was awarded in September 2009 and opened to the public in December 2012 (only 39 months), an amazing feat of engineering, coordination, and execution by the design builder (SNC Lavalin Constructors Pacific) and the design team.

The 8.2-km long West LRT is designed to meet the increasing transportation demands of the southwestern part of the city, particularly for the communities located between the Bow River and the Glenmore Reservoir. This is the largest infrastructure project in the history of Calgary, the first-ever underground and elevated guideway rail systems and stations in Calgary, and the first-ever design-build LRT project contract with the City. This is also the first new LRT line in the City of Calgary in 20 years.

MMM was responsible for the structural design of the 1.5-km elevated guideway, which utilized precast segmental construction erected by both span-by-span and balanced cantilever methods; SNC was responsible for track, tunnels, and trenches structure design; and RJC was responsible for the design of six stations, one elevated, one in-trench, one underground, and three at-grade stations.

1.0 INNOVATION

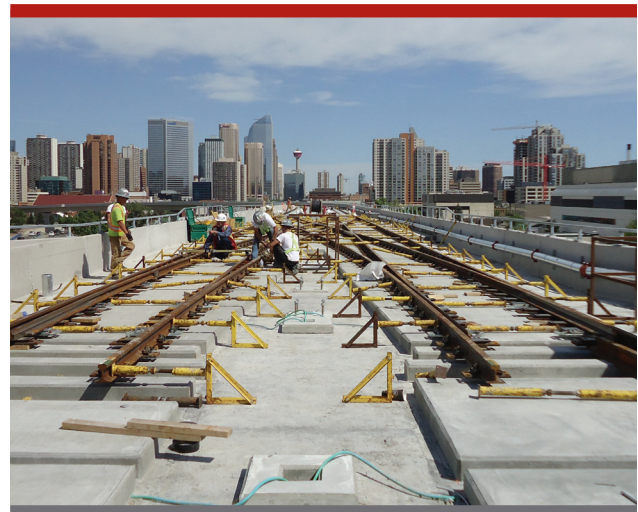
On modern elevated guideways, such as the Calgary West LRT project, direct fixation is much preferred over conventional tie-and-ballast track. Direct fixation utilizes resilient rail fasteners to connect the running rails directly to the guideway surface. This method substantially reduces the dead load and maintenance requirements of ballast, but is not without its challenges.

On elevated guideways, the biggest challenge with direct fixation is the potential for beam movement, particularly in Calgary with the large fluctuations in winter and summer temperatures. Therefore, long structures, such as those used for the Calgary LRT require multiple railway expansion joints.

The project team brought proven and reliable technology to the City of Calgary by constructing its first segmental guideway. This involved designing a diamond crossover on the elevated guideway, which is typically done only at-grade. While direct fixation fasteners allow for differential movement between the rail and structure on plain track, the same cannot be said for switches and crossovers. Adjacent to Sunalta Station, the Sunalta scissors crossover



69th Street Trench Guideway



Diamond Cross Over

allows trains to change tracks in both directions, and is the first such elevated crossover on the Calgary Transit system. It provides much needed operational flexibility, allowing trains to turn back at Sunalta Station to service high-volume special events or run single-track to route around equipment failures or scheduled maintenance activities and maintain service. At 53 m in length, this crossover is too long to fit on a single conventional span. To prevent differential movement from affecting the delicate geometry of this crossing, the project team engineered a link-slab, which binds two simply-supported spans together and provides a continuous platform for the trackwork. At each end, rail anchors fix the running rail to the structure. These further protect the switches by transferring thermal expansion forces generated in the adjacent plain track to the guideway beam. As the running rails also carry the return electrical current from the overhead catenary system, these rail anchors have been engineered to provide a structural bond while remaining electrically insulative. Widening of the forms was also necessary for the additional switch machines. Transverse post tensioning in the deck was used in order to retain the same deck cross-sectional thickness.

This project also included the first underground guideway in Calgary, with cast-in-place dowels to connect the track fixation plinths to the tunnel and trench base slab to facilitate construction. The existing groundwater conditions provided the potential for frost heave, so subdrains were installed along the length of the tunnel to reduce the potential for frost damage. No longitudinal reinforcing steel was provided through the transverse construction joints in the trench walls, so that each trench wall segment could expand and contract within the limits of the continuous welded rail.

One of the key aspects that led to the overall success of this project was the project management structure that was implemented at the time of bid, which continued through the execution phase of the project. SNC-Lavalin Group established four independent joint ventures (for stations, infrastructure, systems, and track) with their own design teams and construction forces to execute the project. This was done under the overall guidance of the design builder which maintained control of the overall schedule, design integration, cost control, quality assurance, environment, and public relations.

The 69th Street Station and terminal tracks are depressed in a 425-m long open trench with a maximum depth of 16 m. A shotcrete and soil nail retaining wall structure was proposed to eliminate the need for temporary shoring adjacent to a major roadway. The double-corrosion protected soil nails and shotcrete surface were installed as excavation advanced. As the 69th Street Station is located in the trench, a high-quality finish was required for the retaining wall surfaces. To achieve the required consistent appearance, and to allow construction to continue through the winter, precast concrete wall fascia panels were designed to be supported on the heads of the soil nails. Incredibly tight survey and fabrication control was required to ensure the complex pieces fit together on site.

The Westbrook Station incorporates a four-storey office building constructed over top of the underground platforms. The second floor of the office building was required to transfer building columns supporting the upper floors of the office tower, over the 25 m clear span of the main floor entrance to the station. The second floor also functioned as a fire separation between the station and the office tower, due

to the required code separations of the building occupancies. The design for this transfer floor utilised post-tensioned steel beams that were encased in concrete. RJC designed the beams to support the weight of concrete without shoring as this would have needed to extend 15 m down to track level and would have disrupted other construction activity at the guideway level. A combination of post-tensioning and two-stage concrete pours to assure composite action produced an efficient structure that reduced the depth of the second floor, reduced the overall weight of the building and allowed construction of adjacent structures to continue concurrently.

As part of the development of Sunalta Station, a new pedestrian bridge connects the elevated station at Sunalta to the existing Greyhound bus terminal via a 40 m main span over CPR tracks. RJC implemented an improved design that replaced a precast concrete girder main span, with a half-through steel truss solution. The revised main span had a reduced deck depth that reduced the overall height of the bridge whilst still respecting CPR clearance envelopes. The net result was an 18-m reduction in length of access ramps and a reduced site footprint, as well as construction benefits associated with lifting a lighter weight steel structure over active CPR tracks.



Sunalta Station

2.0 COMPLEXITY

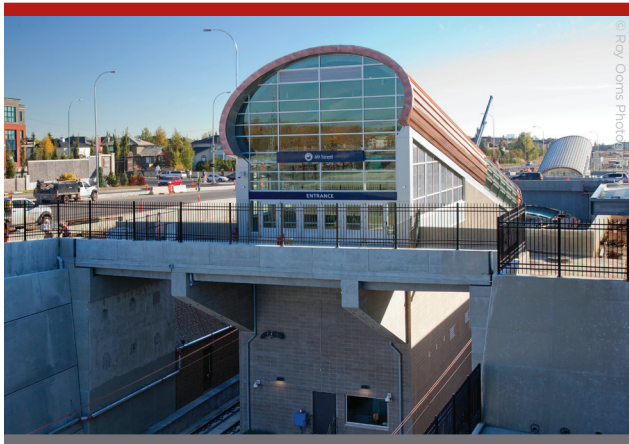
The degree of difficulty on this project was extremely high, as there were many challenges that needed to be overcome in order to deliver a quality product to the Owner, on budget and on schedule.

One such challenge included the need to minimize traffic disruption during construction, and to continue to provide access to businesses and residential areas while limiting the number of lane closures at any given time. This challenge was augmented by the fact that detours could only be to non-residential roads. A detailed traffic management plan was created to address these challenges and to maintain access to property while minimizing disruption to road users.

Another challenge involved minimizing the construction impacts, which was done by using reinforced concrete columns founded on drilled concrete shafts (caissons), and by conducting construction in segments. The caissons could be accurately placed to avoid utilities and other existing infrastructure.

Space restrictions on the project was another challenge. By using a non-standard span design in one particular location, the problem of fitting the piers into a tight environment was solved (and at lower cost compared to other alternatives). Since the span was longer than the standard, specialist vehicle dynamic modelling on the structure was necessary to ensure rider / passenger comfort through minimized vibration frequencies.

Challenges faced and innovations implemented by the design team also include: **(a)** modification and reuse of construction equipment and pre-cast forms from a previous project; **(b)** optimization of span arrangements to minimize



69th Street Station



CPR Special Structure

utility relocation and traffic disruption; **(c)** maximization of the use of standard single-span configuration for ease of design and construction; and **(d)** elimination of rail expansion joints on the elevated guideway to reduce construction and future maintenance costs through rigorous analysis and modelling of rail-structure interaction.

Technical excellence was demonstrated through the integration of track and structure designs for economies in rail anchor and expansion joint designs. MMM Group used Rail Structure Interaction (RSI) modelling on the West LRT project to ensure technical excellence and accuracy. The RSI model was a highly developed three-dimensional structural analysis model used to evaluate the interaction of the rail track on the full length of the elevated guideway including its various span lengths and configurations. The LRT track alignment designed by SNC-Lavalin was imported from CAD design files into SAP 2000, a commercially available, non-linear structural analysis program that enabled us to precisely determine track location on the structure. The track alignment was directly imported from the track designer and allowed us to model the exact track location along the entire length of elevated guideway, which including 30 simply supported spans,

a two-span continuous structure over CP Rail corridor, the 133-m long Sunalta Station, the four-span, 212-m balanced cantilever section.

The substructure was also modeled to take into account the stiffness of substructure columns and foundations. The fasteners between the rail and the structure are the key element for determining the force behaviour. The fastener's non-linear behaviour was modeled using the Owner's test acceptance criteria and a strain histories diagram. The model included the exact spacing of the fixed anchor locations. RSI also allowed us to conduct load case modelling, accurately determining vehicle live loads that will be directly applied to rails, creep and shrinkage, broken rail loads, thermal changes, and any sensitivity to rail end conditions. As a result of using RSI, the team could pinpoint rail forces and stresses, elevated guideway beam forces, column forces and displacements.

The use of erection truss on this project was essential for the span-by-span precast segmental erection method, and provided an efficient system that was suited for this application. This is a tried and tested method used in similar LRT systems, and therefore required minimal upgrades. The LRT system requires a high degree of construction accuracy

to meet very tight track tolerances. The erection truss allows the contractor to place the span to within millimeters of its intended design location.

The elevated guideway at Sunalta Station was designed by RJC as a cast-in-place post-tensioned concrete viaduct structure that supports the LRT tracks, platform components, and station head building. To accommodate the structural movements associated with large temperature changes, the guideway is designed to support the platform and ancillary building components whilst allowing the differential movements arising from thermal expansion and contraction of the guideway.

During the construction of the underground station and parkade at Westbrook, the excavation in bedrock uncovered a narrow steeply sloping underground gravel channel that extended across the LRT alignment and beneath the foundations to the office tower and parkade. This unexpected feature revised the foundation conditions for the tunnel and building and presented a significant risk for differential settlement of the structures. The RJC design team implemented a rapid redesign of the building and tunnel foundations, replacing pad footings with a substantial raft foundation that was able to span over the gravel channel and transfer building and guideway loads to the adjacent competent bedrock.

The at-grade stations on the guideway incorporate complex roof canopies that use a rotated elliptical concrete arch to span over the guideway. Coupled with flowing roof outlines,

this unique geometry has a valued aesthetic impact, however required detailed analysis to ensure that the unbalanced load conditions did not result in excessive movements due to creep.

Managing traffic during construction was a key element during the design and construction. Shoring was used to minimize the impact to traffic in areas where the tunnels and trenches were constructed along a busy transportation corridor. A new interchange was constructed at Sarcee Trail and 17th Avenue. Careful construction staging and detours were necessary to maintain effective traffic operations during construction. An existing rock stack wall along 17th Avenue had to be relocated because it conflicted with a new soil nail wall installation, this created concerns with the embankment's stability that needed to be addressed during construction. An existing timber pathway upslope of the new Mechanically Stabilised Earthwall at Costello Boulevard was rebuilt, which required careful coordination between the contractor, geotechnical engineer and the structural engineer.



Westbrook Station

3.0 SOCIAL AND ECONOMIC BENEFITS

The West LRT opened to great fanfare in December 2012. The unique structures captured people's attention and imagination during construction and attracted many new transit riders. The design of the entire line evokes the energetic nature and civic pride of the City.

The City has celebrated the opening of the West LRT and the social and economic benefits for the City are numerous. The new transit line has helped to alleviate traffic on many roads, particularly during busy rush hour times, as more people now take transit to and from work. The City has conducted surveys that show that thousands more people are taking transit into the city core on a daily basis via the West LRT line. According to data from Calgary Transit's passenger counts and surveys, many riders had never used the City's LRT system prior to West LRT opening.

Residents in nearby communities have benefitted in many ways. There is less traffic on the roads by their homes, and they now have the option to take the LRT rather than driving or using the bus routes. As well, on average most property values within a one kilometre radius of the line have risen.

ECONOMIC BENEFITS

The LRT operations require a significant number of communications and power cables. The design team convinced the Owner to locate the cables inside the box on hangers and cable-trays rather than locating them on the top side near the tracks or hanging from the underside of the structure exterior. This change provides security for the cables, lower maintenance costs by not exposing the cables to the elements, and for a superior aesthetic look for the structure.

The Owner realized added value when the re-use of the Vancouver Canada Line forms were included in the design. The design created added value in the final product by improving structural efficiency of the system which lowered initial capital costs. Further, the design included enhancements for improving durability by using advanced materials technologies which will reduce future maintenance cost.

The reuse of the Canada Line formwork was very important to our client in reducing costs. The forms were widened to provide for the required guideway width. For the balanced cantilever structure over Bow Trail, the segment shape was designed to match the Middle Arm Bridge on Canada Line. Re-use of these forms provided value to the client as new forms did not have to be procured at a high cost and shortened the construction schedule since the forms only required modification prior to use.

In one very constrained location along the elevated guideway, a non-standard 39-m long beam solved a difficult problem of fitting the piers into a tight building environment at a low cost.

Project costs were controlled by the following:

- reuse of forms to minimize start-up cost and schedule
- the erection procedure was nearly identical to that of the Canada Line and the experienced design team did not require the typical learning curve
- elimination of rail expansion joints over the continuous structures, lowered the capital and future maintenance costs
- use of precast segmental structures decreased risks to project costs by allowing span erection from above

- construction using an overhead erection truss, and in conjunction with the caisson foundations, allowed efficient construction of the guideway reducing risks to project costs
- use of the 39 m beam resulted in a lower cost compared to other alternatives, such as relocation of existing infrastructure

SOCIAL BENEFITS

Light Rail Transit (LRT) is a fast, efficient and low cost method of traffic, and as the proposed alignment of the Calgary West LRT enables people to get to and from stations via short feeder buses, this project will enable Calgary to create transit-oriented development (TOD) opportunities, and to increase the overall sustainability of the city.

As a part of the project a multiuse pathway was built along 17th Avenue SW, which provides a continuous and safe connection for both pedestrians and cyclists.

The initial design concept had just a short trenched transition between the tunnel and at-grade guideways. By increasing the length of the trench, the tunnel and at-grade portions were reduced. The longer trench provided benefits to residents by removing more of the guideway from their view. Reducing the tunnel length also reduced the costs.

Based on the City of Calgary's consultation with local residents, noise barriers were provided along the LRT guideway. The exact locations and the height of the noise barriers were based on the resident's input. A special custom design was required to accommodate height changes from 2.4 m to 3.0 m at various locations. This demonstrates the design-build team's commitment to mitigating the social impacts of this development for local residents.

4.0 ENVIRONMENTAL IMPACT

LRT is a green technology of the future which will allow Alberta to shift to more sustainable forms of employment. The concept selected for the elevated guideway (caissons supporting single cast-in-place columns supporting a precast guideway), minimizes environmental issues on the project, and bypasses environmental-sensitive areas. The caisson construction method disturbs the least amount of earth of all foundation methods, and the only significant potential for environmental impact was the auguring of the material to create the caisson, which was handled carefully. The columns for the elevated guideway were constructed using steel forms and there were no significant environmental issues. The precast guideway is very benign as all the concrete work is completed in a factory.

LRT's green technology will reduce vehicle traffic congestion, reducing transportation-related emissions.

The open concept for the stations requires that the majority of its functional and aesthetic elements are structural in nature. As an unconditioned station uses minimal energy on an operational basis, the construction phase is an important contributor to the overall service life environmental impact. Innovative designs and material selection that reduce the initial energy input, reuse or recycle materials can play an important part in the total environmental performance of the station. Efficient design uses less material overall which in turn is better for the environment. The exposed architectural portions of the structure not only reduce material used, but produce a visually appealing framework that comes as close as possible to the most efficient structural form.



Shaganappi Station

The materials that were selected were all considered for their environmental benefits. For example, the steel incorporates reused materials and is itself recyclable, a portion of the cement was replaced with fly ash, and the cement was sourced locally. Wood purlins and wood decking were used as they are less energy consumptive materials and renewable resources.

Low Impact design was also considered project wide primarily for diverting surface storm water to ground to reduce the storm water load and to improve water quality. Station plaza and platform areas were drained to tree wells or guideway subdrains. Whole sections of at grade guideway were also design to infiltrate water.

Runoff from the LRT at-grade section between Christie Gate Park and Sarcee Trail were conveyed downstream through a subdrain system to the proposed trap low at the northwest corner of the Sarcee Interchange. Flows from the southbound off-ramp pavement will also be diverted into this trap low. Since the trap low will be lined with native vegetation, the removal of contaminants will be accomplished through filtration by plant stems, absorption of soil particles, and biological processes.

Runoff from a small section of 17 Avenue east of Sarcee Trail and the northbound off-ramp will flow into the two trap lows at the southeast corner of the interchange. These two trap lows

will be lined with native vegetation, which will promote contaminant removal by plant filtration, soil infiltration, and biological processes.

Low Impact design was also considered project wide primarily for diverting surface storm water to ground to reduce the storm water load and to improve water quality. Station plaza and platform areas were drained to tree wells or guideway subdrains. Whole sections of at grade guideway were also design to infiltrate water.

Contaminated soil pre-existed the West LRT project and will be partially drained and collected by the construction of the Westbrook Station, connecting tunnels, and TOD building. The design included confirming the volume of ongoing groundwater drained by the project in the affected area, confirming expected groundwater contamination levels and then developing, designing, and installing a collection and treatment system for that water so it produces acceptable discharge. Features of the system included a continuous sub drain system to a dedicated well point and pumping system to the treatment plant. The water treatment facility designed is based on discharge to the City of Calgary storm sewer, with emergency discharges to the City of Calgary sanitary sewer. The treatment process focused on the reduction of hydrocarbon contaminants to concentrations that will allow for continuous discharge directly to the City of Calgary storm sewer.

5.0 MEETING CLIENT'S NEEDS

The client's expectations were outlined in the Project Requirements and Reference Concept Drawings. However, not all of the implications and interface issues were fully explored. During the detailed design stage we worked closely with the Client to develop our design and ensure that all the project requirements were met. We demonstrated an initiative to resolve any issues and find sound design solutions.

During construction the City required the team to minimize disruption to vehicular and pedestrian traffic, while also maintaining access to businesses and other stakeholders along the line.

Through careful planning and consideration, the team delivered the project while meeting these requirements, despite construction of the line occurring in some of the City's busiest corridors.



The City of Calgary's West LRT line opened on time and on budget. It has met and in some cases exceeded the functional, operational and aesthetic requirements of the many stakeholders involved in the project. Thousands more people are now using the new line, making it

well worth the City's investment. Calgary Transit estimates a 28% increase in ridership, with 15% of users not regular transit riders before the West LRT opened.

CONCLUSION

MMM Group Limited, Read Jones Christoffersen Ltd., and the SNC-Lavalin Group teamed to provide engineering services for the design of the Calgary West LRT Design-Build Project. The design team provided the structural design for tunnels, trench guideway, elevated and underground stations, and track design for the 1.5 km of elevated guideway which utilized precast segmental construction erected by both span-by-span and balanced cantilever methods, a first for the City of Calgary. The precast segmental structure was constructed using an overhead erection truss, and in conjunction with the caisson foundations, allowed efficient construction of the guideway with minimal impact to existing infrastructure while minimizing traffic disruptions. A detailed analysis of the rail-structure interaction was performed during the detailed design. The 3D model consisted of explicitly modelling the track alignment and profile, rail fasteners and structure to determine force effects of live, thermal and exceptional load cases.

The innovative result was the elimination of rail expansion joints over the continuous structures - lowering the capital and future maintenance costs and shortening the construction schedule significantly.



24th Street Pedestrian Bridge