AECOM

CANADIAN CONSULTING ENGINEERING AWARDS 2012

TRANSPORTATION

NORTH LRT EXTENSION

NORTH LRT EXTENSION DOWNTOWN TO NAIT: STATION LANDS TUNNEL CAVITY

SUBMITTED BY AECOM

THE ONLY WAY TO DISCOVER THE LIMITS OF THE POSSIBLE IS TO GO BEYOND THE IMPOSSIBLE

-Arthur C. Clark, Author

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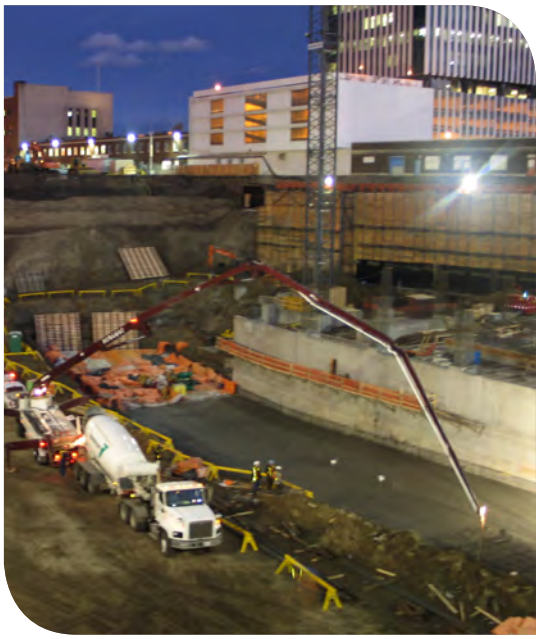
Project Highlights

The North LRT Extension adds a new branch to Edmonton's LRT system. Connecting underground to the existing line just north of Churchill Station, new twin tunnels pass close to the 26-storey CN Tower and below the recently completed 28-storey Epcor Tower at the Station Lands site, turning to west to line up with 105 Avenue. The tunnels surface on 105 Avenue at 103 Street. The LRT line continues at grade to new stations at MacEwan, Kingsway, and NAIT.

Construction for the North LRT Extension started in the summer of 2011 but many might be surprised to learn that construction of a portion of the North LRT, a tunnel cavity to carry the LRT through the Station Lands site, was started in 2008 and completed early in 2011.

The Station Lands site, located immediately north of the CN Tower, was previously the location of CN's downtown Edmonton terminal, and is now the location of Edmonton's newest office high-rise building, the Epcor Tower. During concept design for the North LRT Extension, late in 2007, the design team learned of plans to fast-track the development of the Station Lands property. The location of the proposed tower was potentially in conflict with the



Base slab pour with CN Tower in background

Temporary Lighting in Southbound Tunnel

North LRT Alignment

approved alignment for the North LRT extension. A decision was made to fast-track the design and construction of a structural cavity within the Station Lands development that would later house North LRT lines. The tunnel cavity would be built in parallel with the Epcor Tower, well before construction of the rest of the North LRT.

Early construction of the tunnel cavity at Station Lands allowed the City of Edmonton to avoid the substantial costs, estimated at $140 million, associated with a deeper tunnel below the Station Lands. The parallel fast-tracked design and construction of the two projects involved extensive collaboration between the construction manager and the designers as well as a remarkable level of cooperation between the two owners.

Project Description

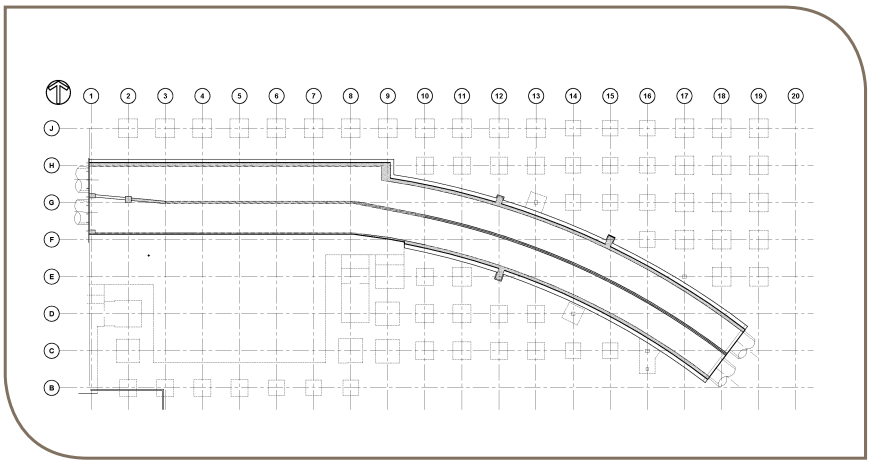
An Unconventional Start

Early in 2008, the design and construction teams for the North LRT and the Epcor Tower began working to coordinate the designs of the two projects. Ledcor Construction Limited provided construction management services for both projects. The engineering leads for the North LRT and the Epcor Tower were UMA Engineering Limited and Earth Tech, respectively, distinct companies at that time. By the end of the project, both Earth Tech and UMA would merge under AECOM. Services provided by AECOM for the LRT tunnel included design, site inspection and contract administration.

The City entered into a contract with the developer and owner of the Station Lands site to build the LRT cavity. The developer, having already retained Ledcor Construction Limited as Construction Manager for the Epcor Tower, extended that scope of work to include the LRT cavity.

Project costs were tracked under two main headings. Tunnel costs were those costs directly associated with the tunnel structure. Incremental costs were those costs to the Epcor Tower project as a result of accommodating the LRT tunnel.

Placing Mudslab for LRT, October 2008



Project Layout

A Word about Ground Conditions

Four main strata underlie the Station Lands site. Much of the site is covered with granular ballast and sub-ballast, not surprising given its railroad history. Below this to a depth of about 6 meters is post-glacial clay. Below the clay is an extremely competent glacial till with outstanding bearing capacity. The till extends to a depth of about 20 meters. Below the till is a thick sand and gravel layer known as the Empress Formation, extending to bedrock at a depth of roughly 35 meters. Because of the outstanding bearing properties of the foundation soils, vertical movements in response to excavation and construction were expected to be largely elastic.

Worksite
November 2008

Southbound Looking West
January 2009

Placing Concrete for Base Slab
November 2008

Roof Reinforcement and Transfer
Girders Between Gridlines 9 and 12
January 2009

Worksite
March 2009

Coordinating the Designs

The Epcor Tower has 28 floors above ground and is surrounded by plaza designed for up to 8 floors above ground and four levels of underground parking. Columns are on a 9.144 meter (30 feet) square grid founded on spread footings. The tower structure has a central core founded on a raft slab. The lowest parking level (P4) is approximately 14 meters below grade.

The LRT structure is a cut-and-cover style box structure immediately below the P4 parking level. At its lowest point, the excavation for the base slab of the LRT tunnel is approximately 24 meters below grade, placing it well into the Empress Formation (sand and gravel).

To coordinate the designs, it was necessary to have a common reference. The grid system set up for the Epcor Tower was adopted for both projects.

From gridline 1 to 9 the LRT structure is aligned with the building above. This makes a somewhat larger tunnel cavity than would ordinarily be required for the LRT but it allows column loads from the parkade and plaza to be taken directly on tunnel walls. East of gridline 9 it is no longer possible to align the cavity structure with the columns above. Support for parkade and plaza columns is provided by 2.2 meter deep transfer girders.

Worksite
May 2009

A number of modifications were made to both structures. The grades at the west end of the lowest parking level were adjusted to make it possible for the LRT alignment to reach grade at the proposed MacEwan Station. The walls and roof of the LRT tunnel cavity were insulated to protect the P4 level from cold air within the tunnel.

From the perspective of the LRT tunnel, the major design issues for the combined structures were: (1) loads from the tower core foundation; (2) loads from parkade and plaza columns within the LRT right-of-way; (3) potential delays of the Epcor Tower project attributed to LRT construction, with possible claims against the City for liquidated damages.

Technical Excellence and Innovation

Several approaches for handling tower foundation loads were considered. Carrying the loads on the LRT would require substantial structure. The innovative solution chosen was to avoid the problem by deepening the tower raft foundation and footings so that their bearing would not load the side walls of the tunnel. For the raft foundation supporting the tower core, this was done with a combination of two strategies: the raft foundation was lowered by 3.5 meters. In addition, an unreinforced concrete wedge running beneath the edge of the raft foundation and adjacent to the LRT base slab brought the foundation bearing of the tower to the same elevation as the LRT base slab. Column footings were also lowered, the amount depending upon their proximity to the LRT tunnel.

The LRT base slab serves as a foundation for both the LRT and a number of parkade and plaza columns from the tower. Reinforcement for the LRT base slab made use of prefabricated cages complete with shear reinforcement. As a conventionally reinforced one-way slab, the thickness of the base slab, governed by shear, would be in excess of 1.5 meters. With the cages, the thickness of the base slab was reduced to 1.2 meters. The shear strength of the base slab benefited both from the addition of a steel contribution and the removal of scale effect.

Modular reinforcement was also used for the LRT roof slab and transfer girders. The modular nature of the reinforcement saved approximately 8 weeks of construction time.

Because much of the concrete work was done in winter, it was important to be able to reduce and remove heating and hoarding without damage to the concrete. Because of the time pressure on the work, it was necessary that heating and hoarding be removed as quickly as possible. Base slabs were cast with sets of temperature gauges. Data from these gauges were used to track temperature gradients through the thickness of the slab. The gradients provided criteria to guide the reduction and removal of heating and hoarding. An extra benefit was that the contractor could take better advantage of favorable weather conditions.

Base Slab Reinforcement

Level of Complexity

Coordinating the structures east of gridline 14 was a major challenge. The task was to devise a structure and construction scheme that would not compromise future development of the Station Lands site. The tower structure requires a truck ramp for delivery access to the first parking level, P1. The simplest solution, simply backfilling and building a grade-supported truck ram, would block future expansion of the parkade. Structurally supporting the truck ramp at this stage was deemed essential for future development of Station Lands but it was complicated by the depth of the excavation, approximately 24 meters below grade, and the skew of the LRT alignment relative to the tower structure. This area is also where the LRT alignment has its nearest approach to the existing CN Tower.

The deep excavation involved staged installation of shoring walls worth $3 million. Given the proximity of the CN Tower, instrumentation in the form of slope indicators and survey points was installed to monitor for any movements.

Administration of the contracts was, for the most part, relatively straight forward; however, assessing incremental costs in the portion of work east of gridline

Complex coordination of construction east of gridline 14; CN Tower in background

Stockpiled Reinforcing Cages

14, which includes the deep excavation discussed above, proved challenging. The excavation east of gridline 14 was geometrically complicated and involved multiple handling of material to accommodate the staged construction of the retaining walls. Costs had to be assigned to the tunnel, to incremental or to the tower. An additional problem concerned the definition of incremental cost for elements, such as the parkade structure below the truck ramp, that were being built ahead of schedule to accommodate LRT construction. A system for distributing project costs was devised that was acceptable to all parties.

Completed tunnel cavity
prior to backfill and landscaping

Environmental Impact

The Light Rail Transit (LRT) system provides Edmontonians with an environmentally responsible alternative to conventional transportation choices. The expansion of the LRT network from the downtown core to the north side of the City will extend this alternative to a vast number of Edmontonians, thereby decreasing the number of individuals driving to the downtown core on a daily basis. This will not only lower Edmonton's carbon footprint, it will improve our air quality and decrease the need for the construction of new roads.

During the design and construction of the tunnel, opportunities to improve the energy efficiency and reduce the environmental footprint of the building were implemented. Lowering the depth of the raft slab presented the designers of the Epcor Tower with a "found" space for a system of earth tubes to reduce heating and cooling needs for the entire building. In addition, the extended core walls were modified to create a water tank to store rain water for use in the buildings sanitary system. Ultimately, the designers achieved LEED Silver certification for the building. These design features would not have been considered if the specific opportunity to adopt them, due to the LRT tunnel construction, had not occurred.

Social and Economic Benefits

The LRT tunnel at Station Lands was fast tracked with the expressed purpose of reducing the cost of construction and social impact of the LRT expansion. If the design and construction of the LRT tunnel had not been completed in partnership with the Station Lands development, there would have been only a few, undesirable options to continue with the LRT expansion. It would have been necessary to create either a tunnel well below the already constructed Epcor tower, or revise the LRT alignment. The impacts of either choice would have been great.

Tunneling under an existing Epcor tower would have required a deeper, longer tunnel, causing steep high risk grades and a high cost of construction. The station at MacEwan would have needed to be underground, and the connection to the existing line north of Churchill might not have been feasible.

Revising the LRT alignment would have put the alignment in a less desirable location and cost the City in both redesign and land acquisition costs. This would have not only been higher cost, it would have negatively impacted surrounding businesses.

It is estimated the collaborative design and construction of the Station Lands LRT cavity and the Epcor Tower saved the City of Edmonton $140 million.

Completion of Tunnel Roof
May 2010

Meeting and Exceeding Owners Needs

By working together to bring the best possible product to the client, the City of Edmonton, the collaborative effort of the Station Lands design and construction team not only provided a lower cost solution to undesirable alternatives, but also completed the project on time and under budget.

Using a construction manager combined with fast-tracked design and build of the LRT cavity is a project delivery method that is new to the City. The project manager provided updated cost estimates for completion of the project but there was no locked-in total cost. Major components such as concrete and steel were governed by unit prices negotiated between the construction manager and various suppliers at the start of the project.

The tunnel cavity project had two main budget components. The first was the cost of the tunnel itself, originally estimated at $25 million. The second was the additional, incremental cost to the tower project as a result of LRT construction. The initial estimate for incremental cost was $15 million. The Station Lands tunnel cavity was completed on time and over $7 million below budget, and final incremental costs for the project were approximately $2 million below budget.

The City achieved its primary goal of maintaining its preferred LRT alignment without the additional costs, estimated at $140 million, associated with a deeper tunnel under Station Lands. Completing the project on time eliminated a potential risk to the City of liquidated damages. With regard to the design and construction of the cavity itself, the City enjoyed a $9 million saving with respect to the budgeted amount. Perhaps most important, the project provided an outstanding example of co-operation between two owners, two design firms, multiple contractors, and one construction manager.

Temporary access to tunnel Cavity

Inside northbound tunnel at mechanical opening