Challenges for Construction of Cut and Cover Structures and Tunnels in Urban Environment

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ABSTRACT
The cut and cover method is frequently used for construction of underground structures in urban areas for expanding infrastructure, building underground utility or transit corridors, TBM launch and extraction shafts, running tunnels and stations, parking and storage spaces, municipal service plants, water and waste-water treatment facilities, water reservoirs, storm water retaining structures, or various industrial-commercial facilities etc. The method often requires special solutions to overcome challenges of difficult geotechnical conditions, constraints due to the built environment and restrictions due to the operating systems maintaining the busy life of the city. After a brief introduction to the basic concept and procedures of cut and cover construction, the authors present some case studies of cut and cover projects built in urban environment with challenging conditions.

1 INTRODUCTION
The authors briefly present the basic concept and procedures of cut and cover construction, as well as the related definitions, terminologies of various types of cut and cover methods.

After that, they are introducing some typical case studies of cut and cover projects built in urban environment with challenging conditions. They will also provide details about several innovative logistics and technical solutions and special methods applied to mitigate and overcome the constraints, challenges and risks related to cut and cover construction in urban environment. The presentation will be illustrated by pictures of the actual construction sites.

Some of the innovative methods, techniques and logistics are getting well-proven typical solutions at certain conditions. However, there are many unique solutions, which require the creativity of the project team.

2 CONCEPT OF CUT AND COVER CONSTRUCTION
When cut and cover construction methods are used, the reinforced concrete structures are built inside an open excavation, and when the construction of the structure (base slab, walls, intermediate, and roof slabs etc.) is completed, it will be covered with backfill material, pavements or various superstructures. Cut and cover construction is used when the structure of underground space is relatively shallow. The excavation is accessible from the surface and it is usually economical in various overburden soils or shallow bedrock. The roof covering the structure can be cast-in-place or made up by precast concrete elements.

Two types of basic construction techniques can be used for cut and cover structures: bottom-up and top-down construction. The pre-planning process shall determine that which type of cut and cover construction fit best to the project, the local site conditions, types of soils or rock, potential ground water, and the constraints imposed by the urban environment.

2.1 Bottom-up Construction
The conventional "bottom-up" construction includes an excavation from the surface, within which the structure is constructed. As frequently required in urban environment, the support of the excavation faces, and support of the structures around the underground space shall also be installed. After the structural work is completed, the excavation is backfilled and the surface restored, or covered with building(s) or urban facilities required.

2.2 Top-down Construction
At "top-down" construction the exterior walls and interior columns are constructed first, installing slurry walls, or secant pile walls along the perimeter, and bored piles or caissons as future columns supporting the final roof slab, which is constructed on the ground tied into the walls and columns already built. The surface is then reinstated and used for surface storage or traffic. The remainder of the excavation and the construction are completed under the roof slab, using a side access, which can minimize the disturbance of urban functions on the surface. For pre-planning and selecting the best construction techniques, sequencing and methods used for the work, the knowledge of the geotechnical conditions and the various site constraints are very important.

3 CASE STUDIES WITH INNOVATIVE SOLUTIONS
3.1 Underground expansion of R.C. Harris Water Treatment Plan by cut and cover method
Constructed in the 1930’s, the R.C. Harris Water Treatment Plant is the largest of the four water plants, supplying 44% of the daily water needs for the City of Toronto and York Region. Located on the Beaches of Lake Ontario in downtown Toronto, this 950,000,000 litre/day conventional filtration plant was designed in the classical architectural Art Deco style. It was declared a national historic civil engineering site in 1992. For upgrading the treatment process to the environmental standards, an underground residue management facility had to be built. After completion of the works, the heritage buildings, topography and features of the green park had to be reinstated exactly to the original condition (See Figure 1).

Figure 1. R.C. Harris Water Treatment Plant

3.1.1 Challenges for the cut and cover construction

Because of the heritage designation of the existing treatment plant and the park around it, construction of an additional treatment building was out of question. The pre-design team concluded that using the available space to build underground the new structures was an innovative and feasible solution. Cost-benefit analysis proved that the significantly lower capital and life cycle operational costs and reduced impacts on the natural and urban environment make the underground facility superior compared to other options.

- The challenges derived from the conceptual criteria, the sizeable and deep new facility had to be built entirely underground by cut and cover method, in various soil and rock conditions.
- The structures and foundations had to be extended below the ground water level communicating the adjacent Lake Ontario.
- The structural integrity and serviceability of the existing heritage buildings and the 50,000,000 litre treated water reservoir under the filter building had to be protected and the operation of the filtration plant supplying potable water to the City to be undisturbed during construction.
- The contract documents included very strict horizontal and vertical movement criteria for the existing structures and the designed enclosure walls.
- Constraints imposed by the downtown urban environment, narrow streets, sensitive residential neighbourhood, strict dust control, noise and vibration control, restricted hours for work and construction traffic, etc.
- Limited space between the historical buildings for the 18m deep cut and cover operations.

3.1.2 Organizational and technical solutions applied to the cut and cover project

After in depth risk assessment, the pre-planning process established the sequencing, construction techniques and logistics for mitigating the potential risks and managing the complex cut and cover construction, which required approximately 100,000m³ of excavation and the construction using 23,000m³ of reinforced concrete.

- For preventing the movements of soils and settlement of adjacent buildings during the deep excavation, large diameter secant pile wall enclosure was built, with various rows of soil anchors, depending on the depths and surcharge loads. The secant pile walls were integrated in the final structural concrete walls creating composite load-bearing walls.
- The specified monitoring system controlled the movement of the targets on the existing and new structures and inside the reservoir. All the results were under the specified alert level.
- The large capacity reinforced concrete piles supporting the new building were tested for both compression and tension. The test results were over the designed capacity.
- For vibration and settlement mitigation - besides the continuous real time monitoring - the vibration-free CFA method was applied for installation of secant pile walls at sensitive areas.
- In lieu of the designed underpinning for protecting the undisturbed city water supply, CFA interlocking pile enclosure was built along to the two sensitive 2100 mm diameter treated water conduits built in the last century.
- The original design required to build a fire exit with mining method under the same large water conduits. After introduction of a new engineering proposal, in cooperation with the design team, the exit corridor was moved above the pipes, preventing their settlement, still complying with the fire regulations.
- To avoid the traffic of heavy dump trucks in the busy and sensitive commercial and residential urban area, the excess excavated earth material was trucked to an on-site temporary dock and removed by barge to a landfill site. (see Figure 2).
3.2 Cut and cover structures added to the Lorne Park Water Treatment Plant expansion

The Lorne Park Plant is a water treatment facility providing potable water for the inhabitants of Region of Peel, and located in wooded parkland on the north shore of Lake Ontario. It is surrounded by residential communities of City of Mississauga. Most of the facility is built underground, or covered by green hills. Recently an overall underground expansion required in order to increase the capacity of water supply for the growing population.

3.2.1 Challenges for the cut and cover construction

The complex project included an extension to the pump station with new raw water and treated water facilities, a new sewage pumping station, several processing upgrades and a water intake tunnel from the Lake Ontario. The construction of new structures and the extensive yard piping works did occupy sizable area of the recreational park.

- The challenges are derived from the design and contractual criteria and from the protection of natural and urban environment.
- The deep multilevel addition to the existing pumping station had to be built underground by cut and cover method, in various alluvial soil layers, underlined by weathered to competent bedrock, and extended below the water level of the Lake Ontario. The deepest point of the complex facility is 27m below surface.
- Beside the additions, complicated connection and alteration works required to upgrade the existing structural and mechanical elements of the plant. The serviceability, structural integrity of the existing facilities had to be protected and the supply of potable water had to be undisturbed during construction.
- Completion of the work required within the very tight contract schedule.
- Noise, dust and vibration impacts on the life of the adjacent residential community and the visitors of the lakefront parkland had to be minimized. The noise and vibration impacts had to be always under the specified level.
- During excavation and construction of the new structures real time soil movement and settlement monitoring required. The existing structures, utilities, buildings and the operating plant and water reservoir were monitored too. All the results of real-time control were under the specified alert level.
- After completion of the underground works the urban parkland had to be reinstated and the new facilities incorporated to the urban park environment.

3.2.2 Innovative logistics and technical solutions applied to cut and cover project

After detailed risk assessment, the pre-planning process established the sequencing, construction techniques and logistics for managing the complex multiple cut and cover constructions, which required 45,000m³ of underground excavation, and using 21,500m³ of reinforced concrete to the structures. The planning process revealed opportunities for improving the constructability and progress of the project to achieve the completion within the tight contract
schedule. Several innovative organizational and technical solutions were planned and introduced.

- To prevent the settlement of the surrounding sensitive structures, pipes and water reservoir secant pile wall enclosure (see Figure 4), was built with multiple levels of soil anchors, holding the earth and water pressure.

- The inside structural reinforced concrete walls on certain areas were integrated with the caisson walls. The permanent composite load-bearing wall made the structure more durable and economical.

- At some areas of the deep structure heavy buttress walls were also constructed to support the structural walls.

- To accelerate the progress of excavation for the deep and relatively narrow foundation area, the contractor introduced a large temporary window at the upper level of the secant pile wall with reinforcing around the opening. It made possible creating long enough earth ramps to the deep excavation starting from outside of the enclosure wall. It allowed the required earth moving equipment and trucks to access the bottom of excavation.

- By shaping and relocating the lower part of the earth ramps inside the cut and cover structure, the critical earth work was completed well ahead of schedule.

- The pile wall opening was closed and reinstated when the bottom-up construction of the deep and multilevel pump station structure started.

- The design included reinforced concrete caissons drilled into the bedrock for supporting the multiple base slab levels inside the deep cut and cover excavation. Due to the various elevations in numerous locations, the designed method would have been required extensive pile drilling and shoring works by moving large drilling rigs, cranes, trucks and equipment in the deep excavation, within the cut and cover walls.

- The contractor applied a simple and effective solution: backfilling the excavation with lean concrete from the rock in the bottom up to the various base slab elevations. They used several conveyor belts for placing the concrete. It was fast, economical and accelerated the construction schedule.

3.3 Weston Grade Separation Railway Tunnel built by cut and cover method

Metrolinx, the transit agency of the Government of Ontario required a cut and cover tunnel in the City of Toronto, as part of the upgraded railway corridor for the new Union - Pearson Express. The express line connects the main railway station in downtown Toronto with the international airport in Mississauga. The Weston Tunnel project is a 1.6 km long section of the rail corridor, expanding the capacity to six railway tracks. Four of them are running in the tunnel without rail/road crossing. The project includes U-shape access ramps and a cut and cover tunnel. The 20 m wide reinforced concrete box structures are replacing the existing street crossings, as well as reducing the noise, vibration and air pollution for the residential communities along the railway corridor (Figure 5).

- The project is built in various sands and clayey silt till, underlain by Georgian Bay Formation shale bedrock. No free groundwater was observed in the boreholes drilled. The invert of tunnel is in the bedrock. The maximum excavation depth for the depressed corridor is about 12 m below grade. At the King Street storm sewer collection complex the deepest excavation is approximately 17 m. The storm water accumulated in the tunnel is cleaned and discharged to the Humber River through the City’s storm water system.

3.3.1 Logistical and technical challenges for the cut and cover construction

The large and complex project included significant enabling works, before the contractor could have started the construction of the cut and cover tunnel. First an overall traffic management plan had to be implemented to the 1.6km long residential area affected by the 3 year long project. It covered the construction
access and haul roads, the existing streets crossing the railway corridor and the parallel streets. The concept was protecting the public, separating the construction and the local vehicular and pedestrian traffic. After that started the removal and by-passing the utilities from the construction area. This enabling works took close to one year.

- The main challenges at the construction are derived from the design concept, the strict contractual criteria and the interpretation of geological conditions, the restrictions imposed by the railway operations and the sensitive residential environment.
- The contract schedule has been very tight with target milestones, especially for the enabling works. Minimum two streets, crossing the railway lines had to be open for the city traffic.
- The challenges of working along railway operations are typical at transit construction in busy downtown environment. When the commuter and freight trains access and crossing the construction site, the construction operations have to stop within the specified distance from the rails. In the morning and afternoon traffic picks the construction is drastically disturbed, the productivity reduced due to time loss (Figure 6).

Figure 6. Train traffic along excavation/concrete works

- Working and managing construction traffic in the sensitive residential area, for supplying construction materials and removing the excavated soil, relocating, by-passing utilities are also slow, the effective working hours are reduced by following the noise and vibration by-laws.
- Due to the expected time dependent rock deformation (swelling shale) at the Georgian Bay Formation the design/specification introduced several restrictions and complicated rock surface preparations.
- Specific interpretation of hydro-geological conditions and the design of robust structures - for resisting the expected up-lift forces on the underground tunnel - required extensive excavation and construction work.

3.3.2 Innovative technical solutions and intensive value engineering applied to the cut and cover project

After thorough risk assessment, the detailed pre-planning process established the sequencing, construction techniques and logistics to mitigate the potential risks and manage the tight schedule. According to the original contract design the project required about 237,000m³ of rock/soil excavation, 110,000m³ concrete, and 9,800 ton reinforcing steel. The Contractor’s pre-planning process revealed considerable opportunities to improve the progress of the project.

- Immediately after the contract award, Metrolinx also have requested the contractor to review and propose alternative solutions, which can accelerate the construction schedule of the Weston Tunnel to meet the very tight completion date.
- The project team and the engineers of Contractor, in collaboration with Consultants, Metrolinx and all stakeholders have analyzed the project documents and the site conditions, worked out and submitted ideas and methods, which could improve the constructability and the schedule of the project.
- For resolving the major challenge related to the time dependent rock deformation, an innovative construction and monitoring method was introduced by the contractor. Consultation with the structural and geotechnical engineers, they developed a time and movement monitoring method, which can accelerate the construction of the long underground railway corridor by accommodating the potential swelling of shale bedrock.
- On each section of concrete tunnel walls the time and time dependent rock deformation was monitored for minimum 100 days. Considering the expected residual value of movement (only few mm) according to the geotechnical model, the gap behind the wall had been received the final backfill.
- For resolving the challenge related to buoyancy, the contractor presented an innovative proposal for permanent gravity drainage system, based on the Hydrogeological Report in the contract, and supported by additional studies, recommendations of consultants, geotechnical and environmental experts.
- The relatively low quantity and flow rate of the groundwater offered an excellent opportunity to create a durable and reliable application of permanent gravity drainage system below the structure - with accessibility for monitoring, cleaning and maintenance if required. This will prevent buoyancy and keep the hydrostatic pressure under control. The drain pipes
convey the clean water through the Superpipe tunnel and through the city storm system to the Humber River. Pumping facility and energy consumption are not required.

- It made possible to build a less deep and robust cut and cover structure, reducing the excavation, concrete and reinforcing steel to the structure. The reduced volume and the improved constructability of works helped to accelerate the project schedule and decreased the impacts and inconveniences for the residential neighbourhood.
- Numerous additional innovative technical solutions and alternatives were introduced and approved by the contracting parties for the benefit of the large project. Among others, some of the more significant issues:
- Replacement of the reinforced concrete roof beams with galvanized steel pipe struts; (see Figure 7).
- Alternative two sided wall forming/stripping method; Innovative false work for roof slab (see Figure 8. and 9. below);
- Alternative secant pile/tie back connections and shotcrete shoring system; Under-slab permanent drainage system with slotted pipes; Chambers and drainage access holes;
- Alternative TBM construction method for the Superpipe storm water tunnel etc.
- Continuous traffic management required for providing accessible streets and driveway entrances for the residential community. As the construction progressed the traffic pattern has continuously changed to maintain the safe undisturbed pedestrian and vehicular traffic movements.
- The contractor worked in close cooperation with the railway companies to follow their rules and requests, as well as with the residential community through Metrolinx and their Community Office. The safety of public and the undisturbed railway traffic had always priority.

4 CONCLUDING REMARKS

There are many risk factors and challenges working underground. When the cut and cover construction takes place in a very busy urban environment, close to sensitive buildings, congested utilities, busy traffic and live railway operations, the impacts of those factors are multiplied. The challenges require innovative thinking, effective and economical solutions from all parties of the project team.

The authors’ most important conclusion is that during the thorough risk analysis and pre-planning of the underground cut and cover projects all the potential construction methods, well-proven and innovative new ideas as well as the risks related to them shall be reviewed by all the stakeholders. For each project, the urban environment, the specific soil, rock, groundwater and topographical conditions are different.

The innovative organizational and technical solutions presented by the authors had resolved and mitigated various risks and constraints imposed by the urban environment, and improved the schedule, constructability and economy of the design and construction of the cut and cover project.