“Well-Founded” Technology

Rammed Aggregate Piers Improve the Windsor Tunnel Plaza Project

The Ontario Ministry of Transportation (MTO) completed its first successful use of rammed aggregate piers at the site of the Windsor Border project. In July 2013, 226 rammed aggregate piers were installed at the Windsor Tunnel Plaza to support floor slabs and structural footings within the foundation footprint of the new Canadian Border Services Agency building.

Rammed aggregate piers are an innovative soil reinforcement system used to improve poor foundation conditions. The rammed aggregate piers for the Windsor project were designed by GeoSolv Design-Build (Geopier Foundation Company) for the Contractor, Coco Paving / Rosati Construction.

Project Site

The Windsor-Detroit Tunnel is one of three border crossings linking Windsor, Ontario and Detroit, Michigan. The tunnel opened to traffic in 1930 and is a single tube under the Detroit River, 1.6 km long carrying one lane of traffic in each direction with toll and inspection plazas on each side of the border.

Improvements to the Canadian Plaza of the Windsor-Detroit Tunnel were part of the $300 million Let’s Get Windsor-Essex Moving (LGWEM) strategy, jointly funded by Ontario and Canada.

The overall purpose of the project was to improve capacity and operational efficiency at the Canadian plaza while addressing existing traffic concerns and anticipated future needs of border traffic in the Windsor-Detroit corridor.

This work included a new Canada Border Services Agency Commercial Building and a new Detroit-Windsor Tunnel Maintenance Building.

The original design for the building foundations was conventional strip and spread footings on engineered fill. However, two potential issues arose during project design:

- Foundation investigations indicated that the subsurface stratigraphy at the site consists of asphalt and granular base with variable layers of fill over a deep deposit of clayey silt. A contamination study revealed that the fill was contaminated in some areas and would require excavation, trucking and disposal at an approved landfill, followed by replacement with engineered fill.
- A need for sheet piling / shoring for excavation of the fill since the new Canada Border Services Building footprint lies only 2.2 m (7.2 feet) from the roadway curb.
Rammed Aggregate Piers Improve the Windsor Tunnel Plaza Project, continued

The original design would have required excavation of the existing fill within the building footprint, supply, installation and compaction of engineered fill to the underside of floor slab granular base, and placement of conventional footings with form wall and backfill.

Rammed aggregate piers were selected as an alternative to excavating the fill layer. This option reduces construction costs, eases construction and reduces construction truck traffic in Windsor’s downtown core.

**Rammed Aggregate Piers**

Rammed aggregate piers are installed by drilling 760 mm (30 inch) diameter holes and ramming thin lifts of well-graded aggregate into the holes forming very stiff, high-density aggregate piers. The drilled holes typically extend from 3 m to 7.5 m (10 to 25 feet) below grade and 2 m to 6 m (7 to 20 feet) below footing bottoms. The first lift of aggregate forms a bulb below the bottoms of the piers, providing pre-stressing and pre-straining of the soils to a depth equal to at least one pier diameter below drill depths. Subsequent lifts are typically about 300 mm to 600 mm (12 to 24 inches) in thickness.

Ramming takes place with a high-energy bevelled tamper that makes the aggregate denser and forces the aggregate laterally into the sidewalls of the hole. This action increases the lateral stress in the surrounding soil, further stiffening the stabilized composite soil mass. The end-result of the rammed aggregate pier installation is a significant strengthening and stiffening of subsurface soils that then support high bearing capacity footings.

The system controls foundation settlements and is designed to limit post-construction settlements to less than 25 mm (1 inch) with a maximum differential settlement of 20 mm (¾ inch).

**Design**

The compacted aggregate pier system is designed to support pier spread footings and strip footings based on the following criteria specified in the contract:

- Factored geotechnical resistance at Ultimate Limit States (ULS) of 225 kPa.
- Geotechnical reaction at Serviceability Limit States (SLS) of 150 kPa.
- Estimated long-term total settlement of ≤ 25 mm defining the SLS geotechnical reaction.
- Estimated long-term differential settlement of ≤ 20 mm defining the SLS geotechnical reaction.
- Design long-term uniform pressure on floor slab of 25 kPa.
- Design life of the building structure of 50 years.

Footing loads for spread footings supported on rammed aggregate piers ranged between 50 kN and 270 kN at SLS. Rammed aggregate piers supporting the floor slab were designed to support a load up to 25 kPa.

The design for this project included a system of rammed aggregate piers that were more widely spaced under floor slabs than under footings, typically ranging from 1.5 m to 3.5 m.

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**Figure 2: Rammed aggregate pier construction process – (1) auger the hole, (2) place open-graded stone, (3) tamp bottom bulb, (4) tamp well-graded stone in thin lifts.**
Rammed Aggregate Piers Improve the Windsor Tunnel Plaza Project, continued

**Construction**

Following removal of topsoil and pavement, the rammed aggregate piers were installed. Augered excavations for the aggregate piers fully penetrated the existing fill and advanced about 1 m into the underlying native grey silty clay. This formed a crust of soil upon which the footings are supported. The contractor then excavated to expose the tops of the piers and compacted the footing base using a “jumping jack” type tamper. The footing was then placed over the improved ground. More than 200 rammed aggregate piers were placed within the building footprint.

For wet excavations, one to two lifts of clear stone (19 mm or ¾”) were placed and compacted using a hydraulically operated compactor. Installation then continued by placing and compacting 350 mm to 400 mm thick lifts of Granular A. Compaction of each lift was considered adequate after 20 seconds had elapsed. After 20 seconds, there is generally no further vertical displacement of the compactor.

Several Dynamic Cone Penetrometer Tests were carried out by the contractor using hand-held equipment on the finished surface of the compacted Granular A. Results of the tests met the criteria of at least 15 blows per 45 mm penetration as an indicator of acceptable density.

A full-scale modulus load test was performed on a non-production aggregate pier installed on-site to verify the parameter values selected for design. The test results showed acceptable performance.

**Cost Savings**

Using rammed aggregate piers at this site resulted in significant project cost savings. This innovative method eliminated the need for sheet piling / shoring to protect the roadway – a savings of $375,000, excavation of contaminated fills and trucking off-site to disposal at an approved landfill – a savings of $280,000, and engineered replacement fill – an additional savings of $145,000.

**Environmental Benefits**

Implementing rammed aggregate pier foundations reduced environmental impacts such as exhaust emissions, noise, and traffic from an estimated 1100 truckloads that would have navigated through the downtown core removing contaminated fill and supplying engineered fill.
Rammed Aggregate Piers Improve the Windsor Tunnel Plaza Project, continued

Future MTO Applications
The ministry anticipates future applications of rammed aggregate piers to include improved foundations for embankments, retaining walls and retained soil systems, commercial vehicle inspection facility buildings, ferry terminal buildings and slope stabilization. In addition, recycled concrete can be used as aggregate for the rammed aggregate piers.

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Photos provided by Tulloch Engineering and Thurber Engineering.
Culvert Replacement using the Tunnel Boring Machine

Highway 11 Culvert Replacement using Innovative Contract Delivery and Installation Methods

The Ontario Ministry of Transportation (MTO) replaces or rehabilitates many culverts each year. During a regular culvert maintenance inspection in 2010, it was determined that an existing corrugated steel pipe culvert under Highway 11, a major north-south corridor, had deteriorated, displaying excessive deformations. The ministry replaced the culvert in 2012 using an innovative new contract delivery model and a state-of-the-art installation method.

The ministry considered many alternative culvert installation methods and multiple delivery models for acquiring design and construction services for this project. MTO identified the Highway 11 centerline culvert replacement project as a candidate for the DesignBuild (DB) method for delivering construction projects. The ministry implemented the Design Build Type B Minor model due to project complexity, the opportunity for innovation and the need to reduce the time for project completion.

Highway 11 Project Site and Preliminary Field Investigations

Installed in 1975, the original 215m long, 1.8m diameter corrugated steel culvert crossed both the southbound lane (SBL) and northbound lane (NBL) highway embankments. The embankments are 17 m high; the slopes are covered with sparse vegetation, cobbles and large boulders.

The depth of the embankment fills along the existing culvert alignment ranged from 1.4 m along the east toe of the NBL embankment, to 16.8 m over the SBL. The new culvert was to be installed between the embankment fill and the underlying native deposits.

In May 2011 and February 2012, two separate foundation investigations at the site identified subsurface soils consisting of a superficial layer of sand and gravel fill underlain by silty sand. Borehole samples taken on the embankment crest showed groundwater levels approximately 1.0 m to 2.0 m above the existing culvert invert. Subsurface conditions at the site would require a tunnelling operation below groundwater level to replace the culvert.

Accessing the Launch Site

In order to accommodate the tunnel-boring machine, access roads were cut into the southeastern slope of the adjacent creek valley with a 25 to 30 per-cent slope down to the valley floor.
Highway 11 Culvert Replacement using Innovative Contract Delivery and Installation Methods, continued

In September 2012, the DB team began construction of the entrance pit with the installation of sheet-pile walls to hold back soil in the excavation. The necessary dimensions for the entrance pit were 8 m in length by 4.9 m wide and 485 mm below the invert level of the concrete pipe. Once the entrance road was complete and all sheet piles were installed, the backstop area for the boring machine was constructed. Concrete was placed between the steel components and inserted in the eight friction tube piles installed creating a massive support system for the jack station.

A 250 mm concrete slab was placed on the native subgrade. To provide extra support for the south sheet-pile wall of the entrance pit, 5 m long H-Piles were installed in one row, three meters away from the pit, and anchored with steel cables passing through the braced walls. The installed system combined steel H-Piles and steel cables to minimize deformations on the braced sheet-pile wall.

Tunnel Boring Machine

Marathon Drilling Co. Ltd., tunnelling contractors, a DB team member, and experts in trenchless installation technology, installed a 1.5 m diameter concrete jacking pipe Class 140-D culvert using an 1800 mm tunnel boring machine (TBM).

The Earth Pressure Balance tunnel boring machine, operated and owned by Marathon Drilling, is state-of-the art equipment, manufactured by the Palmieri Group in Italy, and is the only one available in Ontario.

The TBM consists of a cutting head connected to an enclosed pressure chamber where, spoils are passed into the TBM by a screw conveyor. The 18-080 mm cutting head is equipped with rock cutters. This mechanized Earth Pressure Balance machine allows different deposits to be tunnelled safely, including wet, soft deposits and unstable ground.

Since the tunnelling site consisted of fine granular soil in the presence of an elevated ground water table, the use of the Earth Pressure Balance tunnelling machine maintained a balance between the TBM face pressures and the earth pressures and eliminated the need for dewatering along the tunnel alignment. Bentonite slurry was used as a lubricant for the cutting head and to fill the possible spaces and any remaining voids outside of the pipes.

Monitoring

Based on the performance-based specification’s minimum requirements for an instrumentation monitoring system and settlement monitoring criteria, the DB team installed more than 40 ground movement monitoring points consisting of surface points, in-ground points and deep in-ground points.
Highway 11 Culvert Replacement using Innovative Contract Delivery and Installation Methods, continued

Five non-yielding survey control points were also installed as benchmarks outside the zone of influence of the tunnel. The ministry will continue to monitor ground movement at the culvert site.

Lessons Learned

Many aspects of this experience were successful and the ministry acquired valuable learning experiences for reducing construction difficulties. Numerous challenges arose during the placement and installation of the entrance pit components leading to revisions to the design, installation methods and construction techniques.

Since this project, the ministry has begun conducting more detailed preliminary foundation investigations to detect organic material deposits underneath existing embankments. The ministry will consider trenchless technologies for the replacement of culverts situated in deep fill embankments and encourage its use where technically applicable for its foundations component. Since rock fill embankments are common along new alignments and extensions throughout the province, using innovative ways to replace structures under deep embankments are necessary.

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Figure 5: All concrete pipe segments installed in the tunnel.
Queen Elizabeth Way Pavement Markings Test Deck

Drivers in Southern Ontario may have noticed a collection of seemingly out-of-place pavement markings on the Niagara-bound Queen Elizabeth Way (QEW) near Beamsville. These unusual road markings contribute to the Ministry of Transportation’s (MTO’s) goal to ensure Ontario’s highways are among the safest and most reliable in North America. In 2004, Road Talk reported on an earlier test deck, on Highway 401 in Eastern region, used for evaluating new pavement marking application methods and materials to improve visibility under wet conditions.

Pavement markings, including solid and dashed lines called “skips,” help to guide traffic and play a major role in road safety. They separate lanes of opposing traffic, assist motorists to safely overtake other vehicles, and inform drivers of freeway lane changes. Pavement markings are continuously exposed to traffic, salt, sand, snow, snowplow abrasion, humidity and temperature changes. All of these elements degrade pavement markings and can make them less effective. The ministry is committed to researching the best pavement marking materials available to ensure a safe driving experience for commuters.

The QEW test deck was engineered by MTO’s Materials Engineering and Research Office (MERO) to test new pavement marking materials. “Tests conducted on the test decks include evaluation of colour, daytime luminance factor, durability and retroreflectivity,” – Winston Chand, Chemical Corrosion Engineer at MERO. Retroreflectivity, meaning visibility at night, requires pavement markings to contain reflective materials like glass or ceramic beads to reflect light from a vehicle’s headlights back into the driver’s eyes.

The QEW test deck focuses on evaluating performance under high traffic volumes and typical Southern Ontario winter conditions. MERO currently has another test deck on Highway 400 northbound near Port Severn; the focus of that test deck is evaluating marking performance under typical Northern Ontario winter conditions.

The QEW test deck placement began in July 2014 when MERO staff applied over 50 different types of water-based paint and bead combinations to the road using MERO’s application equipment. MERO also assisted manufacturers in applying over 50 non-water-based materials, including solvent-based paint and durable marking materials such as methyl methacrylates (MMA), preformed tape, and thermoplastics. MERO engineers conducted full inspections of this test deck in August 2014, at the three month mark in October, and in the spring of 2015. In addition to physical inspections, photographs have been taken at various intervals over the course of the test deck’s life to track the durability of the paint.

If a permanent pavement marking material passes all of MTO’s requirements after one year on a test deck, then it becomes eligible for inclusion in the Ministry’s Designated Sources for Materials (DSM) list; a list of prequalified materials from which contractors can choose to use on provincial roads. Of the 100 different materials submitted to MTO for assessment, 92 were permanent, and eight were temporary marking materials. Thirty-four of the 92 permanent materials from four different suppliers passed the requirements, and will be added to the ministry’s DSM list.
Queen Elizabeth Way Pavement Markings Test Deck, continued

The temporary marking materials were evaluated over a three month period on the test deck. These consisted of orange markings to be used in construction zones and temporary, removable HOV (high occupancy vehicle) diamond marking tape. Six orange materials were tested; five water-borne paints and one MMA. The testing outcome resulted in one of the diamond tapes, three waterborne paints and one MMA marking material added to the DSM list, representing three different suppliers.

Pavement markings must also meet all of MTO’s technical and safety requirements, Health Canada’s Lead Regulation, and Environment Canada’s Volatile Organic Compounds Regulation before they are eligible for inclusion on the DSM list. Although the DSM list is intended for Ontario provincial highways, it has been used by other provinces as well as federal and municipal agencies.

Pavement markings on test decks are not actively removed by MTO following the completion of a study, they are usually allowed to simply wear away. However, companies who are developing new methods of removing road markings may be allowed to use completed test decks to test their new methods or materials.

For over 25 years MTO has tested pavement markings. Standards continue to be upgraded as more information is gained and new products are introduced by the industry. MERO’s analysis of innovative pavement markings and application methods advances the ministry’s commitment to maintain a safe and reliable highway network in Ontario.

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Getting the Most from the Safety Analyst Software Tool

*MTO Increases Versatility of Safety Analyst Tool*

Since 2009, the Safety Analyst (SA) software tool has been the industry standard across North America, used by highway agencies for highway safety management. The Ontario Ministry of Transportation’s (MTO) use of this statistical analysis tool is unique.

In keeping with the ministry’s commitment to innovation and safety, MTO adopted the Safety Analyst software tool in 2012. This tool was designed by the Federal Highway Administration (FHWA) to support highway agencies’ safety decision-making. Released by the American Association of State Highway and Transportation Officials (AASHTO), this tool provides state-of-the-art statistical analysis for identifying and implementing site-specific highway safety improvements.

Prior to the ministry’s adoption of Safety Analyst, statistical analysis for safety decision-making was conducted manually with spreadsheets, requiring a great deal of time and effort and increased the potential for human factor errors. Manual analysis is very difficult; for example, defining a collision pattern is often challenging because of a number of factors including site type, traffic exposure, and the overall collision experience. The tool eliminates human factor errors, easily analyzes a multitude of incident factors, and can complete statistical analysis in a few hours instead of months.

**Safety Analyst Software Customization**

The software’s basic manufacturer’s configuration defaults to diagnoses for non-freeway roads and intersections but was designed for analysis flexibility. Freeways and ramps are a large part of Ontario’s provincial highway network, so it was necessary to modify Safety Analyst to diagnose and analyze scenarios involving freeways and ramps. Consultant team CIMA+, TES Information Technology Ltd., Navigats Ltd., and Persaud and Lyon Inc. partnered with MTO to configure Safety Analyst completing the required modifications.

To develop diagnostic scenarios for freeways and ramps, the ministry first conducted a review of the collision history associated with freeways and ramps and identified collision patterns. See Figure 1 for an example of a diagnostic scenario Safety Analyst produces. As noted in Figure 2, the predominant collision impact types associated with freeways are single motor vehicle (SMV), sideswipe, and rear-end collisions, which constitute almost 96 per cent of all collisions on freeways. As a result, it was decided that the SA diagnostic scenarios should be modified to address these collision patterns. These modifications provide flexibility for scenario adjustment. For example, ministry users can select or skip diagnostic questions based on whether the freeway design is rural or urban.

The second ministry-specific modification to Safety Analyst is the MTO Site Prioritization Tool (SPT). This innovative modification is unique to the ministry. The SPT takes SA’s Ontario highway incident data analysis and ranks collision sites according to chosen specifications. The ministry’s SPT takes different types of network screening, such as expected collisions and excessive collisions, and combines them into one adjusted rank. Locations that are high in this combined rank are identified as areas for potential improvement.

**Safety Analyst Components**

Safety Analyst comes with four components:

- network screening
- diagnosis and countermeasure
- economic appraisal and priority ranking
- countermeasure evaluation

Many jurisdictions have configured only one or two of the components. MTO has fully configured all four components of the SA software, using all of the Safety Analyst components for comparing and prioritizing different projects and solutions according to different criteria, for instance net benefit or benefit/cost ratio.

**Safety Analyst Recommendations**

Safety Analyst is capable of making suggestions for road safety improvements including the installation of roundabouts, rumble strips, or median barriers. The software tool does not replace or eliminate the role of ministry experts; a technical >
MTO Increases Versatility of Safety Analyst Tool, continued

Figure 1: One example of the many diagnostic scenarios created by Safety Analyst
MTO Increases Versatility of Safety Analyst Tool, continued

SA is a tool used to easily and efficiently analyze statistical data and assists in safety management recommendations for highway improvement decision-making priorities.

Safety Analyst is also part of MTO’s process for prioritizing and implementing safety and operational improvement projects. The safety benefits (expected reduction in collisions) calculated by SA in combination with calculated operations benefits (increased capacity, reduced travel time/delay) are used to score projects and rank them. The resulting ranking is used as a method to select those projects that will be implemented based on available funding. This method of ranking improvement projects, using Safety Analyst, reduces the time spent by staff documenting and selecting projects for implementation.

Because Safety Analyst is a statistical analysis tool, it is limited by available data. MTO is continuing to collect and update collision data and is seeking new methods of doing so. The Ontario Provincial Police (OPP) provides collision data to the ministry that is collected and recorded electronically, resulting in data that is easily added to the tool’s data base. Due to annual variances in traffic collision data, long-term data will result in better statistical improvement conclusions.

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Figure 2: Table summary of the total number of collisions from January 1, 2006 through December 31, 2010 on ministry freeways.

<table>
<thead>
<tr>
<th>Collision Type</th>
<th># of Collisions</th>
<th>Proportion of Total Collisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle</td>
<td>1349</td>
<td>0.45%</td>
</tr>
<tr>
<td>Approach</td>
<td>5283</td>
<td>1.78%</td>
</tr>
<tr>
<td>Rear-end</td>
<td>117228</td>
<td>39.49%</td>
</tr>
<tr>
<td>Sideswipe</td>
<td>56095</td>
<td>18.89%</td>
</tr>
<tr>
<td>Single Motor Vehicle (SMV)</td>
<td>111833</td>
<td>37.67%</td>
</tr>
<tr>
<td>Single Vehicle unattended</td>
<td>1787</td>
<td>0.60%</td>
</tr>
<tr>
<td>Turning Movement</td>
<td>2555</td>
<td>0.86%</td>
</tr>
<tr>
<td>Other</td>
<td>764</td>
<td>0.26%</td>
</tr>
</tbody>
</table>

Figure 3: The expert system is used to identify potential countermeasures that address collision patterns identified during the diagnostic process.

Step 1: Review the results of the basic network screening using the excess method.
Step 2: Review the collision summary report.
Step 3: Review the collision diagram.
Step 4: Review the test of collision proportion for all collision patterns of interests.
Step 5: Identify the collision patterns for a specific site which deserve further review.
MTO Increases Versatility of Safety Analyst Tool, continued

MTO is a leader in safety and innovation, and will continue to modify and tailor Safety Analyst to get the most value from the software, to ensure Ontario’s highways remain among the safest in North America.

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Figure 4: Safety Analyst display of collision data for each attribute