

## "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,

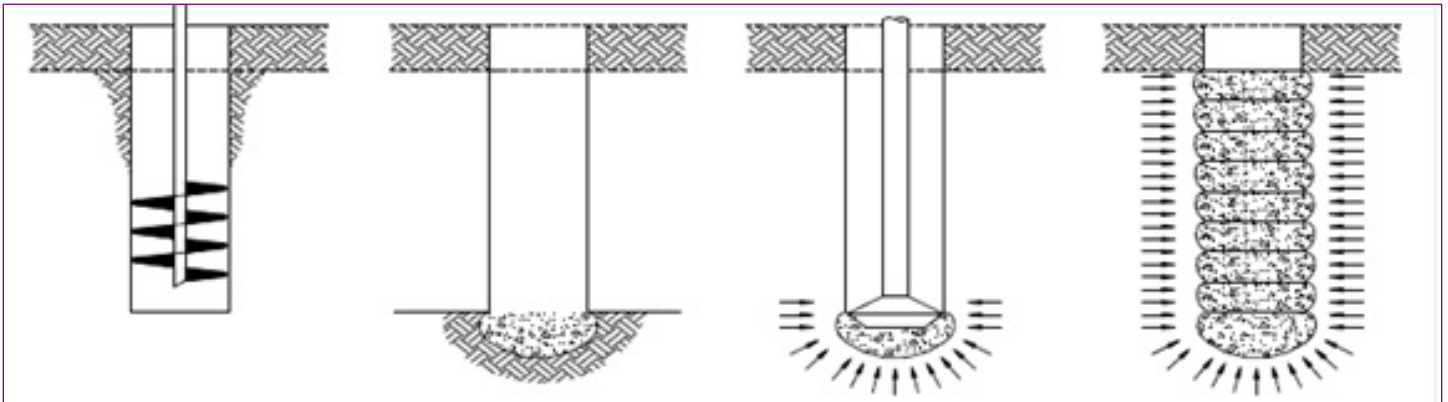


*Figure 1: Rammed aggregate piers are placed within the foundation footprint of the new Canadian Border Services Agency Building in Windsor.*

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



**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.**

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 ( $\frac{3}{4}$  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  $\leq 25$  mm defining the SLS geotechnical reaction.
- Estimated long-term differential settlement of  $\leq 20$  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.



## *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  $\frac{3}{4}$ " ) 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

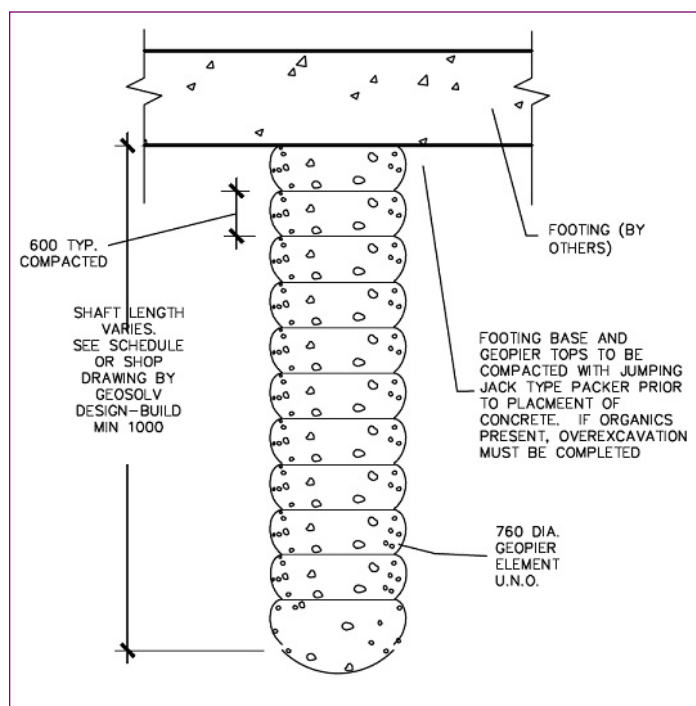
Using rammed aggregate piers at this site resulted in significant project cost savings. This innovative method eliminated the need for sheet piling / shoring to protect the roadway – a savings of \$375,000, excavation of contaminated fills and trucking off-site to disposal at an approved landfill – a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



*Figure 3: Bevelled tamper increases lateral pressure.*



*Figure 4: Typical rammed aggregate pier for a footing.*

## *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. ●

### **For more information, please contact:**

David Staseff, P. Eng., Senior Foundations Engineer,  
Pavements and Foundations Section,  
Materials Engineering and Research Office (MERO),  
at (416) 235-4073 or [David.Staseff@ontario.ca](mailto:David.Staseff@ontario.ca)

*Photos provided by Tulloch Engineering and Thurber Engineering.*



*Figure 5: Conducting the Dynamic Cone Penetrometer Test (DCPT) with hand-held equipment.*



*Figure 6: Modulus test set-up.*



## 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.

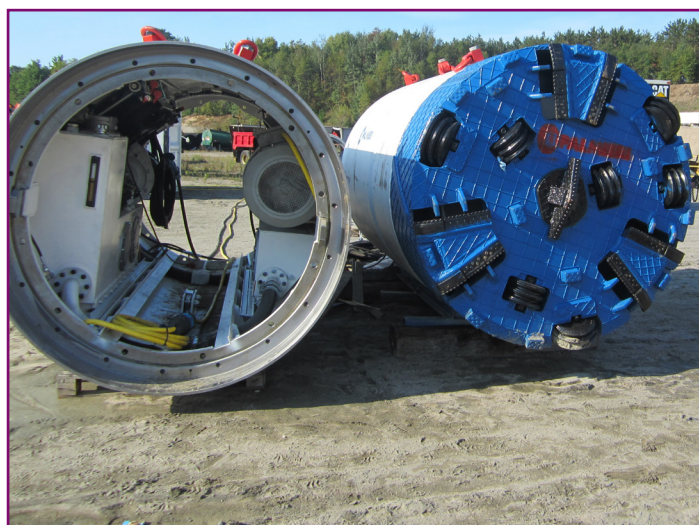
The ministry considered many alternative culvert installation methods and multiple delivery models for acquiring design and construction services for this project. MTO identified the Highway 11 centerline culvert replacement project as a candidate for the DesignBuild (DB) method for delivering construction 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 1.0m to 2.0m 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



**Figure 1: 1800 mm tunnel boring machine.**



**Figure 2: A sinkhole developing in the east embankment threatens the integrity of the adjacent northbound lane on Highway 11.**

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.



*Figure 3: Two sections of the Corrugated Steel Pipe braced in 2009 to prevent further movement.*



*Figure 4: Access road for the exit pit located at the west side of the southbound lane.*

### **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. •

### **For more information, please contact:**

Márcia Mora, P.Eng., Head of Corridor Management,  
at (705) 497-5530, or at [Marcia.Mora@ontario.ca](mailto:Marcia.Mora@ontario.ca)



*Figure 5: All concrete pipe segments installed in the tunnel.*