Road Talk

Ontario's Transportation Technology Transfer Digest

Ministry of Transportation

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Discover how MTO is revolutionizing infrastructure development with cutting-edge engineering techniques

Rigid Inclusions for a Highway 401 Embankment

The Ministry of Transportation Ontario (MTO) took an innovativ¬e approach to infrastructure development by using rigid inclusions (RIs) for the Highway 401 underpass at County Road 2/34 in eastern Ontario. This project offers a cost-effective, sustainable solution to address the challenge of building bridge embankments over a deep deposit of weak clay.

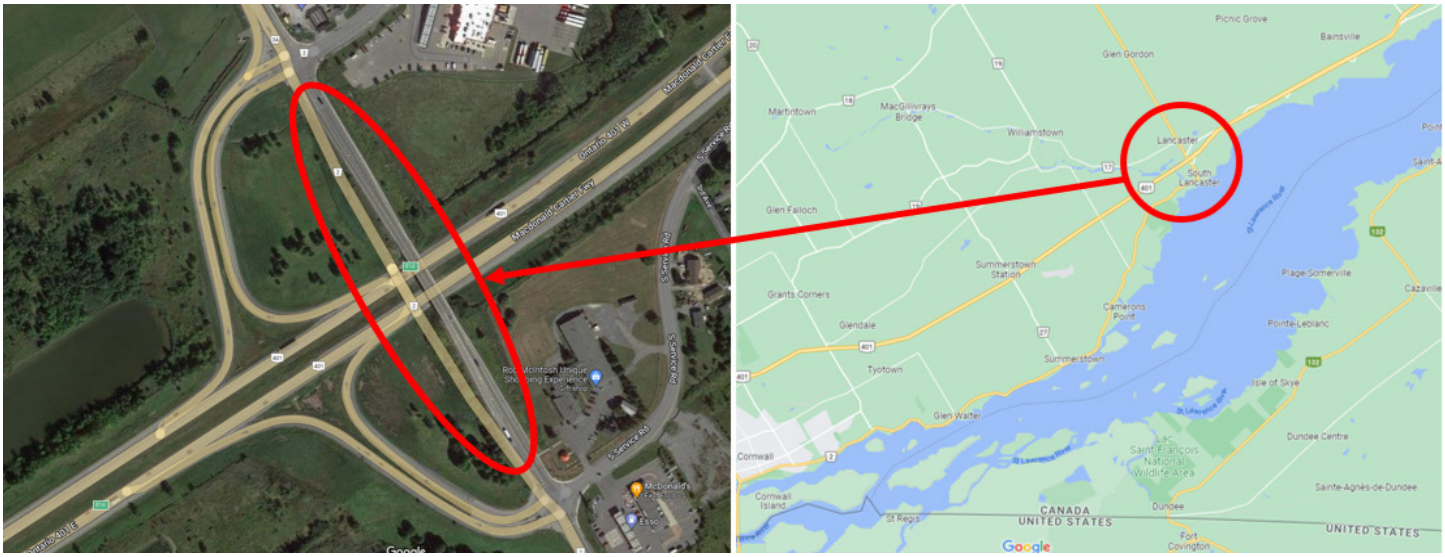
Background and Project Overview

In 2019, the construction of a high embankment for a Highway 401 underpass in eastern Ontario presented significant engineering challenges due to a deep deposit of weak clay at the site.

Traditional methods like lightweight fill were too expensive, and installing wick drains with a preload/surcharge would have taken months.

Innovative Solution: Rigid Inclusions

To address these issues, the ministry modified the ground at the site with RIs. This involved placing concrete columns in the ground at precise depths and intervals to stabilize the weak clay foundation, providing the necessary support for the embankment. RIs transfer most of the load from the embankment to the native soil using a layer of compacted granular soil reinforced with geogrids. This distributes the load uniformly across the RIs, reducing the stress on any single inclusion.



The location of the Highway 401 underpass at County Roads 2/34 on the north side of the St. Lawrence River, near Lancaster, Ont., , just over 28 km east of Cornwall.

The Benefits of Rigid Inclusions

- **Time Savings:** RIs significantly reduce construction time, minimizing disruptions to traffic and enhancing project efficiency.
- **Cost-Effectiveness:** RIs reduce labour expenses and material costs – there is no need for extensive excavation or expensive lightweight fill.
- **Environmental Impact:** RIs stabilize, rather than remove, the existing soil in the ground, minimizing the environmental footprint of a construction project. They also reduce the need for transporting massive quantities of new materials, further decreasing a project's carbon footprint.
- **Versatility:** RIs can be used in a wide range of soil conditions and for several types of structures, making them a versatile solution.
- **Settlement Reduction:** RIs mitigate settlement by increasing the stiffness and bearing capacity of soil. They are particularly beneficial in soft or variable soil conditions.

Project Description

The Highway 401 underpass at County Road 2/34 underwent a significant transformation to address longstanding structural issues and accommodate modern traffic demands. The embankments experienced a substantial settlement of approximately one to 1.5 metres shortly after the underpass was built in 1963, necessitating a comprehensive replacement and realignment project.

Looking east at the west side of the embankment.

Looking west – the remnants of the old embankment.

The replacement structure is a four-lane, two-span underpass designed to enhance traffic flow and safety. The underpass was shifted to the west to optimize alignment with the existing road network. The new embankments, which are approximately eight metres in height, overlap the slopes of the original embankments.

The bridge foundations at the abutments and the pier are supported by H-piles driven into bedrock to ensure the bridge's long-term performance.

Project Challenges

A primary concern was the underlying clay, which was projected to cause settlements of approximately one metre over a 50-year period. Additionally, keeping the existing embankment in service during construction posed a risk of differential settlement, which could compromise the stability and functionality of the existing embankment.

Another critical challenge was the global stability of the embankments under design seismic loading. The factor of safety (FoS) for global stability was calculated to be less than the required 1.1, indicating a potential risk of failure during seismic events. This necessitated robust engineering solutions to ensure the safety and stability of the embankment.

To address these challenges, MTO conducted a comprehensive cost analysis of various ground improvement options, including:

- **Expanded Polystyrene:** Cost range of $4.5 - $5 million.
- **Wick Drains with Surcharge:** Cost range of $4 - $4.5 million.
- **Ground Improvement – Controlled Modulus Columns (CMCs):** Cost of $3 million.
- **Ground Improvement – Deep Soil Mixing:** Cost range of $4.8 - $6 million.

RI installation at the south embankment. The orange markings indicate the surveyed locations for RIs and wick drains.

Ultimately, MTO developed a special provision for the tender that specified design build requirements, including design build qualifications and performance requirements. This provision ensured that the selected contractor would have the necessary expertise and resources to address the project's complex challenges.

Design Build Model

The design-build model for the Highway 401 underpass was developed with stringent performance requirements to ensure long-term stability, safety and functionality of the underpass while addressing the unique challenges posed by the project site.

Performance Requirements

1. **Settlement:** The design had to account for and mitigate settlement issues, including addressing the potential for differential settlement between new and existing embankments, to ensure the structural integrity of the underpass.

2. **Global Stability:**
   - **Seismic Instability:** The FoS for global stability under seismic loading conditions had to exceed 1.1, ensuring the structure could withstand seismic events without compromising its stability.

   - **Static Instability:** The FoS for global stability under static loading conditions had to exceed 1.3, ensuring the structure would remain stable under normal operational loads.

3. **Warranty Period:** A three-year warranty period, during which time the contractor would be responsible for addressing any defects or issues, was mandated for the project to ensure the structure met specified performance criteria.

These performance requirements were incorporated into the design build model to provide a clear framework for the project's execution. By setting high standards for settlement control, global stability and post-construction performance, the project aimed to deliver a reliable and resilient infrastructure solution.

Ground Improvement Design

The ground improvement design was developed to address the complex geotechnical challenges of the site. Menard Canada, the contractor awarded the project, used CMCs and wick drains to ensure the stability and longevity of the new structure.

- **CMCs** are vertical RIs installed using a full displacement auger. This minimizes soil disturbance and provides a stable foundation for the embankment. The CMCs transfer loads from the embankment to the underlying stiffer soils, enhancing the structure's stability.

- **Wick drains** were strategically placed to accelerate the settlement of the clay under the embankment. These drains assist with the rapid dissipation of pore water pressure, reducing construction time by allowing the embankment to settle more quickly and uniformly.

- A **load transfer platform** was installed over the CMCs and wick drains. This platform distributes the embankment load evenly across compressible soils and the stiffer reinforcing columns, ensuring effective load management and reducing the risk of differential settlement.

The combination of CMCs and wick drains addresses the immediate challenges of settlement and stability and ensures the long-term performance of the underpass.

Monitoring and Implementation

The use of RIs remains heavily monitored to ensure the new base platform provides the necessary support for the embankment, maintaining the integrity of the highway structure.

Conclusion

The Highway 401 underpass project was completed in August 2021, demonstrating the effectiveness of advanced ground improvement techniques to address significant geotechnical challenges. CMCs have carried a greater portion of the embankment load, thereby reducing stress on the underlying clay. Actual settlements observed in the new embankments align closely with the predicted values. Data shows that approximately 25 mm of settlement occurred in the embankments within two years. The adjacent unimproved ground experienced about 150 mm of settlement. The settlements were achieved within the six-month period specified in the contract, which was crucial to the project schedule and ensured stability of the new structure.

This project exemplifies Ontario's dedication to applying advanced engineering techniques to overcome challenges and deliver modern infrastructure solutions that meet the needs of today's road users. It serves as a model for road authorities worldwide, demonstrating the importance of proactive infrastructure management and innovative design in maintaining and upgrading critical transportation networks.

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