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DEPARTMENT OF TRANSPORTATION
OFFICE OF RESEARCH & INNOVATION

TECHNICAL SUMMARY

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Investigator:
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PROJECT COST:
$198,000

The hammer impact method to sense pile depth uses a simple sledgehammer.

Nondestructive Detection of Pile Length for High-Mast Light Towers

What Was the Need?

Hundreds of high-mast light towers (HMLTs) are installed throughout Minnesota, and many have been in place for several decades. MnDOT's Office of Bridges and Structures is tasked with ensuring the towers and their foundations meet AASHTO's current Load and Resistance Factor Design (LRFD) specifications and redesigning them, if necessary.

To make that determination, engineers need to understand the structure, geometry and dimensions of the HMLT foundations. While Minnesota's HMLT foundations are generally designed with a triangular concrete pad secured at its vertices by three angularly embedded piles, details may be unknown because construction documentation and soil data for many towers are lacking.

Whether an HMLT foundation meets LRFD specifications depends on the depth of the piles. Without construction records or other evidence of pile depth, foundations would need a costly retrofit or replacement to ensure design standards are met.

High-mast light towers in Minnesota need to meet design standards to ensure load-bearing stability. A new method to detect underground foundation pile depths may allow MnDOT to avoid costly retrofits or replacements and help prioritize light towers in need of redesign.

Other MnDOT programs have been exploring or implementing various remote or nondestructive sensing technologies for asset inspection. The agency wanted a screening tool to identify in-place pile lengths to effectively prioritize which HMLTs need attention.

What Was Our Goal?

The goal of this project was to develop a nondestructive method, including hardware and offline data analysis, for determining in-place pile lengths.

What Did We Do?

The research team used a multipronged approach to devise a field technique that would sense the lengths of foundation piles underground. Team members identified a sensing methodology based on two mechanical vibratory techniques: a steady-state vibration from a pneumatic piston shaker and a single hammer impact on a mounting plate.

Both methods applied the vibration above the pile stem. A seismic cone penetrometer pushed into the ground tested the soil profile—or stratification—and was fitted with a motion transducer at its tip. A separate steel rod inserted between the pile cap and vibration source provided a physical connection for the mechanical vibrations to transmit through the pile. Due to the high seismic impedance contrast between the pile and surrounding soil, the seismic waves caused by the vibrations are transmitted down to the pile's bottom and into the surrounding soil. The wave data picked up by instrumentation is used to help estimate the pile length.

After reviewing the limited existing construction data on Minnesota's HMLT foundation designs and soil characteristics, researchers created a computational model to simulate and analyze in 3D the interaction between the soil and piles in the context of the sensing methodology and, ultimately, the correlation between the waveform patterns and pile depth. The model also informed the most effective testing parameters for the two methods, including the optimal vibration frequency and location of seismic sensors.

continued

"It's been a challenge to monitor high-mast light towers to ensure current design standards are met. But successful field testing and an in-depth analysis resulted in a very useful and cost-effective tool."

—Rich Lamb,
Foundations Engineer, MnDOT Office of Materials and Road Research

"While our method may seem costly—$5,000 to analyze an individual tower—it has the potential to save Minnesota taxpayers up to $8 million as it costs approximately $40,000 to replace an HMLT foundation."

—Bojan Guzina,
Professor, University of Minnesota Department of Civil, Environmental and Geo-Engineering

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MnDOT has much of the equipment necessary to perform this testing method. After training on the techniques and data analysis functions, staff can quickly assess risk and allocate resources effectively.

The research team designed deep neural networks—sets of algorithms—to interpret the vibratory and hammer impact data as it related to pile depth. While adequate field data is normally required to create a machine learning algorithm, researchers used thousands of model simulations as proxy training data.

Finally, with minor adjustments to the planned design, the team tested the sensing system on multiple HMLT foundations in the Twin Cities metro area over 15 months. At each site, the orientation and geometry of the in-ground pile caps were first identified to guide the placement of the testing equipment. Both steady-state and hammer impact methods were used, and soil was tested to understand the soil profile down the length of the pile. Researchers compared pile lengths identified by their methods to existing MnDOT HMLT construction data.

What Did We Learn?

Using sensors, soil data, 3D simulations and machine learning, investigators developed an analytical, nondestructive approach to determine the depth of supporting piles under an HMLT foundation. The method produced consistent results six months apart. Overall, the results showed that the hammer impact method closely matched the MnDOT data more often than the steady-state vibratory method, though researchers recommend using both for robust estimates.

The team also determined that an entire HMLT foundation with three piles can be evaluated in one day using the hammer impact method, concluding that this method—compared to the costs of retrofitting or replacing—could save substantial resources for MnDOT.

What's Next?

This project provided a potential screening tool to help inform MnDOT's decisions to replace, retrofit or leave existing HMLT foundations as constructed. The agency is considering a pilot program that would prioritize HMLTs and use this sensing method to evaluate those without construction documentation to determine if current design standards are being met.

This Technical Summary pertains to Report 2022-28, "Detecting Foundation Pile Length of High-Mast Light Towers," published August 2022. The full report can be accessed at mndot.gov/research/reports/2022/202228.pdf.