Executive Summary, Research Readiness Level Assessment, and Technology Transfer

High Mast Tower Foundation – Phase I and Phase II

Research Benefits

1. Provided an alternative base design that will eliminate the pole-to-base plate connection that contains weldment details and bolts that are fatigue prone.
2. Reduced inspection and maintenance costs reviewing welds and bolt tightness.
3. Provided a different approach to the pole-to-ground connection that could be used nationwide.
4. Provide a design guide for structural strength I and fatigue loads.
5. Validate the present methods for drilled shafted used the NDOT.

Phase I Objectives

1. Evaluated the various types of foundations used in other structures that are similar in height and shape to the High-Mast Towers. This included evaluating drilled shafts and direct embedment foundations for Power Transmission Line Structures.
2. Evaluated the corrosive environment with steel pole structure being embedded either in soil or concrete and propose mitigation measures for any corrosion issues found.
3. Based on these findings, provided design and construction provisions that will be integrated into NDOT specifications for design and construction.

Phase II Objectives

1. Develop a pole design and procedures for the construction of foundations for high-mast poles.
2. Demonstrate these procedures with the installation of high-mast poles.
3. Confirm the performance with static tests to approximate the design winds.
4. Obtain damping ratios for these poles.
5. Dynamically test the pole to model long-term performance under dynamic loads.
6. Based on these findings, provide design and construction provisions to be integrated into NDOT specifications for design and construction.
7. Document the work product in a final report.
8. Share results nationally via COBS T-12 that maintains the AASHTO specifications for these structures (this is beyond the scope and is longer term)

Background

High Mast Tower (HMT) foundations have been traditionally designed and constructed using a cast-in-place foundation with anchor bolts that are used to secure the tower to the ground. This type of design requires a large base plate that is welded to the tower shaft. The Nebraska DOT (NDOT) has experienced issues with stresses that this type of design presents at the anchor bolt/foundation interface and base plate/tower shaft interface. This issue in worst case may lead to a premature failure of one of the towers at Milford, Nebraska that recently fell down during a winter snowstorm event. There have been many research efforts in the past decade to evaluate the fatigue behavior of these High-Mast Lighting Towers, to propose retrofits that could reduce wind-induced vibrations in these structures, to develop reliability-based design procedures for High-Mast Lighting structures, and field instrumentation and testing of these structures to list a few. However, while most of these studies focused on the 100-120 ft tall structures, there are limited, or no research conducted for the substructure related specifically to poles. Therefore, this study will propose studying possibilities evaluating alternative designs for the foundations, either directly buried, or through drilled shafts, that may drastically reduce the stresses that are present in High Mast Tower designs.

Phase I Conclusion

This research project objective was to develop an alternative design for HMT foundations with direct embedment of HMT which can eliminate fatigue-prone details associated with the pole-to-base plate connection which is the primary location of failure. First, the literature that includes research from academia and industry, current and proposed state of practice from industry, examples of design specifications and guidelines, and corrosion for buried structures were reviewed. Secondly, structural loads for the typical 120- and 140-ft HMTs constructed in Nebraska and the soil resistance for them were calculated. The structural loads were computed using the AASHTO LRFD Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals, with a spreadsheet based on the fundamental principles of structural analysis. The geotechnical foundation resistance calculations were made to check the vertical and horizontal soil capacity for the typical HMTs used in Nebraska. In addition, further parametric study was conducted using two numerical software: LPILE and COMSOL for varying soil conditions and foundation systems with different embedment length and backfill diameter for the service level base moment and shear. Required embedment length and backfill diameter are provided as a matrix using the LPILE analysis results. Finally, based on the site considerations and constructability, a draft design and construction specification for soil parameters that can be used for Nebraska soil conditions are provided.

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Interested in finding out more?

Phase I Final Report Available: NDOT Website

Phase II Final Report Available: NDOT Website

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Phase II Conclusion

High mast light towers used in the US transportation sector are typically steel poles that are attached to a baseplate via a butt or socket weld and bolted to a deep foundation. Many have failed primarily due to fatigue cracking at the weld toe. The tests in this project demonstrated the application of direct embedment for high mast towers for potential use in the transportation sector. The tested poles behaved well even under extreme loads much larger than the 700-MRI design wind. The foundation design requires a p-y analysis for the soil conditions to estimate the groundline translations. Acceptable (codified) translations have not yet been set, and this research will help to guide those judgments. To set standards, NDOT could develop conservative shaft details for soil profiles typically located in the state. Although the foundation designs in this research were shallow by design, increasing the embedment depth to provide a more conservative shaft could provide a standard design at a marginal cost. Finally, the gravel backfill for foundations were found to be resilient to large displacement events that created voids, showing slight self-healing characteristics which can be readily backfilled after the event.

Phase I NDOT Recommendations Based Off Research Project – 2021

This research provided the Department an alternative design for the High Mast Tower Foundations which can eliminate fatigue-prone details associated with the pole-to-base plate connection where primary failure occurs. The Department will consider raising a tower in an operational environment to address the following:

- Ground Effect Corrosion - because some districts have corrosive soil, and because the foundations for these HMT will not be very deep and close to the surface where oxygen content may be higher, anti-corrosion protection measures may be needed.
- HMT designed to 80 ft, since that is the maximum height NDOT is currently considering for future applications. NDOT may consider designs up to 140 ft, if the future presents more of a need for that application
- Check and monitor the computed the loads provided by the study for Structural Supports for Highway Signs, Luminaires, and Traffic Signals.
- Monitoring the welding around handholds since it is a stress point.

The Department recommends a Phase II proposal and start planning for 2021 September's request for proposals.

- *As provided by Mick Syslo and Mark Burham, Lead TAC Members*

Executive Summary, Research Readiness Level Assessment, and Technology Transfer

Phase II NDOT Recommendations Based Off of Research Project – 2025

This research provided the NDOT with basic specifications for the installation of high-mast towers with direct embedded foundations and determined through full scale testing that, given an adequate design, a direct-embedded tower has the potential to safely reach 140-feet or more. Current bolted designs work adequately for high-mast towers 80-foot or shorter; however, for larger towers, direct-embedding is a viable alternative to a bolted attachment. A future discussion with the Roadway Lighting Section will provide insight on the effectiveness of 120-foot or 140-foot towers relative to the standard 80-foot towers for a standard/sample interchange to compare the number of poles necessary for each design. This will provide the potential cost benefits of a taller, direct-embedded design. To this end, the Department is considering contracting a company with existing specifications for a direct-embedded light towers rather than creating its own specifications. These discussions and future projects could determine whether the NDOT will move forward with adding taller direct-embedded high-mast towers to their toolbox or continue with the current bolted design which still works for 80-foot or shorter towers.

- *As provided by Mark Fischer, Lead TAC Member*

Phase II: Technology Transfer

Webinars/Presentations

- AASHTO Committee on Bridges and Structures, Traffic Structures Technical Committee, Direct Embedment of High-Mast Poles, June 18, 2024. (This committee maintains the AASHTO LRFD Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals. The research is planned for implementation in AASHTO; this was an update presentation)
- AASHTO Committee on Bridges and Structures, Traffic Structures Technical Committee, Direct Embedment of High-Mast Poles, November 20, 2024. (This committee maintains the AASHTO LRFD Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals. The research is planned for implementation in AASHTO; this is a final report presentation. The goal is to start discussion for an agenda item scheduled for a vote in June 2025)

Research Readiness Level (RRL) Assessment

RRL 3

Level 3: Development / Field Level

Phase I – Level 3: Development/Field-Level.
Phase II – Remained in Level 3, follow up in one year.

This brief summarizes Project SPR-P1(20) M111 and SPR-FY23(013):

"High-Mast Tower Foundation"
"High-Mast Tower Foundation – Phase II"
Nebraska Department of Transportation Research Program