Wind-Loaded Structures

Objectives

- Assess the behavior and extent of loads transferred to two drilled shafts
- Evaluate the potential for using smaller-sized drilled shafts to reduce material and construction costs

Benefits

- Structural response monitoring provided critical information about the in-service performance of the traffic sign structures
- Real-time sensors helped understand the effect of real wind and environmental conditions on traffic sign structures

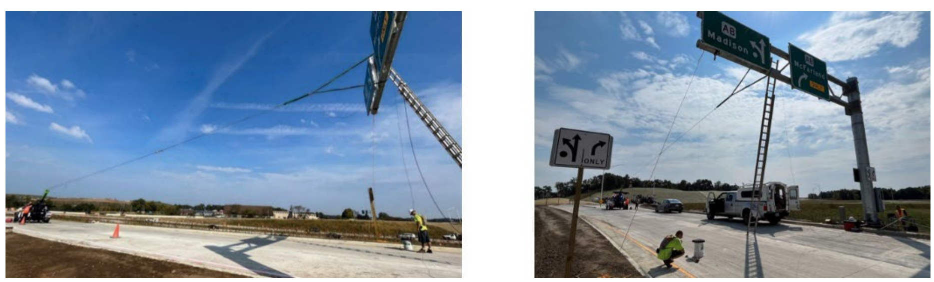
Background

Cantilevered traffic sign support structures are regularly exposed to wind and truck-induced gusts, which generate complex torsional and flexural forces that must be effectively transferred to their foundations. These wind-induced stresses, particularly torsional and moment loads, pose significant challenges in design of structure and foundation of such systems. Recognizing the need for consistency and safety, the Wisconsin Department of Transportation (WisDOT) developed standardized foundation plans for these structures. However, questions remain regarding the adequacy and potential conservatism of these designs.

This study investigated the structural behavior and load transfer mechanisms of cantilevered traffic sign structures under wind loading, with a particular focus on the transmission of moment and torsional forces through the foundation system.

Methodology

The research involved geotechnical surveys, finite element modeling (FEM), and structural health monitoring (SHM) to analyze foundation behavior and evaluate torsional capacity. Validation of the computational models was achieved through comparison with experimental results from free-vibration, static pull tests, and long-term monitoring.



Static tests for torsional upstream and torsional downstream forces

A parametric study was also conducted to explore opportunities for optimizing foundation design. Two full-span cantilevered truss sign structures with drilled shaft foundations were subjected to both static and dynamic loading to assess performance under realistic operational and environmental conditions. To assess performance under extreme loading conditions, FEM was performed using SAP2000 software. This computational approach simulated high wind speeds, transient gusts, and extreme scenarios. FEM allowed for a detailed analysis of stress distribution, structural deformations, and potential failure mechanisms.

Principal Investigator

Alice Alipour
Iowa State University
alipour@iastate.edu

Project Manager

David Staab
WisDOT
david.staab@dot.wi.gov

"This project investigated the loading and foundation demand of wind-loaded sign structures. The research results have the potential to improve current foundation designs, resulting in simplified and lower construction costs, while maintaining equivalent safety and reliability to existing foundation designs."

– David Staab, WisDOT

These simulations were cross-referenced with SHM data to validate the models.

Results

Two traffic sign structures, S-13-562 and S-13-570, located in different soil conditions, were instrumented and subjected to pull tests involving statically increasing loads. These tests helped characterize the loads, stresses, and strains within the structures and their foundations. Since the structures remained in service, the applied loads engaged only 12–40% of the shafts' ultimate capacity, as estimated from L-pile analysis. While the tests primarily captured the shafts' linear response and were not sufficient to define their full capacity, they proved valuable for evaluating the performance of the installed strain gauges and provided a foundation for validating numerical models.

The long-term structural health monitoring continued for a year after instrumentation. Wind observed at the two sites were at a maximum speed of 27 mph which is 23% of the design wind speed of 115 mph. The structure and foundation were only stressed to a fraction of ultimate design. However, this data was used to verify numerical models. Due to low winds observed at the location of structures, synthetic winds were generated and applied to the FEM. These stochastic winds were used to assess the structural response and loads transferred to the piles at higher wind speed ranges. The loads at the top of the shaft were transferred to the L-Pile to characterize the maximum bending moment in the foundation.

Recommendations for Implementation

The research indicates that the serviceability limits specified in the WisDOT Bridge Manual may be overly conservative. These results highlight the potential for more efficient foundation designs without compromising structural performance or safety.

To achieve an optimized foundation design, it is essential to consider structural limitations, loading conditions, and soil characteristics. A parametric study was conducted using linear analysis of 25 shaft models developed in FEM. The results support the feasibility of reducing shaft length without compromising performance. The study further suggests that shorter shaft types—such as the Two-Chord Truss Full Type II (TFII) or Type IV (TFIV)—can offer a more efficient and balanced design in terms of structural performance and material usage when compared to the longer Two-Chord Cantilever Type IV (TCIV).

Interested in finding out more?
Final report is available at:
[WisDOT Research website]

This brief summarizes Project 0092-22-06
Wind Loaded Structures

Wisconsin Highway Research Program