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RESEARCH PROJECT TITLE
Improved Method for Determining Wind Load On Highway Sign and Traffic Signal Structures

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IMPROVED METHOD FOR DETERMINING WIND LOAD ON HIGHWAY SIGN AND TRAFFIC-SIGNAL STRUCTURES

tech transfer summary

Objective

The main goal of this study is to use state-of-the-art Computational Fluid Dynamics (CFD) tools in order to obtain information on the airflow around large panels found in the highway sign and traffic signal structures. Three-dimensional numerical simulations are used to estimate the total force on different panels, as well as the actual pressure distribution on the front and back-faces of the panels. The pressure distributions are invaluable for detailed structural dynamic analysis of truss structures supporting these panels.. The present study investigates the effects of aspect ratio and sign spacing for regular panels, the effect of sign depth for the dynamic message signs that are now being used on Iowa highways, the effect of the presence of back-to-back signs, the effect of the presence of add-on exit signs, and the effect of the presence of trucks underneath the signs potentially creating "wind tunnel" effect.

Problem Statement

Accurate estimation of wind forces on large highway sign structures is important due to possible structural failure of these sign structures under strong winds. The panels of these structures are becoming large and increasingly more common as we attempt to better manage the highway traffic flow and automate the highway systems. In recent years, there is increasing evidence that design of such structures does not take into account the specific loadings experienced by these large panel structures. Consequently, some of these structures have required frequent inspections, retrofitting, and even premature replacement. In order to be able to predict behavior of these structures accurate knowledge of the forces and moments on these structures must to be known.

Damage to two highway structures due to high winds.

Research Description

The present study concentrated on the estimation of wind loads (total forces and their distributions on the panel surface) on typical Iowa highway structures. The study focused on several aspects that cannot be predicted by using the empirical formulas employed in the typical design process. The AASHTO 2003 standard used in the design of these structures considers only static wind loads based on the expected maximum wind speeds acting normal to the isolated rectangular panels and uses a static-strength design approach. Several important effects due to forces and moments induced by the interaction between close panels or changes of the forces on panels of complex shape are not accounted for by this simplified methodology. CFD can help get quantitative answers related to these important effects.

A detailed CFD study was performed to determine the wind loads and pressure distributions through accurate numerical simulations of air flow characteristics around large highway sign structures under severe wind speeds conditions (only the case of a wind direction perpendicular to the panel was considered). Three-dimensional Reynolds-Averaged Navier-Stokes (RANS) simulations were used to estimate the total force on different panels, as well as the actual pressure distribution on the front and back-faces of the panels. The pressure distributions available from the CFD simulation are needed in case a detailed structural dynamics analysis will be performed to test a particular design under a certain set of wind parameters.

The study investigated:

- the effect of aspect ratio and sign spacing for regular panels
- the effect of sign depth for the dynamic message signs that are now being used on Iowa highways
- the effect induced by the presence of back-to-back signs,
- the effect of the presence of add-on exit signs
- the effect of the presence of trucks underneath the signs potentially creating “wind tunnel” effect.
- the reduction in the mean pressure force on the panels as a result of the presence of small air holes in a wide rectangular panel

Sixteen test cases were considered. The main geometrical dimensions of the panels and their relative position are summarized in Table 1. In all cases the wind direction was perpendicular to the panels, corresponding to the case when the maximum wind load is expected to occur on the panels. The last figure in this summary document shows typical solution for a test case with two back-to-back panels whose axes are offset by 12 ft. Solution is shown in a horizontal plane cutting at mid-height level through the center of the panels; a) non-dimensional pressure contours, b) turbulent kinetic energy (TKE) contours, c) streamlines.

Main Findings

The simulation results served to better understand the range of conditions over which the empirical formula used to determine the mean pressure difference between the two sides of a panel is adequate. Some of the main conclusions of the study are as follows.

1) For panels of complex shapes or for multiple signs panels the pressure distributions can be highly non-symmetrical. As a result, besides the mean force acting on the panel, strong rotational moments can also be present. These moments are practically impossible to estimate using empirical formulae.

2) For cases when back-to-back signs are present, the wind load factor in the AASHTO 2003 should be increased by 30%. However this still does not take into the effect of the moments on the panel. A detailed CFD analysis for cases when moments can be high is needed.

3) The pressure distribution data should be used to conduct a detailed aeroelastic structural analysis of traffic sign structures. Advanced finite-element codes should be used for structural analysis of the typical structures (e.g., cantilevered mast arm traffic signal and its supports) subject to the loads estimated using CFD.

Geometrical characteristics of the simulations containing panels without holes.

Cases	Height (ft)	Width (ft)	Thickness (ft)	Number of Plates	Distance between Plates (ft)	Position of the Plates
1	14.75	55	-	1	-	-
2	14.75	W1 = 27 W2 = 27	-	2	1	Side by side
3	14.75	W1 = 24 W2 = 24	-	2	7	Side by side
4	14.75	W1 = 24 W2 = 12	-	2	12	Side by side
5	14.75	W1 = 12 W2 = 12 W3 = 12	-	3	9.5	Side by side
6	12	70	-	1	-	-
7	12	W1 = 24 W2 = 24	-	2	22	Side by side
8	10.17	W = 32	6.42	1		-
9	10.17	W = 32	-	1	-	-
10	14.75	W1 = 24 W2 = 24	-	2	d_b =6.67	Back to back
11	14.75	W1 = 24 W2 = 24	-	2	d_b = 6.67 d_s = 12	Back to back Side by side
12	14.75	W1 = 24 W2 = 24	-	2	d_b = 6.67 d_s = 24	Back to back Side by side
13	14.75	W1 = 24 W2 = 24	-	2	d_b = 6.67 d_s = 30	Back to back Side by side
14	8.5	22.5	-	1	-	-
15	H = 8.5 h = 2.5	W1 = 22.5 W2 = 9	-	2	-	Small on top of large one
16	H =10.17 ht1 = ht2 = 11.5	W = 32 wt1 = wt2 = 8.5	T = 6.42 tt1 = tt2 = 6.42	1	Distance between the trucks and the plate = 4	Trucks under the plate

Recommendations

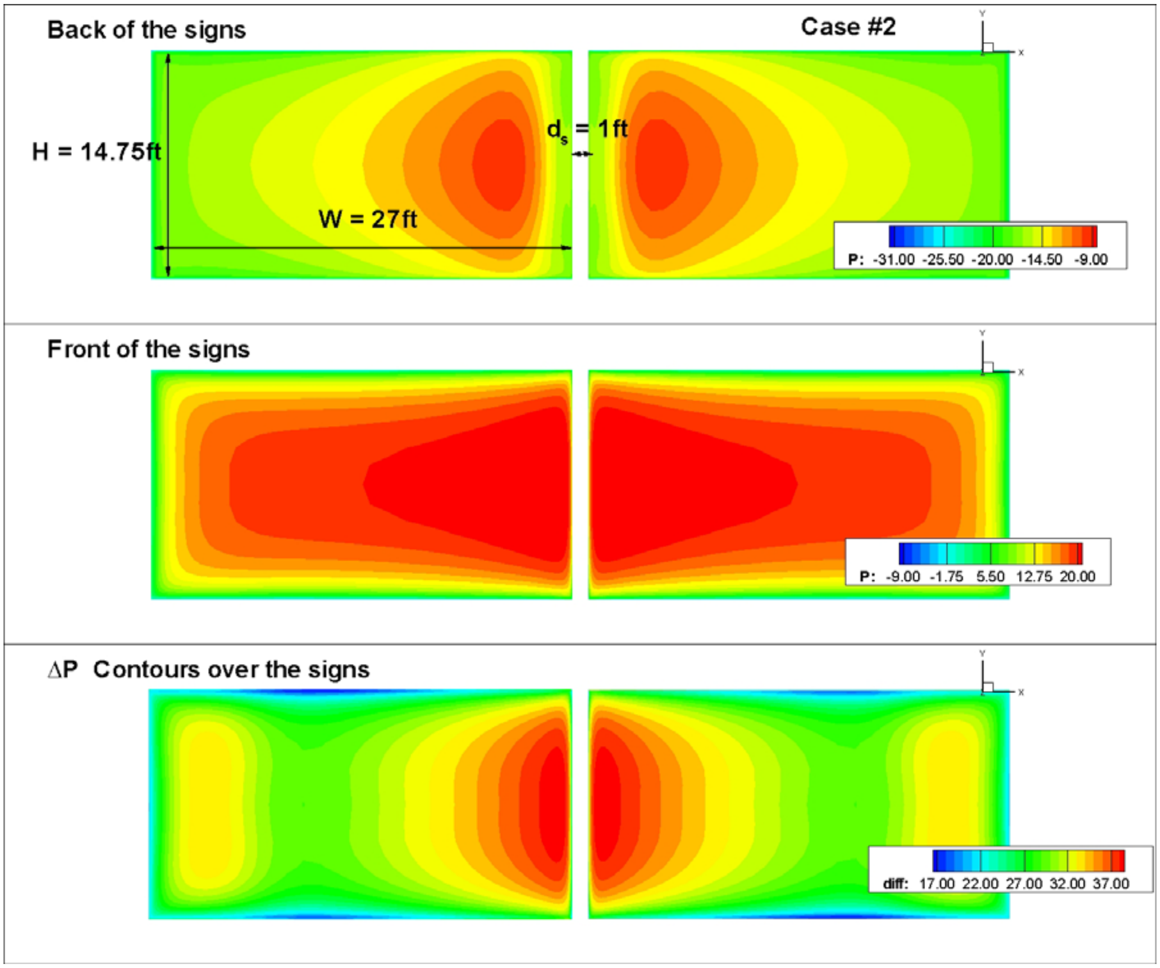
The findings of this work showed there is a need to enlarge the set of parameters considered in the present study and to perform a structural analysis of typical traffic sign structures in order to be able to quantify the effect of wind loads. Both a static and aeroelastic structural analyses should be conducted.

The main recommendations are listed below:

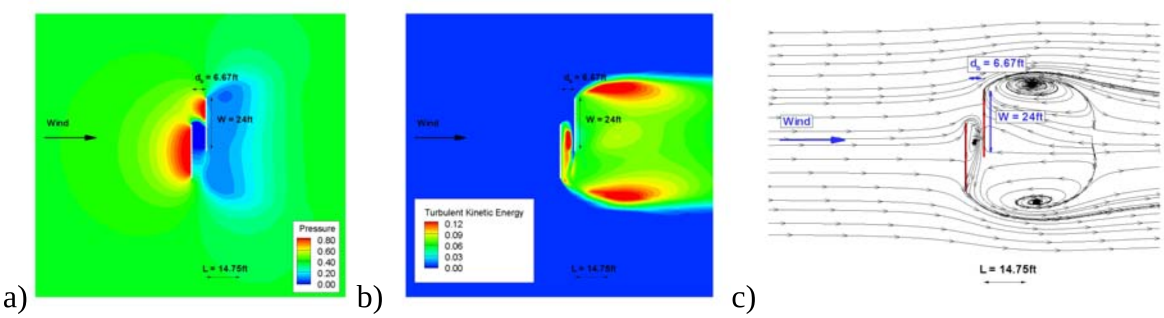
1) Study effect of wind direction on the pressure distributions. Especially for back to back signs largest forces and moments may occur when the wind direction is not necessarily perpendicular to the panels. A detailed parametric study needs to be conducted with respect to the effect of wind direction.

2) Perform a detailed study on dynamic message signs (DMS) to investigate the premature cracking observed at many of these signs. Some dynamic effect may be present for the DMS cabinet (4000 pounds) when mounted eccentrically on an overhead sign truss. For example, it is possible that natural wind or passing trucks excite the cabinet and truss, and since there is little damping, the truss continues to vibrate and accumulate fatigue cycles. It is proposed to investigate the effect of attaching relatively flexible lightweight signs of large surface area to provide damping not available from the relatively stiff and concentrated mass of a DMS.

3) Improve supporting angle design. This study raised one structural question regarding the sign attachment. Currently vertical angles are bolted to the back of sign panels. These angles are spaced and designed for the average 30 psf. However depending on the sign placement, the pressure on one part of the sign may be as



Distributions of the back side pressure (top), the front side pressure (middle) and the pressure difference between the two sides (bottom) for two side-to-side panels. The dimensional pressure levels (psf) are shown.



Visualization of the solution for case 11 in a horizontal plane cutting at mid-height level through the center of the panels; a) non-dimensional pressure contours, b) TKE contours, c) streamlines.

much as 37 psf near a slot condition. This might suggest a reconsideration of supporting angle design.

4) Estimate wind loads on large esthetic shape signs of complex shape. It can reasonably be expected that the wind loads on these signs will be considerably different than that estimated from the empirical formulae designed primarily for rectangular panels.

5) Estimate the dynamic loads on sign structures. The presence of unsteady loads due to vortex shedding behind the panels can produce resonance, causing large amplitude relatively steady vibrations of the structure. Estimation of these dynamic loads requires performing unsteady RANS simulations. A dynamic analysis of aeroelastic effects is worse pursuing for these cases.

6) Use an integrated CFD-computational structural analysis approach to properly account for aeroelastic phenomena like flutter and buffeting. Through these analyses one should be able to evaluate the errors that are made when a steady-state approach is used to estimate the wind loads on these structures. At the present time both the AASHTO 2003 Standard and new design method in NCHRP 17-10 generally neglect any aeroelastic phenomena.