An Investigation of Wind Loads on Roadside Signs

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This paper presents the results of an investigation of forces and moments that exist on roadside signs when subjected to wind velocities at varying angles of incidence. The effects of sign shape on the forces and moments are also considered.

To accomplish the investigation, a full-scale sign was instrumented and tested in its natural environment. Results of the full-scale tests are compared with data obtained through wind tunnel tests of sign models. Based on a close correlation of these data, conclusions are drawn concerning wind load criteria for highway signs. Recommendations are made with regard to the AASHO wind load design specifications.

•DEVELOPMENT of modern Interstate freeway systems has been accompanied by a need for an adequate signing system to warn and inform the motorist. Dimensions of the sign and its message must be such that the motorist will have time to take necessary action. Often an extremely large sign is required, and massive supports are needed to resist wind loads. Large supports, in turn, present a hazard to the motorist since the sign is often placed in close proximity to the edge of the road.

An obvious means of reducing this hazard would be the relocation of the sign at a safer distance from the roadway. Installation of a "break-away" post (1) that disengages from its foundation upon impact offers an alternative method of reducing the hazard.

These two means of reducing this roadside hazard cannot always be employed. In any case, if the wind loads used in designing a sign are excessive and can be reduced, the stiffness and mass of the structure can be reduced. Such changes in the sign structure could prove beneficial to the traveling public from the standpoint of safety.

Before this study, doubts prevailed as to wind load specifications recommended by AASHO, in particular the magnitude of shape factors used in computing wind pressures. This study attempts to clarify the uncertainty.

OBJECTIVE

The basic objective of this study was to substantiate existing shape factors used in wind load design criteria (2) on conventional highway signs, or provide a basis for revisions to the criteria.

LITERATURE REVIEW

Wind load studies of flat plates have been conducted since the middle of the 19th Century. Some of the earlier methods used in testing the plates were rather crude by present standards. For example, Eiffel (3), during the initial stages of his tests, dropped plates from towers and observed the changes in velocity and forces on the plates. Other investigators mounted the plates on moving vehicles.

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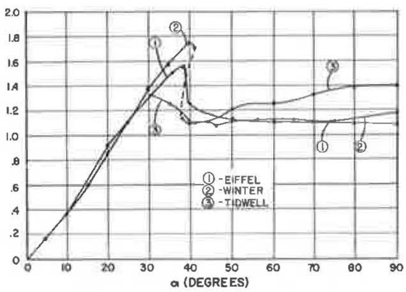

Figure 1. Normal force coefficient versus angle of attack for a square flat plate.

Eiffel was also among the first to conduct wind tunnel tests on flat plates. Stanton (4) used a wind tunnel for most of his wind load studies of plates. He was the first to take accurate pressure readings across a plate and give firm proof that the maximum resultant force on a plate does not always occur when the plate is normal to the direction of flow. Winter (5) and Tidwell and Ross (6) are among the more recent investigators of wind loads on plates.

Figure 1 shows the results of some of these studies for a plate with a height to width ratio equal to 1.0 (square plate). It is obvious that differences exist in the results. These differences are attributed to several factors, some of which are as follows:

1. Model size—the area of the models used in these tests ranged from 3 sq in. to 4 sq ft.
2. Method of testing—some of the earlier methods were crude, which would include the earlier wind tunnel tests.
3. Manner in which the model was supported—the methods used to support these models during wind load tests varied: some were supported by wires; others were mounted on rigid fixtures.

Regardless of the differences in these tests, the fact remains that practically all the plates tested were small in area. The majority of the tests were also conducted under ideal conditions, i.e., controlled environment, such as uniform flow in a wind tunnel. These questions then arise: (a) Are the wind loads on plates (or signs) a function of size? (b) To what extent does the natural environment influence the wind loads as opposed to an ideal one? (c) Can wind tunnel tests of sign models be used to determine wind loads on larger signs?

In searching the literature only one instance of tests on large plates was found, that by Stanton (7, p. 175) in 1907. Stanton tested three plates which had height to width dimensions of 10 ft by 10 ft, 10 ft by 5 ft, and 5 ft by 5 ft. His method of testing these plates, although good for that period of time, is now considered to be inadequate and the validity of his results is in question.

The criteria now being used for wind loads on signs were determined by use of the previously referenced material and by wind tunnel tests similar to those mentioned in the references. It is therefore desirable that more accurate and up-to-date information be gained on this subject.

METHODS OF RESEARCH

In order to meet the objective, two methods of research were pursued: field studies on a full-scale sign and wind tunnel studies on sign models.

Full-Scale Studies

A full-scale sign, 10 ft by 10 ft in size, was built and instrumented for use in determining wind loads on a typical sign when subjected to field conditions, i.e., its

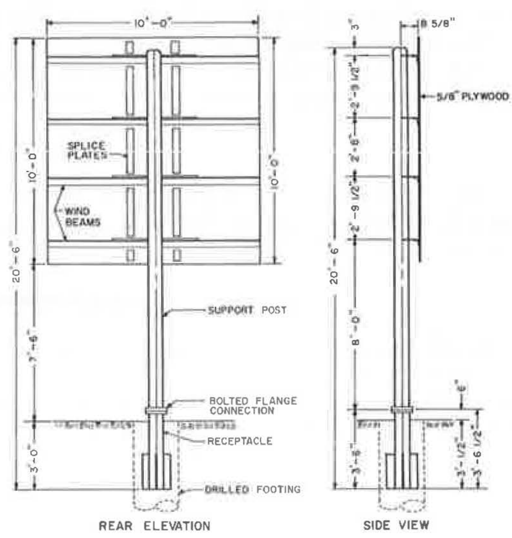

Figure 2. Full-scale sign detail.

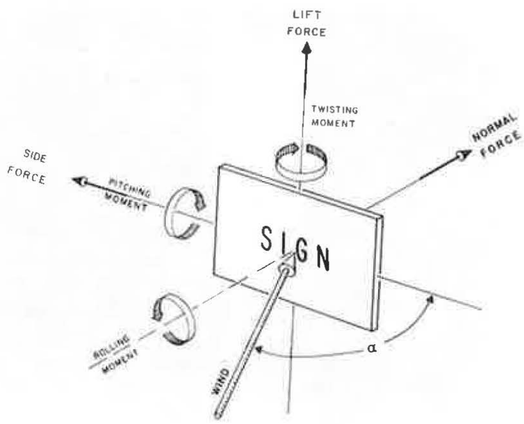

Figure 3. Wind actions on sign.

natural environment. Details of the sign are shown in Figure 2. Some of its more important features are described in the following.

1. In general, six actions are necessary to describe the effects of wind acting on a body (Fig. 3). However, for a flat, rectangular, solid background sign, three of these actions will sufficiently describe the wind effects; namely, side force, normal force, and twisting moment. The other three actions are negligible. Thus, the support was instrumented with five full electric strain gage bridges for use in determining the side and normal forces and the twisting moment on the sign.
2. The single tubular support was a statically determinate structure. This feature was advantageous from an instrumentation standpoint since the loads have but one path after entering the support.
3. The flanged connection at the base of the tubular support permitted the sign to be rotated in 22.5-deg increments.
4. Wind loads on a sign with a single tubular support are of the same order of magnitude as those on signs with two or more supports. The test results, therefore, are applicable to other support configurations.

Electric resistance strain gages were mounted on the sign support at known locations. Conversion of flexural and torsional strains into bending and twisting moments was accomplished by dead weight calibration of the instrumented support post. Normal and side forces were computed by using the principle that transverse shear in a beam is the rate of change of moment.

The bending moment transducers were installed 6 ft apart on the support post, and appropriate compensation was made for the small effect of wind forces on the support post in this finite length.

The sign was placed on a remote site of the Texas Transportation Institute's Safety Proving Grounds (Fig. 4). The site was free of any large obstructions for several hundred feet in all directions, allowing the wind a relatively undisturbed path to the sign.

Figure 5 shows the basic equipment employed in conducting the tests, i. e., the instrumented sign, wind speed and direction indicators, a mobile instrumentation

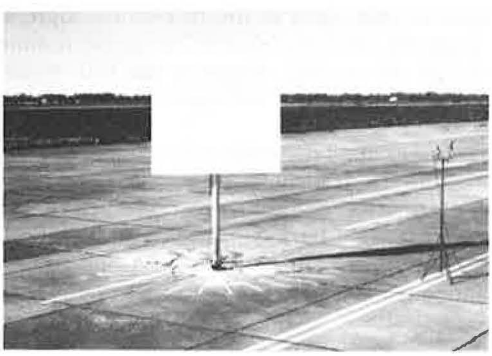

Figure 4. Full-scale sign on test site.

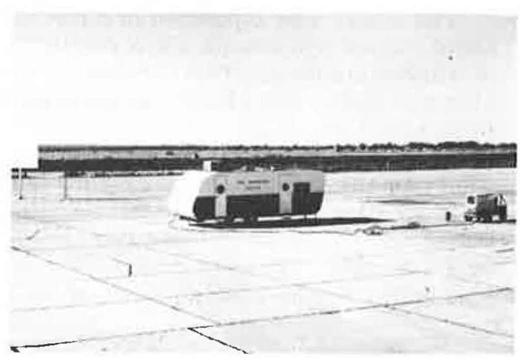

Figure 5. Basic test equipment.

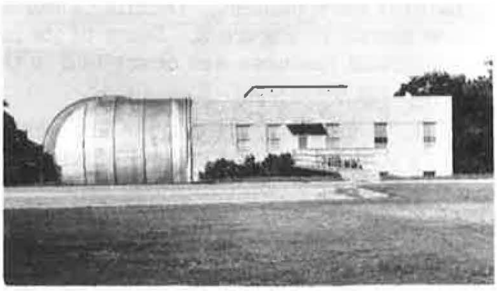

Figure 6. Wind tunnel facility.

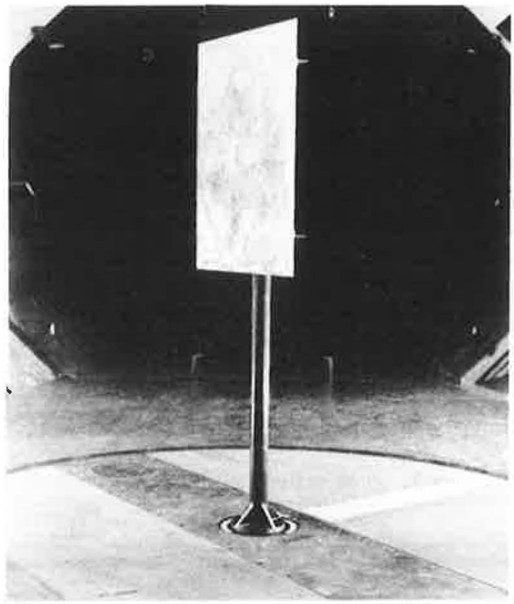

Figure 7. Flat-plate model mounted in wind tunnel.

laboratory, and a portable generator for supplying electrical power. The mobile instrumentation laboratory housed the instruments used in recording data.

Tests were made as wind conditions permitted. When possible, tests were made with wind velocities above 20 mph. Highest sustained winds during any particular day of testing were about 35 mph.

Simultaneous readings of moments, wind speed, and wind direction were made at a given sign angle of attack, α (refer to Fig. 3 for α). Readings were made continuously for about five minutes, which constituted a run. The sign was then rotated to a different angle and the readings resumed. Data were obtained on 7 different days of testing with an average of 9 runs per day.

Oscillographic recorders were used to record the information collected from the strain gage bridges. The anemometer, used in measuring the wind velocity, and the wind direction indicator (Fig. 4) were placed at an elevation equal to approximately that of the sign's center. They were about 20 ft from the center of the sign in a direction perpendicular to the direction of the wind. The latter location was used so that the instruments would not disturb the wind into the sign. Data from the wind instruments were collected by ink recorders.

Model Studies

A scale model of the full size sign, 1.84 ft by 1.84 ft, was tested in Texas A&M University's 7 by 10 ft low-speed wind tunnel (Fig. 6). The model is shown oriented 45 deg to the direction of flow in Figure 7.

The model was supported in a method similar to that used in the full-scale sign, i.e., angle shaped windbeams and a single tubular support, with the exception of the number of windbeams used. Two windbeams were used on the model, whereas the full-scale sign had four. The effect this difference had on the relative wind loads was assumed to be small.

Forces and moments on the sign model were measured directly with respect to the wind tunnel instrumentation axis for a given sign angle of attack.

In addition to the model test, two other flat-plate sign models were tested in the wind tunnel. Dimensions of these two models were 1.3 ft wide by 2.6 ft high, and 2.2 ft wide by 1.6 ft high. These models were tested in order to determine the variations in wind load as the height-to-width ratio of the plate (aspect ratio) varied.

DATA REDUCTION

In analyzing the effects of wind on a body, it is usually convenient to reduce the experimental, or theoretical, results to dimensionless coefficient form, i.e., express the forces and moments acting on the body in dimensionless form. It is convenient in many cases because the coefficients are independent of the Reynolds number, whereas the forces and moments are dependent on the Reynolds number. Being independent of the Reynolds number means the coefficient is not a function of either the body's relative size or the wind velocity.

Results of this study, both the full-scale and the wind tunnel tests, were reduced to dimensionless coefficient form for analysis. These coefficients are defined as follows (also see Fig. 3 for illustration of normal force, side force and twisting moment):

Normal force coefficient, C_N

$$C_N = \frac{F_N}{qA_s} \tag{1}$$

Side force coefficient, C_T

$$C_T = \frac{F_T}{qA_s} \tag{2}$$

Twisting moment coefficient, C_{MT}

$$C_{MT} = \frac{M_T}{qA_sW} \tag{3}$$

where

F_N = normal force,
F_T = side force, and
M_T = twisting moment;

and

A_s = frontal area of sign,
q = impact pressure ($\frac{1}{2}\rho V^2$), and
W = width of sign;

where

ρ = mass density of air, and
V = velocity of air.

Full-Scale Tests

For a flat plate, solid background sign, three coefficients are sufficient to describe the effects of wind forces at various angles of attack. These are the side and normal force coefficient, C_T and C_N, and the twisting moment coefficient, C_{MT}. The lift force and the pitching and rolling moment are essentially zero. There may be some pitching moment on signs due to the wind velocity gradient that occurs in the vertical direction. However, this effect was found to be negligible.

A computer program was written to assist in reducing the data obtained from the full-scale tests. Input to the program consisted of the strain gage data, wind velocity

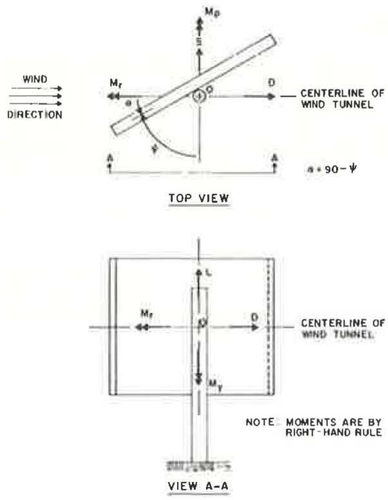

Figure 8. Positive sign convention for wind tunnel axis system.

and direction, sign direction, and atmospheric conditions. Output consisted of three coefficients, C_N, C_T, and C_{MT}.

A Gerber digital data reduction system was used to reduce the oscillograph records. It was interconnected with an IBM 026 keypunch machine for automatic card punching.

Information of wind speed and direction was recorded on strip charts, scaled so that the values could be read directly.

Wind Tunnel Tests

Six actions were measured and recorded for each model at a given angle of attack and wind velocity. These actions: drag force, D; lift force, L; side force, S; yaw moment, M_y; pitch moment, M_p; and roll moment, M_r, were in the "wind tunnel" axis system (Fig. 8) and had to be transformed into the "sign" axis system (Fig. 3). After transformation, the actions were reduced to dimensionless coefficients.

A computer program was written to assist in reducing the wind tunnel data. Input to the program consisted of the model geometry, impact pressure of wind, sign angle of attack, and the six actions in the wind tunnel axis system. The program transformed the actions to the sign axis system. Output consisted of three coefficients, C_N, C_T, and C_{MT}.

DATA ANALYSIS

Full-Scale Tests

Table 1 summarizes the eight tests that were completed on the full-scale instrumented sign. The information gained from these tests was considered to be adequate to describe wind loads on the sign.

The test results contained a considerable amount of scatter, attributable to several factors. One of the main contributing factors was the difference in response time of the two types of instrumentation used in obtaining data. Instrumentation for measuring the forces and twisting moment on the sign consisted of strain gages and an oscillograph recorder. This type of instrumentation is, for all practical purposes, instantaneous. A cup-type anemometer and a vane-type wind direction indicator, together with pen-type ink recorders, were used to obtain the wind velocity and direction. Response of this type of instrumentation is somewhat less than instantaneous.

This difference in response time presented a problem when correlating the forces on the sign with the corresponding wind velocity and wind direction. However, steps were taken to cope with the problem. The first corrective action was to locate the anemometer several feet upstream from the sign. This met with limited success. Better results were obtained by a closer examination of the data. For each test, an attempt was made to compute actual lag time, i.e., the amount of time by which wind velocity and direction data lagged the strain gage data. In this manner, a better correlation of the data was realized. Another means used in reducing the data was to take advantage of recorded

TABLE 1

SUMMARY OF FULL-SCALE TESTS

Test	No. of Runs	Average Velocity (mph)[a]
1	8	15
2	11	20
3	9	20
4	9	25
5	9	25
6	8	No wind
7	10	30
8	9	25

[a]Estimated.

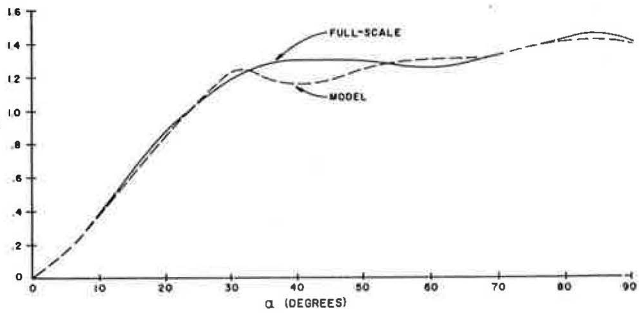

Figure 9. Normal force coefficient versus angle of attack, full-scale and model tests.

periods of time in which the wind velocity was relatively steady. These periods, which usually lasted three or four seconds, allowed the wind recording devices enough time to stabilize and "catch up" with the strain gage readings.

Another major factor which is believed to have contributed to the scatter was a difference in wind velocity and direction at the location of the wind instruments and the sign itself. As mentioned earlier, the wind instruments were located at the same elevation as the center of the sign, but approximately 20 feet from the center of the sign in a direction perpendicular to the wind direction. Velocity gradients as large as ±25 percent have been measured over a distance of eleven feet (7, p. 178). However, with the large number of data points recorded, the effects of this velocity gradient were assumed to be self-equilibrating, i.e., in some cases the recorded velocities were higher than the average velocity of wind on the sign, whereas in other cases the recorded velocities were lower.

A multiple regression curve fitting computer program was used in analyzing the full-scale data due to the amount of scatter. Different degree polynomials were used in determining the best curve fit.

Wind Tunnel Tests

No particular problems were encountered in the analysis of the wind tunnel data.

RESULTS

In general, close agreement was obtained between the results of the full-scale wind load study and the wind tunnel tests as evident in the plot of C_N in Figure 9. Variations in the curves at angles of attack between 30 degrees and 45 degrees were attributed to the environments in which the tests were conducted. In the wind tunnel, air flow entering the test section is maintained at constant velocity and is in a streamlined state with no turbulence. Under these conditions, a distinct drop in the normal force occurs upon reaching a certain angle of attack, that point being termed the stall. In a sign's natural environment, the air flow is usually turbulent, and its direction is continuously changing. These conditions are not believed to be conducive to the formation of a well-defined stall point.

The normal force coefficient and twisting moment coefficient of the three flat-plate models are shown plotted against the angle of attack in Figures 10 and 11, respectively.

The normal force coefficient increases as the aspect ratio decreases for the range tested (Fig. 10). This trend is in agreement with the results of Winter (5) and Tidwell (6) in their tests of flat plates for the same aspect ratio. The magnitudes of the maximum normal force coefficients obtained by Winter were somewhat higher than those shown here, with Tidwell's values being slightly lower.

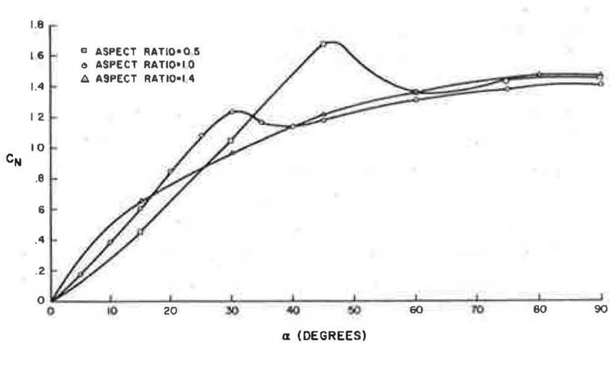

Figure 10. Normal force coefficient versus angle of attack, flat-plate models.

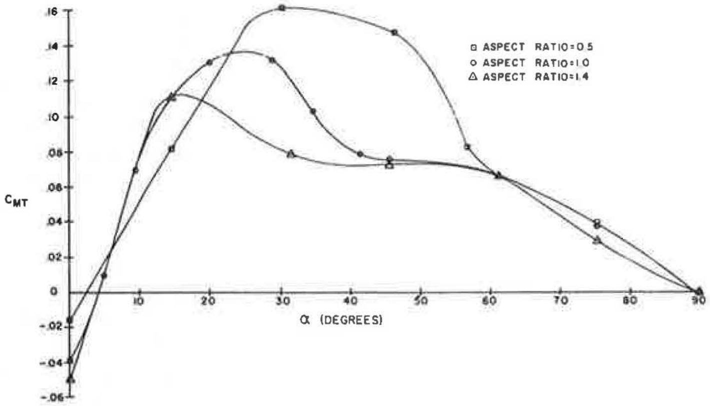

Figure 11. Twisting moment coefficient versus angle of attack, flat-plate models.

Results of the full-scale tests and wind tunnel tests on conventional flat-plate signs clearly indicate that the current wind load design criteria (2, p. 7) with regard to wind pressure, are not excessive. In fact, the results show the criteria to be unconservative.

The equation that is currently being used for wind pressure on a sign is as follows:

$$p = 0.00256 \left(C_g V\right)^2 \left(C_s\right) \quad (4)$$

where

V = wind speed (mph),
C_g = gust factor = 1.3,
C_s = shape coefficient = 1.3, and
$0.00256 = \frac{1}{2} \rho \left(K_V\right)$;

where

ρ = mass density of air at sea level = 0.00238 lb-sec/ft^4,
K_V = conversion factor for converting V in mph to ft/sec, and
$K_V = (1.467)^2 = 2.15$.

In Eq. 4, the shape coefficient is equal to 1.3 for all conventional signs, regardless of shape, i.e., height to width ratio (or aspect ratio). Results of this study show that shape coefficient to be inconsistent. Values of the shape coefficient C_s (termed C_n in this paper) were found to vary from 1.7 for an aspect ratio of 0.5 to 1.5 for an aspect ratio of 1.4. It is to be noted that the aspect ratios of many highway signs are within this range.

In addition to the above inconsistencies in normal loads or pressures, there also exists a difference in the value of the twisting moment on a sign. Current criteria do not specify a twisting moment for signs with more than one support. This is likely due to a belief that a conventional sign is subjected to its most critical wind loads when the wind direction is normal to the face of the sign, i.e., when the angle of attack is 90 deg, in which case the twisting moment is zero. However, this is not always the case. In some instances, the critical condition will occur at angles of attack less than 90 deg. Consider the following example.

Given:

A sign with dimensions as shown in Figure 12 subjected to 100-mph winds.

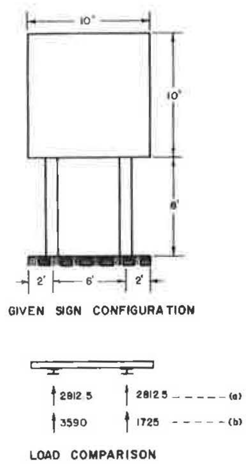

Figure 12. Comparative load study of a typical sign.

Required:

Compute the critical support loads by:
(a) current criteria
(b) results of this study

Solution:

By (a), current criteria:

Normal wind pressure p, (from Eq. 4)

$$p = 0.00256\ (1.3V)^2\ (1.3)$$
$$p = 0.00256\ [(1.3)\ (100)]^2\ (1.3)$$
$$p = 56.25 \text{ lb/ft}$$

Load per support P_S,

$$P_S = pA_s/2 \tag{5}$$

where

A_s = the area of the sign = 100 ft^2.

Therefore

P_S = 56.25 (100)/2 = 2812.5 lb.

From the findings of this study (b) the critical load condition for an aspect ratio of 1.0 occurs when the angle of attack is 30 deg to the face of the sign (Fig. 13). For this direction, the combination of normal force and twisting moment gives a more critical load condition on the support than any other wind angle. As in case (a) the normal wind pressure is computed by

$$p = 0.00256\ (1.3V)^2 \left(C_N\right) \tag{6}$$

In this case,

C_N = 1.23 at α = 30 deg (Fig. 10)

Thus,

$$p = 0.00256\ [(1.3)\ (100)]^2\ (1.23)$$
$$p = 53.2 \text{ lb/ft}^2$$

The total normal force N is computed by

$$N = pA_S = 53.2\ (100) = 5320 \text{ lb} \tag{7}$$

The twisting moment M_T is computed by

$$M_T = \left(C_{MT}\right) (1/2)\ (p)\ (V)^2 \left(A_S\right) (W) \tag{8}$$

where

C_{MT} = moment coefficient, and
W = width of sign (feet)

and all other terms are as previously defined.

If a gust factor of 1.3 is multiplied by V and if V is in miles per hour, the equation for M_T in ft-lb reduces to

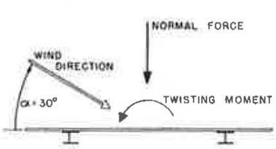

Figure 13. Critical load orientation.

$$M_T = 0.00256\ (1.3V)^2 \left(A_S\right) (W) \left(C_{MT}\right) \qquad (9)$$

For the given sign, at α = 30 deg,

C_{MT} = 0.13 (Fig. 11, α = 30 deg)
W = 10 ft.

Thus,

$M_T = 0.00256\ [(1.3)(100)]^2 (100)(10)(0.13)$
M_T = 5605 ft-lb.

The total load per support P_S is computed by

$$P_S = N/2 \pm M_T/a \qquad (10)$$

where,

a = support spacing = 6 ft.

Therefore,

$P_S = 5320/2 \pm 5605/6$
P_S = 3590 lb & 1725 lb.

Results of the comparison are shown in Figure 12. It is evident that differences exist between the current criteria and the results of this study. It is also evident that the critical load condition does not necessarily occur when the wind direction is normal to the sign's face. To determine the critical condition one must therefore take into consideration not only the shape of the sign (aspect ratio) but also the twisting moment and normal force at all angles of attack and the support spacing.

Values recommended in the current criteria (2) for the side (or transverse) force were essentially verified in this study.

CONCLUSIONS AND RECOMMENDATIONS

Wind Loads on Conventional Signs

Before this study it was generally believed that current design criteria for highway signs, with regard to wind pressure, were excessive. The findings of this study prove otherwise. Close agreement between results of the full-scale investigations and model tests forms a basis for this conclusion. This close agreement also demonstrates the applicability of conventional sign model data to full-scale signs.

Wind pressure criteria were actually shown to be unconservative, i.e., a sign structure built to the criteria specifications would be underdesigned. Inconsistencies were found to exist in the design methods. The shape coefficient as used in the criteria in computing wind pressures has a constant value of 1.3, regardless of the sign's shape (or aspect ratio). It was shown that the shape coefficient is dependent on the shape. The coefficient was found to vary from 1.7 for an aspect ratio of 0.5 to 1.5 for an aspect ratio of 1.4. Maximum wind load condition, as specified in the criteria, occurs at an angle of attack of 90 deg (when the wind direction is normal to the face of the sign). It was shown that the critical wind load condition can occur at angles other than 90 deg, in which case the combination of normal force and twisting moment provides the critical condition.

Based on these conclusions, it is recommended that the results of this conventional sign wind load study be considered in establishing new design criteria for highway signs. The new criteria should take into account variations in shape coefficient with aspect ratio and should give consideration to the effects of a twisting moment.

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