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PERFORMANCE TESTING OF A 60-FOOT, OPEN WEB SECTION,
BOX TRUSS ALUMINUM OVERHEAD SIGN SUPPORT STRUCTURE

G. R. Cudney

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PERFORMANCE TESTING OF A 60-FOOT, OPEN WEB SECTION, BOX TRUSS ALUMINUM OVERHEAD SIGN SUPPORT STRUCTURE

This is an interpretation of the results of experimental load tests conducted by McGraw-Edison personnel on their proposed aluminum overhead sign support structure on August 18 and 31, 1961. The reasons for this test loading program are outlined in a letter from W. W. McLaughlin to Harry Bell of the McGraw-Edison Company on April 18, 1961. This experimental testing together with an analysis made by the Bridge Design Division involves determining the adequacy of the proposed design with respect to "Recommended Design Criteria for Traffic Sign Support Structures" as outlined in a letter from E. A. Finney to F. J. Cook on March 23, 1959. In addition, this interpretation is also concerned with the new AASHO "Specifications for the Design and Construction of Structural Supports for Highway Signs," adopted June 12, 1961, and superseding all previous design criteria.

AASHO vs MSHD Specifications

For purposes of discussion and comparison with the previous MSHD design criteria, the new AASHO Specifications as applied to the proposed McGraw-Edison structure may be summarized as follows:

Loading. The AASHO design wind velocities designated for Michigan include three isotachs--67, 80, and 90 mph. The 67-mph zone includes the central and southwestern lower peninsula, the 80-mph zone the northern and coastal areas of the lower peninsula and northwestern portion of the upper peninsula, and the 90-mph zone the Straits region and eastern portion of the upper peninsula. This discussion is concerned only with the 80- and 90-mph velocities and corresponding design pressures. For 80 mph, AASHO specifies normal design wind pressure as 35 lb per sq ft on the sign, and 77 lb per sq ft on the exposed structure. For 90 mph, these wind pressures are increased to 45 and 99 lb per sq ft, respectively. In addition, the structure is considered to have a transverse loading equal to 20 percent of the normal loading, i. e. , wind on sign and all exposed structural surfaces as just defined acting uniformly on both vertical end supports. The normal and transverse loadings are both considered to act simultaneously. In contrast to these AASHO

standards, the Department's own criteria specified normal loading as 30 lb per sq ft on sign and exposed structural surfaces, and a transverse loading of 30 lb per sq ft on the transverse exposed areas of sign and structure, with each of these loadings considered separately.

Stiffness. The AASHO Specifications call for a limiting vertical dead load deflection equal to $\frac{d^2}{400}$ where d is the depth of the supported sign. Further, the specifications require a vertical camber of the structure equal to the dead load deflection plus $\frac{L}{1000}$ where L is the span length. The MSHD criteria specified a minimum vertical dead load deflection of $\frac{1}{1200}$ of the span length, a minimum horizontal wind load deflection of $\frac{1}{350}$ of the span length, and a limiting natural frequency of vibration of 4 cps.

Stress. With the exception of certain connecting bolts, all components of the McGraw-Edison structure are aluminum alloy 6061-T6, and the welds made with filler alloy 4043. Assuming the allowable stresses as listed in Table 1 of the AASHO Specifications ("Allowable Stresses in Aluminum Alloys - ksi") apply for 6061-T6 welded with 4043, the corresponding allowable tensile stress and weld shearing stress would be 14,500 and 7,250 psi, respectively. However, if the AASHO table is to be rigidly interpreted, so its stress values apply to only the specific alloy and weld combinations listed, computations would have to be based on "Specifications for Structures of Aluminum Alloy 6061-T6," ASCE Proc. Paper No. 970, Jrnl. of the Structural Div. (May 1956), in which case allowable tensile stress for the 6061-T6 would be 11,600 psi and allowable shearing stress for longitudinal or eccentrically loaded fillet welds would be 5,800 psi. Corresponding MSHD stresses would be 10,700-psi tension and 5,300-psi weld shearing, respectively. In all these cases, allowable tensile stresses for 6061-T6 pertain to the heat affected zone due to welding.

The McGraw-Edison Structure

The proposed McGraw-Edison structure consists of a horizontal truss unit composed of angles as chord members and T-sections as diagonals. The T-sections are welded to the legs of the angles through the flange of the T. These elements form a box truss 2 ft 6 in. deep (vertical) by 3 ft wide (horizontal), back to back of angles. The horizontal

span unit is connected to the vertical end supports through a knee brace truss affording a semi-fixed end connection.

The vertical end support unit is composed of the same angles and T-section diagonals as utilized in the horizontal span unit, forming a

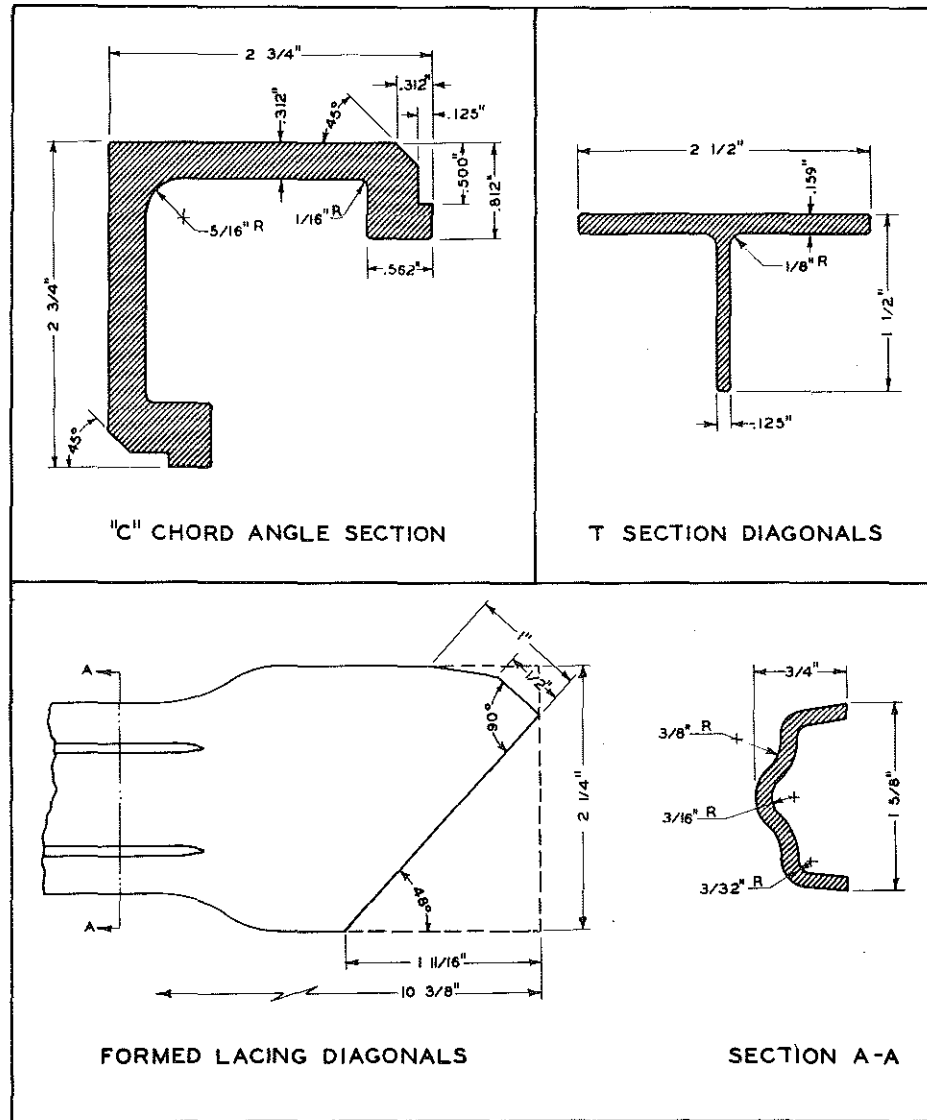


Figure 1. Typical cross-sections.

rectangular box truss 3 by 1 ft. The T-sections are used for the diagonal members on the 3-ft faces, and a specially pressed section designated as "formed lacing" is used for the diagonals for the 1-ft faces. Cross-sections of all these elements are shown in Fig. 1.

TEST PROGRAM

The location and position of 20 SR-4 Type A-1 strain gages on the structure are shown in Fig. 2. All strain gages mounted on the webs of the T-sections were centered 3/8-in. from the bottom of the web. All gages on the chord angles were mounted at the centers of the legs with the exception of Gages 19 and 20. These latter two gages were positioned 2-1/16-in. from the heel of each leg. Also, all gages mounted to the T-section and formed lacing diagonals were fixed at the midpoint of the individual member.

Since this structure is statically indeterminate, stresses occur due to temperature change. To attempt to measure load stresses only, the conclusions regarding strains in the various members are based on maximum loads and zero residual strains, thereby reducing the time interval for static loading, and minimizing subsequent temperature effects. This approach was used for the determination of deflections as well. In the August 18 testing, however, the fourth arm of the measuring bridge circuit was simply another strain gage sandwiched between two pieces of cardboard. This rather unstable condition led to some erratic and unreliable readings. In a meeting on August 8, the need for adequate temperature compensation and the use of unstrained aluminum "dummy gages" had both been emphasized. In the August 31 testing (Load Test 3) suitable compensating gages were used, and more consistent strain readings achieved.

Load Test 1, August 18

This test loading consisted of a 5,000-lb horizontal load applied symmetrically at the center of the span, plus a 625-lb weight applied vertically in the plane of one vertical truss. The horizontal loading was applied manually through cables attached to a dynamometer and suitable pulleys. Assuming a 52.5-ft span, simply supported at the knee braces, a horizontal load of 5,000 lb at the center of the truss will produce a center span moment equivalent to a horizontal wind pressure of 32.6 lb per sq ft, acting on a 26 by 7.5 ft sign placed at the center of the structure, and on the remaining exposed structural surfaces. The test setup and application of the 5,000-lb horizontal load are shown in Fig. 3.

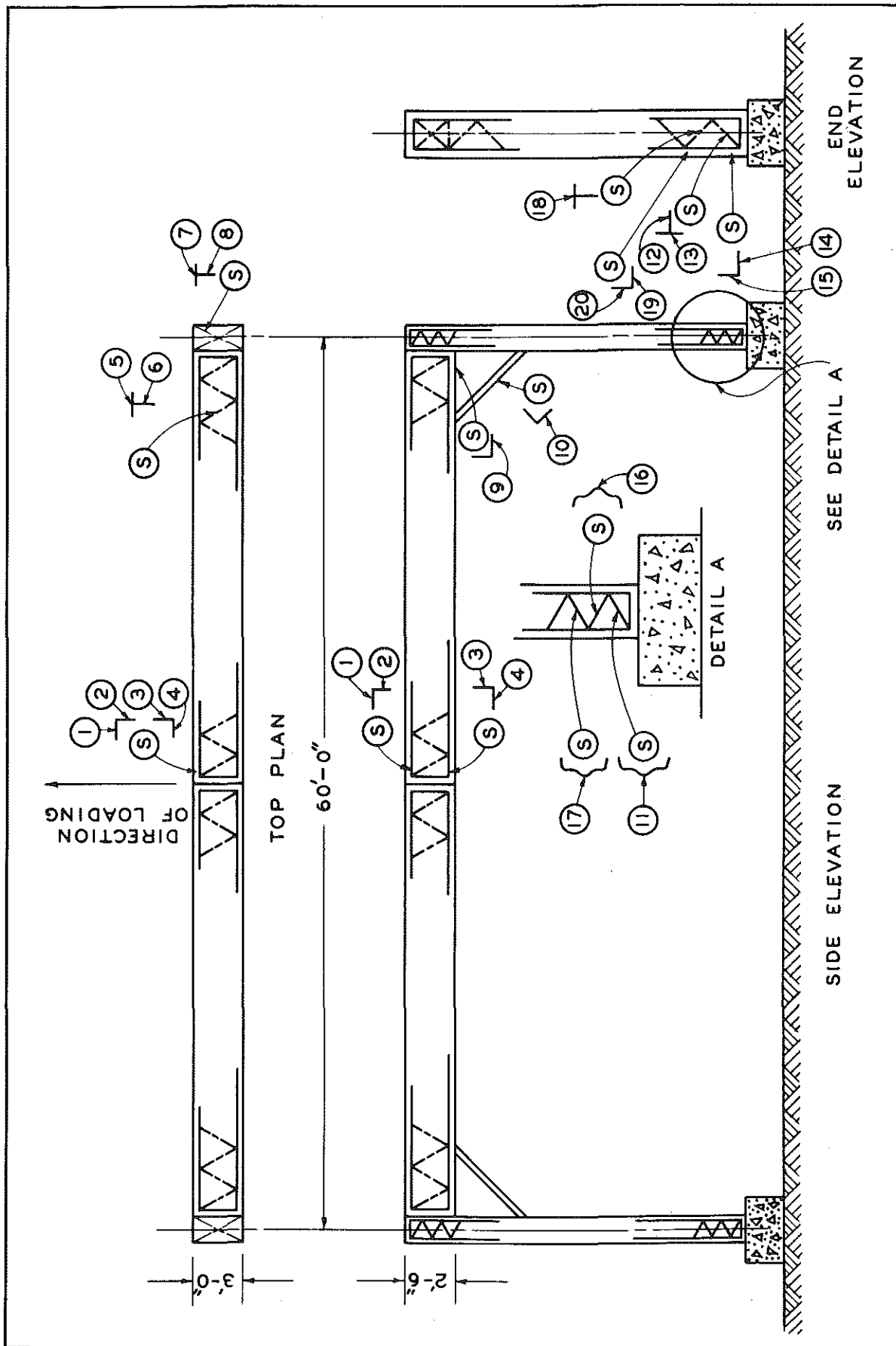


Figure 2. Locations of strain gages.

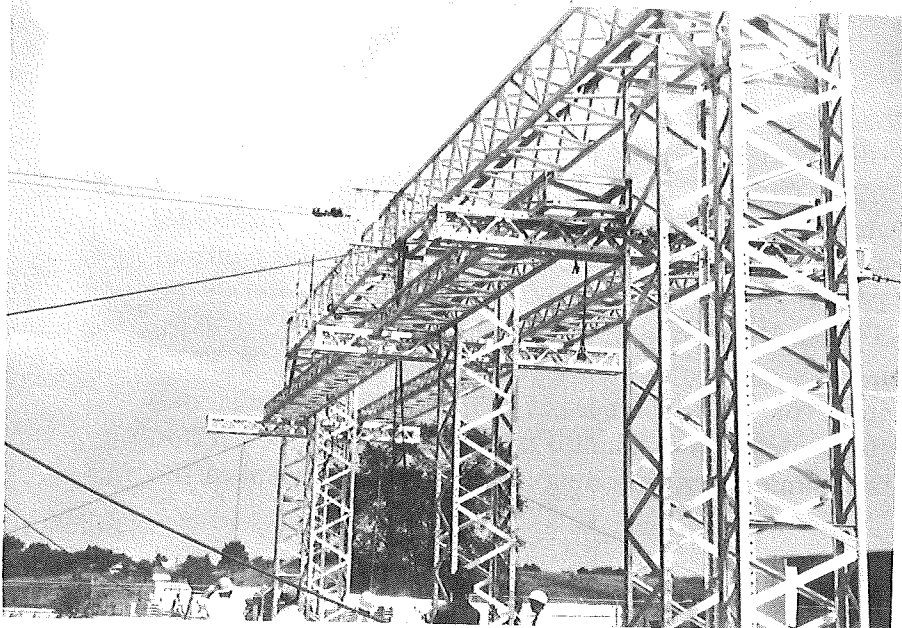
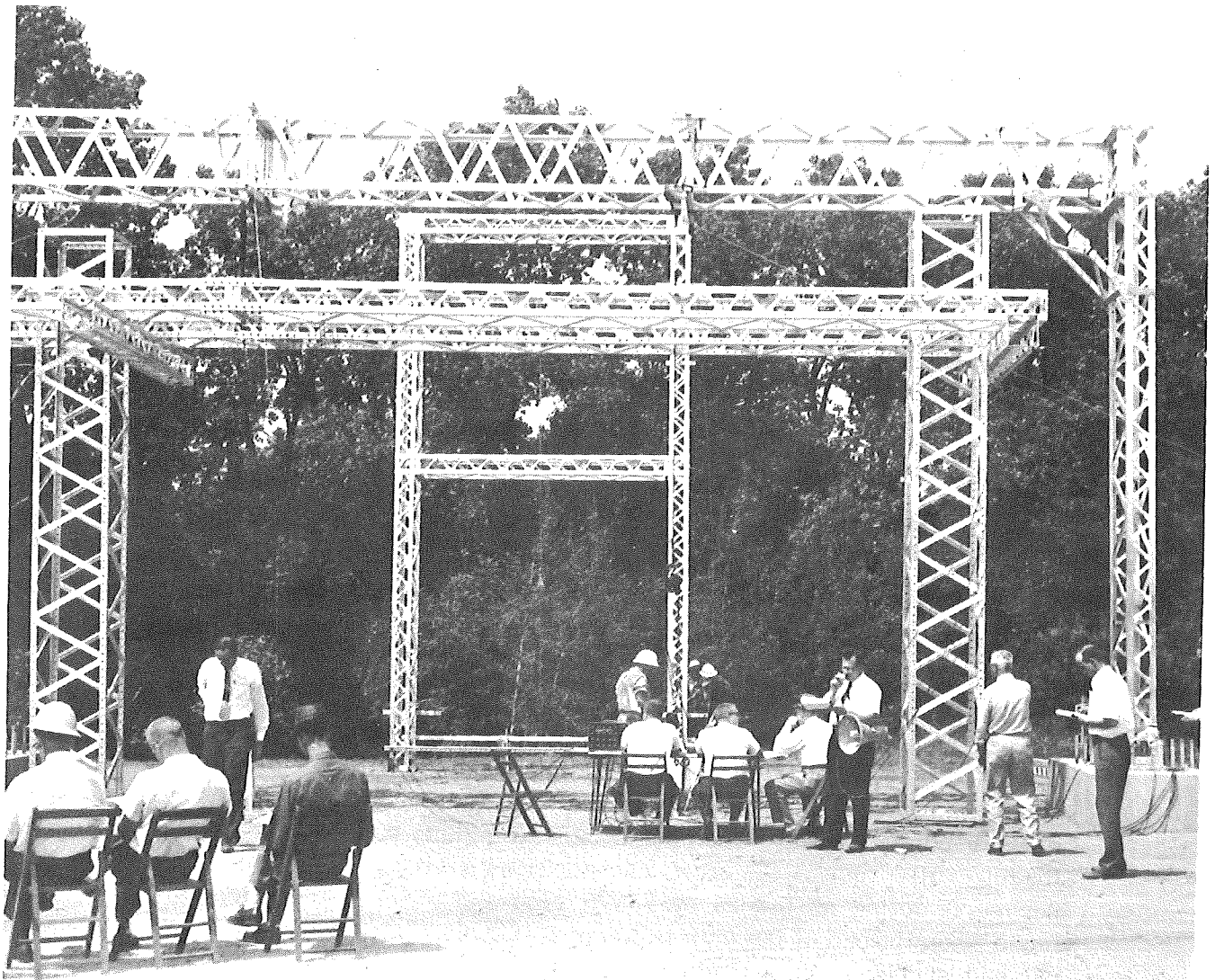


Figure 3. Quarter-point loading test in progress (left), with 5000-lb horizontal load being applied at midspan (bottom).

This loading produced stresses in the chord members at center span of about 8,500 psi. The total horizontal center deflection of the structure under this loading was 2-13/16-in. and the horizontal deflection of the horizontal truss unit alone was about 1-15/16-in. The natural frequency of vibration was found to be 6.5 cps.

The 5,000-lb loading was subsequently increased to 7,000 lb, representing a center span moment equivalent to that produced by a wind pressure of about 43.5 lb per sq ft acting on the centrally placed 26 by 7.5 ft sign, and 95.6 lb per sq ft on the exposed structural surfaces. This loading caused chord stresses of about 12,000 psi. The corresponding center deflection was 3-7/8-in. and the center deflection of the horizontal span unit alone was 2-3/4-in. The maximum center vertical deflection was measured at about 1/16-in. However, this deflection was measured on the vertical plane truss opposite from the one to which the vertical load was applied. Based on a percentage of the 5,000-lb horizontal deflection, the average center vertical deflection would be about 0.2 in.

Load Test 2, August 18

This test loading consisted of a 6,000-lb symmetrically applied horizontal load at the quarter-point of the span coupled with a 625-lb weight applied vertically in the plane of one side of the box truss, also at the quarter-point. Again, assuming a 52.5-ft simply supported span, this loading will produce the same end-shear as a wind pressure of 30.3 lb per sq ft acting on the 26 by 7.5 ft sign and exposed structural surfaces when the end of the sign is placed 5 ft from the center of the vertical end support. This loading simulates the maximum design shear in the horizontal truss diagonals and on the components of the vertical end support truss.

Unfortunately, the recorded strains in the cross diagonals (Gages 7 and 8) and bottom T-diagonal (Gages 12 and 13) of the vertical end support, and the knee brace chord angle (Gage 10) were inconsistent and unreliable. For example, under the 6,000-lb quarter-point horizontal loading, the measured strains in the bottom T-diagonal of the vertical end support (Gages 12 and 13) showed a tensile stress of 900 psi at the top of the flange and a tensile stress of about 800 psi at a point 3/8-in. from the bottom of the web. Since these diagonals are loaded eccentrically through the flange, the ratio of stress at the flange top to stress 3/8-in. from the bottom of the web should be about 6 to 1 if deflection is considered and it is assumed that this diagonal takes 50 percent of the

simply supported end shear for the 6,000-lb load applied at the quarter-point. Also, if the deflection of the member is neglected, the eccentrically applied tensile force at the flange of the T would produce a compressive stress at this point on the web. The recorded strain in the flange of the T-diagonal (Gage 5) for the 6,000-lb load at the quarter-point was not commensurate with the strains produced by the 5,000 and 7,000 lb loads at the half point. Based on a 52.5-ft simply supported span, and the stress values for these latter two loads, the stress caused by the 6,000-lb quarter-point load should have been about 6,000 instead of 4,600 psi.

The measured strains in the chord angle (Gages 14 and 15) vertical truss member near the base, and the lower diagonal formed lacing member (Gage 11) appeared to be consistent and indicated maximum stresses of 11,600 psi and 17,800 psi, respectively. It was also evident from the strain measurement on the chord angle, i. e., tensile stress in one leg and compressive stress in the other, that this member was subjected to bending due to the semi-fixed end span connection, and to torsion applied to the vertical column as a result of horizontal loading.

Load Test 3, August 31

This test was essentially the same as Load Test 2 with the application of the 6,000-lb horizontal load and 625-lb vertical load at the quarter-point. This test was prompted by the high stresses which occurred during Test 2 in the bottom formed diagonal lacing member of the vertical end support (Gage 11). Additional strain gages were mounted on the second and third formed lacing diagonals from the base (Gages 16 and 17), on the flange of the second T-diagonal from the base (Gage 18), and on both legs of the chord angle (Gages 19 and 20) 2-1/16-in. from the heel 2 ft above the gage positions used in the previous test (Gages 14 and 15).

The first phase of this test consisted of applying the 6,000-lb horizontal load and resulted in stresses of 11,800 psi (Gage 16) and 4,000 psi (Gage 17) in the formed lacing members, 3,500 psi in the flange of the T-diagonal (Gage 18), and 7,500 psi in one leg of the chord angle (Gage 20).

The second phase of the test involved the same loading condition, but with the addition of 0.5-in. thick stay plates bolted to the short faces of the column near the base (Fig. 4). This loading condition produced a decrease in stress in the second formed lacing diagonal (Gage 16) of about 50 percent from 11,800 to 6,000 psi, and a slight increase in the stress (3,900 to 4,400 psi) in the third formed lacing diagonal

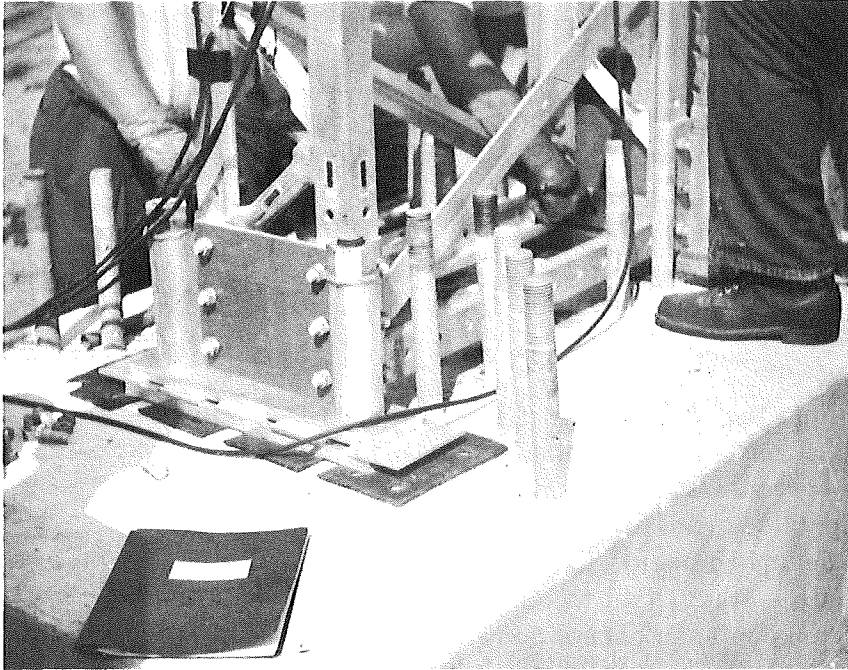
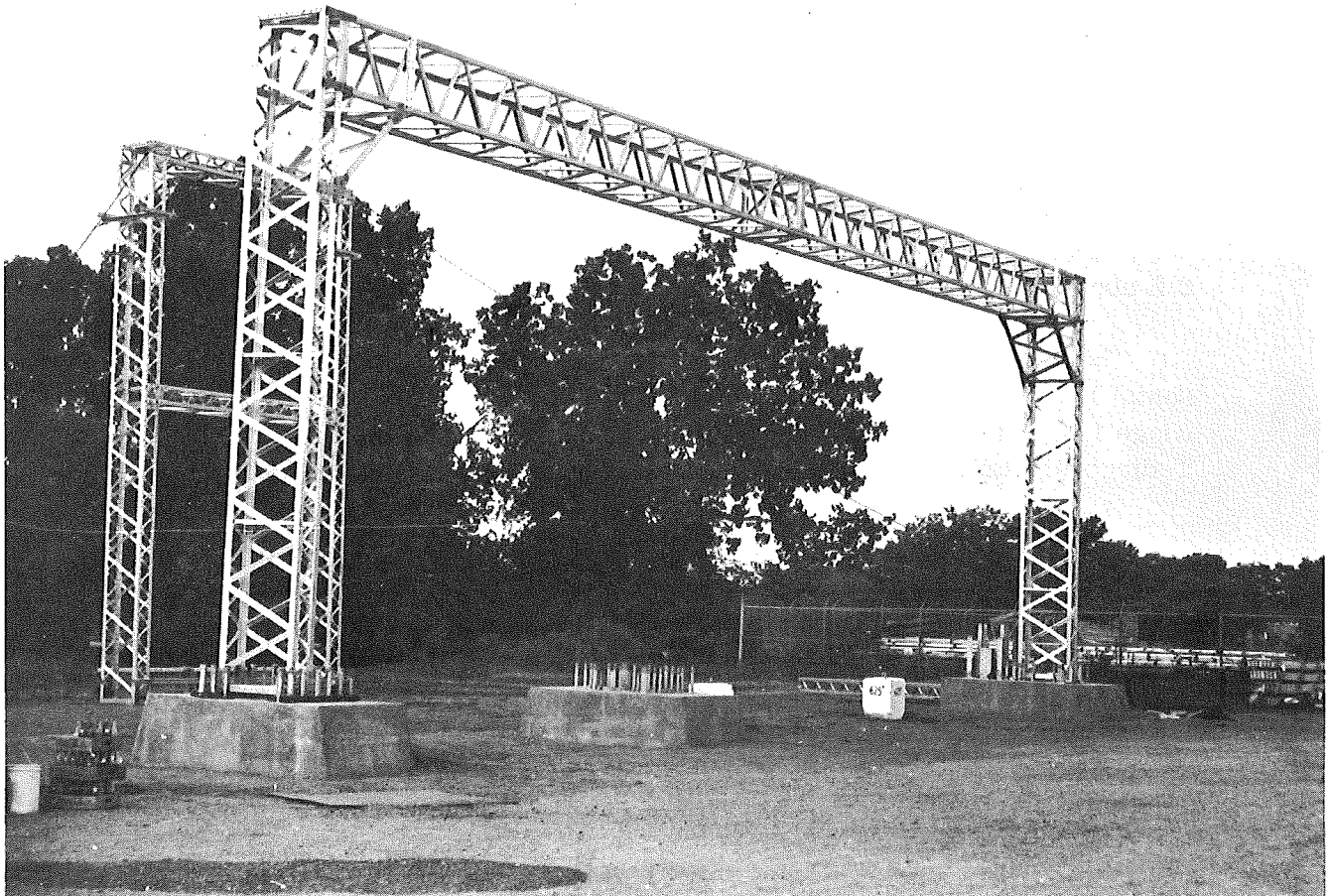


Figure 4 (left). Bolting 0.5-in. thick stay plates to column.

Figure 5 (below). Appearance of structure after completion of tests.



(Gage 17). The strains in the remaining members were essentially the same as before adding the stay plate. The horizontal load was subsequently increased to 7,000 and to 7,200 lb representing equivalent wind loads of about 35.4 and 36.4 lb per sq ft on the sign and 78 and 80 lb per sq ft on the exposed structural surface, respectively. The 7,200-lb loading produced stresses of about 9,000 psi in the chord angle (Gage 20), 7,000 psi in the formed lacing diagonal (Gage 16), and 4,000 psi in the flange of the T-diagonal (Gage 18).

On the basis of these last tests, it was concluded that addition of the 0.5-in. thick stay plates was effective in reducing the formed lacing diagonal stresses by about 50 percent, but would have little effect on the stresses in the chord angles (Gages 4 and 5) and T-diagonal (Gage 3). Further, it would be expected that the 17,800-psi stress in the bottom formed lacing diagonal would be reduced to at least 9,000 psi as a result of adding the stay plates. Some reduction in stress in the chord angle of the vertical end support near the base (Gage 14) would also be expected as a result of the additional rigidity provided by the stay plate at this location on the chord.

On both test dates, with the maximum horizontal applied loads of 7,000 lb at the center and 7,200 lb at the quarter-point, inspection of the structure revealed no visible weld cracks, or excessive or permanent deformation of any members or components. The structure is shown in Fig. 5 after the tests were completed.

SUMMARY OF TEST RESULTS

The results of the experimental load tests permit certain conclusions concerning the structure's strength and stiffness, in terms of the AASHTO and MSHD specifications. These conclusions concern only those structural members that were instrumented, and do not involve the structural adequacy of connections, bases, or footings. The strength results are discussed successively for the chord angles and T-diagonals of the horizontal span, and the chord angles, T-diagonals, and formed lacing diagonals of the vertical end supports. The discussion indicates, depending on the criteria used, whether the successive elements met or failed to meet the respective requirements.

Stiffness

Stiffness	Horizontal Wind Load Deflection, in.	Vertical Dead Load Deflection, in.	Natural Frequency of Vibration, cps	Camber at Center, in.
Measured	2.09*	0.45*	6.5	None
MSHD Requirement	2.06 max.	0.60 max.	4 min.	None
AASHTO Requirement	None	0.48 max.**	None	1.17

* Horizontal wind load deflection of structure based on MSHD loading criteria and an equivalent concentrated load at midspan of 5400 lb, representing the center deflection of the horizontal span unit only. The vertical dead load deflection of structure is based on an equivalent midspan concentrated load of 510 lb and a computed center deflection due to dead load of structure only, assuming a 60-ft simply supported span.

** Based on minimum depth of sign of 4 ft.

It appears that the structure essentially meets the stiffness requirements of either the MSHD or AASHTO requirements with the exception of the AASHTO provision for camber.

Strength--Horizontal Span Unit

1. Chord Angles (assuming angles are loaded concentrically)

Strength	MSHD Loading, stress psi (a)	80 mph, AASHO Loading stress psi (b)	90 mph, AASHO Loading stress psi (c)
Measured*	8,300	10,000	12,800
Allowable	10,700 tension	11,600 or 14,500 tension**	11,600 or 14,500 tension
Allowable	10,700 compression	11,600 or 14,500 compression	11,600 or 14,500 compression

* Based on extrapolation of maximum recorded chord stress of 8,500 psi under 5,000-lb concentrated center load.

** 11,600 psi based on ASCE Paper 970; 14,500 psi based on AASHO Specifications, if applicable.

(a) Based on equivalent concentrated horizontal load of 4,600 lb and vertical load of 625 lb at midspan, plus structure deadload chord stress of 490 psi.

(b) Based on equivalent concentrated horizontal load of 5,630 lb, and vertical load of 625 lb at midspan, plus structure deadload chord stress of 490 psi.

(c) Based on equivalent concentrated horizontal load of 7,240 lb, and vertical load of 625 lb at midspan, plus structure deadload chord stress of 490 psi.

It appears that the chord angle section meets the strength requirements corresponding to the MSHD criteria and the AASHO 80-mph loading specifications. The section would or would not meet the AASHO 90-mph loading specifications depending on the applicability of AASHO Table 1.

2. T-Diagonals

a. MSHD Criteria. Based on extrapolation of measured values and considering an equivalent concentrated 6,000-lb horizontal load and a 625-lb vertical load at the quarter-point, the maximum tensile stress in the flange of the T would be about 6,000 psi, considerably less than the allowable value of 10,700 psi. Based on the allowable compressive stress interaction formula for members subjected to bending as well as

direct compressive stress, the allowable compressive stress would be about 3,000 psi or about half the actual stress:

$$\text{Allowable compressive stress, } f_b = 10,700 \left[1 - \frac{P/A}{10,700} \right]^2 \quad (1)$$

Thus, the T-diagonals would be overstressed and would not meet requirements.

b. AASHO (80-mph loading). Based on extrapolation of measured values and considering an equivalent concentrated horizontal load of 7,000 lb and a vertical load of 625 lb at the quarter-point, the maximum tensile stress would be about 7,000 psi, or less than the allowable values of either 11,600 or 14,500 psi. Based on the allowable compressive stress interaction formula,

$$\frac{f_a}{8800} + \frac{f_b}{9560} \leq 1 \quad (2)$$

and a maximum diagonal compressive force of 3,100 lb, this member would meet requirements if the allowable stress criteria apply as listed in AASHO Table 1 for Alloy 6061-T6.

Based on an effective 1/4-in. fillet weld length of 2.5 in., the corresponding allowable tensile load on the eccentrically loaded weld would meet the allowable shearing stress requirement if the values apply as listed in AASHO Table 1 for 4043 weld filler. If they do not, the allowable fillet weld stress value of 5,800 psi would govern, the welds would be overstressed by about 20 percent, and consequently would not meet the requirements.

c. AASHO (90-mph loading). Based on extrapolation of measured values and considering an equivalent concentrated horizontal load of 9,000 lb and the vertical load of 625 lb at the quarter-point, maximum tensile stress would be about 9,000 psi, less than the allowable values of either 11,600 or 14,500 psi. The maximum compressive stress, however, would exceed the allowable compressive stress as given in Equation 1 above. Based on an effective 1/4-in. fillet weld length of 2.5 in., the corresponding eccentrically applied tensile load of 4,000 lb would cause an overstress of about 24 percent in the weld, assuming the values in AASHO Table 1 for 4043 weld filler apply.

Strength--Vertical End Support Unit

1. Chord Angles

a. MSHD Criteria. Based on the equivalent 6,000-lb horizontal load and the 625-lb vertical load at the quarter-point, and considering the stay plates as effectively reducing the 11,600-psi chord stress of Load Test 1, it appears that the member essentially would meet the allowable 10,700-psi tensile or compressive stress requirement.

b. AASHO (80-mph loading). Based on an equivalent 7,000-lb horizontal load and the 625-lb vertical load at the quarter point, plus a 20-percent transverse load amounting to about 93 lb per ft uniformly distributed to each vertical end support, one gets a computed stress of about 7,000 psi due to the transverse loading plus the measured stress of 8,900 psi from Gage 20 (Load Test 3), or 15,900, which is greater than either the 11,600 or 14,500 psi allowable. This member would not meet specification requirements.

2. T-Diagonals

a. MSHD Criteria. The recorded 3,500-psi compressive stress in the flange of the T-section when subjected to the equivalent 6,000-lb horizontal load and the 625-lb vertical load at the quarter point, is about 17 percent greater than the allowable compressive stress as determined by use of the interaction formula in Equation 1 above. This member would not meet specification requirements.

b. AASHO (80-mph loading). The equivalent 7,000-lb horizontal load and the 625-lb vertical load at the quarter-point caused a compressive stress of about 4,000 psi in the flange of the T (Gage 18). This is less than either the allowable compressive stress due to combined loading, or the allowable tensile stress of either 11,600 or 14,500 psi. The corresponding tensile load on the eccentrically loaded fillet weld, again considering an effective 1/4-in. fillet weld length of 2.5 in., would meet the allowable shearing stress requirement of 5,800 psi.

c. AASHO (90-mph loading). Based on the 4,000 psi flange compressive stress cited earlier in discussing Load Test 3, and the equivalent concentrated horizontal load of 9,000 lb and the vertical load of 625 lb at the quarter-point, the compressive stress in the flange would be about 6,500 psi, which is less than the allowable compressive stress due to combined loading or the allowable tensile stress of 11,600 or

14,500 psi. The corresponding tensile load on the eccentrically loaded 2.5-in. length fillet weld would meet the allowable shearing stress requirement of 5,800 psi.

3. Formed Lacing Diagonals

a. MSHD Criteria. Assuming this member is concentrically loaded, and based on the measured strains with the 0.5-in. stay plate in place, when subjected to the equivalent 6,000-lb horizontal load and the 625-lb vertical load at the quarter-point, the resulting stress of about 9,000 psi would be less than the allowable tensile or compressive stress of 10,700 psi. Based on an effective 1/4-in. fillet weld length of 2.5 in. and the corresponding tensile load of about 3,100 lb, the weld would be overstressed by about 31 percent and thus this member would not meet the specification requirements.

b. AASHO (80-mph loading). Again, assuming this member is concentrically loaded, and including the 0.5-in. stay plates, when subjected to the equivalent 7,000-lb horizontal and the 625-lb vertical load at the quarter point, the resulting stress would be about 10,500 psi. In addition, assuming the formed lacing member takes half the shear, the stress caused by the 20-percent transverse load of 93 lb per ft would be about 4,400 psi. The total stress of 14,900 psi would essentially meet the allowable tensile or compressive stress of 14,500 psi. Based on an effective 1/4-in. fillet weld length of 2.5 in. and the corresponding tensile load of 5,150 lb, the weld would be overstressed by about 37 percent, if the values listed in AASHO Table 1 for 4043 weld filler apply. This member then would not meet specification requirements.

c. AASHO (90-mph loading). Based on the same assumptions as in the last paragraph above, and considering the equivalent 9,000-lb horizontal load and the 625-lb vertical load at the quarter point, and the corresponding 20-percent transverse load, this member would not meet the specification requirements.