R-244

266

MICHIGAN
STATE HIGHWAY DEPARTMENT
Charles M. Ziegler
State Highway Commissioner

THE STRUCTURAL CHARACTERISTICS OF TWO OVERHEAD SIGN SUPPORTS

(A 100 Foot Steel Tubular Beam and a 100 Foot Aluminum Truss)

by
G. R. Cudney - L. T. Oehler

Highway Research Project 54 G-73

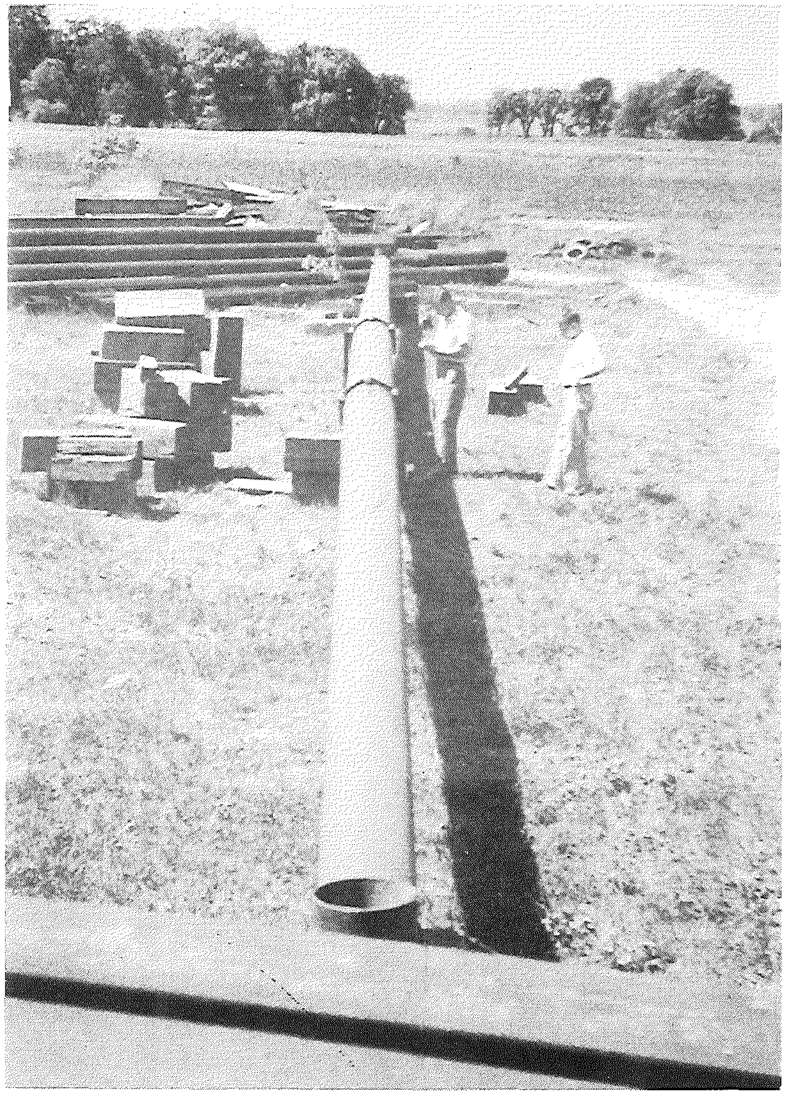
Research Laboratory
Testing and Research Division
Report No. 244
December 15, 1955

THE STRUCTURAL CHARACTERISTICS OF TWO OVERHEAD SIGN SUPPORTS

On February 11, 1955, at the request of M. Hoffman of the Planning & Traffic Division, the Research Laboratory started a comparative structural analysis of steel and aluminum bents used for supporting overhead traffic signs. The steel bent is composed of a steel beam in the form of two round tapered end sections bolted together through extended flanges, which are welded to the section, and pin connected at the ends to vertical round tapered steel poles. For longer spans, a uniform diameter center section is added, and bolted to the end sections in a similar manner. The aluminum bent consists of an aluminum beam in the form of two equilateral triangular space frame trusses bolted together through extended flanges, which are welded to the three main longitudinal members, and rather ridgidly fastened at the ends to round vertical aluminum poles.

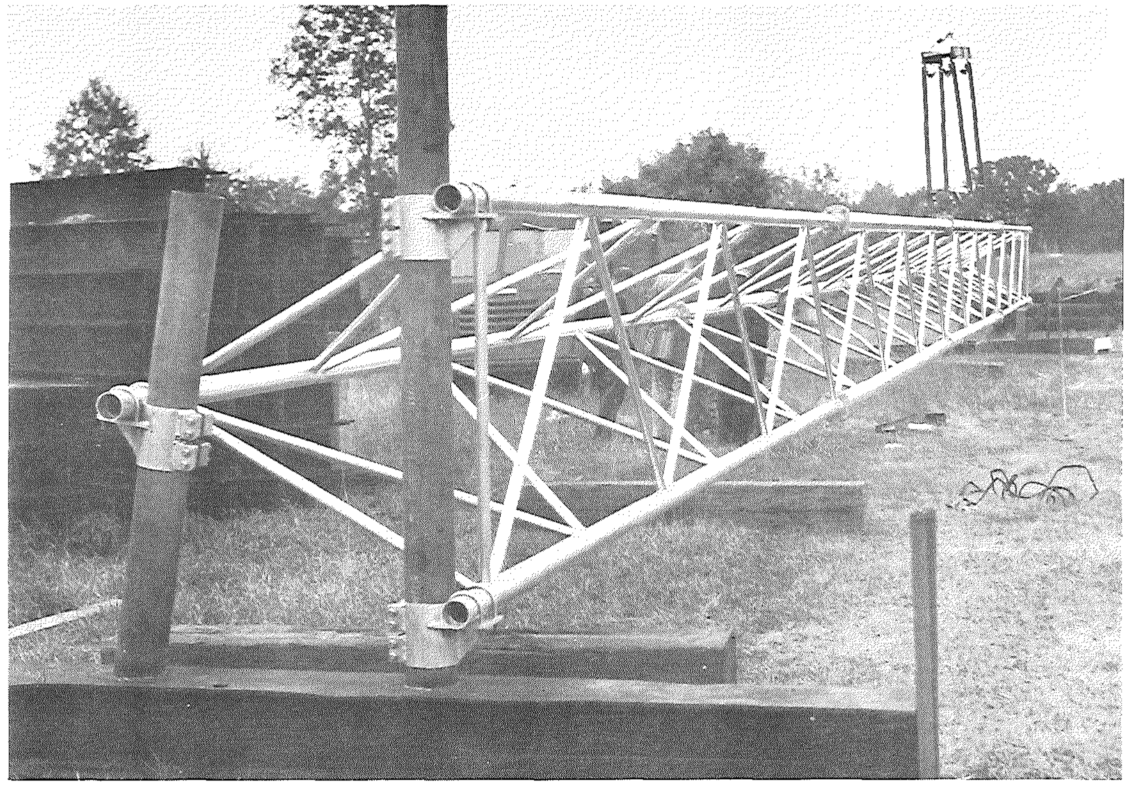
On May 19, and on September 26, 1955, the Research Laboratory was asked to cooperate with the Planning and Traffic, and Maintenance Divisions in the field testing of a 100 foot steel beam manufactured by the Union Metal Manufacturing Company, and a 100 foot aluminum truss manufactured by Pfaff and Kendall. A photograph of each of the two beams is shown in Figure 1.

The steel beam was composed of two round end sections, (yield point stress 48000 psi) each 40 feet long, with a uniform taper from 10.46 inches to 16.06 inches in diameter, and a round center section (yield point stress 25000 psi) 20 feet long with a uniform diameter of 16.06 inches. The wall thickness was approximately 3/16 inches (7 gage) for the end sections and approximately 5/16 inches (0 gage) for the center



A. STEEL BEAM

THIS VIEW ALSO SHOWS THE INITIAL HORIZONTAL CROOKEDNESS OF THE FAR END SECTION.



B. ALUMINUM TRUSS

FIGURE 1
GENERAL VIEW OF EACH TYPE OF STRUCTURE

section. Each end section was connected to the center section by six 1-1/4 inch diameter high strength steel bolts fastened through the extended flanges on the connecting members. The end sections were pin connected to short vertical posts during the test, employing the same type of end connection that would be used under actual conditions.

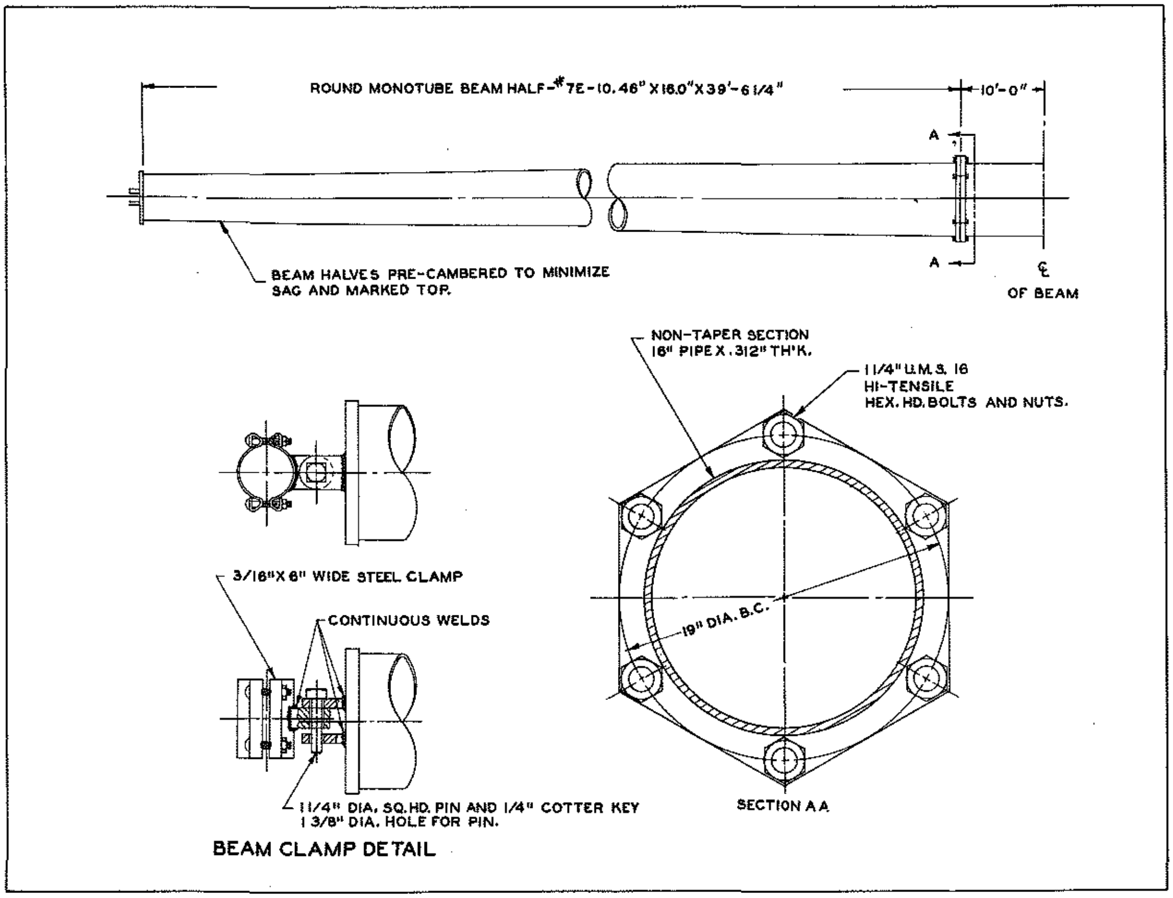
The aluminum beam consisted of four equilateral triangular space frame truss sections each 25 feet long, fabricated from Aluminum Alloy 6061-T6 (yield point stress 35000 psi). Each side of the triangle measured 4 feet 0 inches center to center of the main longitudinal members. The main longitudinal members for the two end sections were 3-1/2 inches in diameter, and the diameter of the main longitudinal members for the two center sections was 5 inches. All of the diagonal bracing members were 1-1/2 inches in diameter. The wall thickness for all members was 0.188 inches. Each section was connected to the adjacent section with five 3/4 inch diameter stainless steel bolts fastened through the extended flange on each of the three main longitudinal members. All of the diagonal bracing members were welded to the main longitudinal members. The end sections were rather rigidly fastened to three short vertical posts during the test, using the same type of end connection that would be employed under actual conditions.

A drawing of each of the two beams is shown in Figure 2.

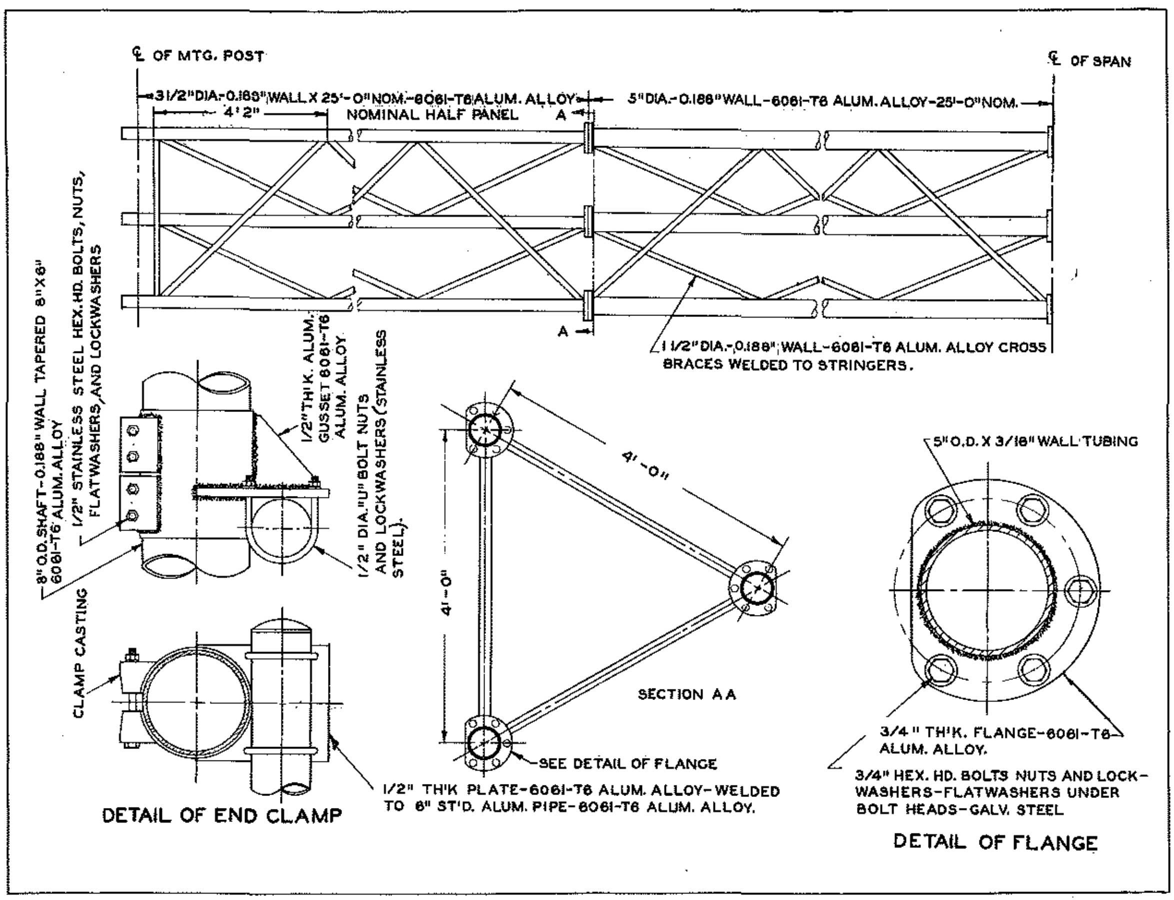
TEST INSTRUMENTATION AND PROCEDURE

(A) Steel Beam

Type A-1, SR-4 electrical strain gages were bonded to the center of the beam at the lower extreme fiber and also at the top and bottom extreme fibers at the large end of one end section, 7-3/4 inches from the bolted connection. Deflections at the center of



A. DETAILS OF STEEL BEAM SECTIONS



B. DETAILS OF ALUMINUM TRUSS SECTIONS

FIGURE 2

the beam span were obtained by means of a transit sighted on a 1/32 inch division scale affixed to the beam. The transit was also used in obtaining the dead load center deflection. The beam was loaded in a vertical plane with 50 and 1000 pound weights up to a maximum of 2000 pounds in the following manner:

1. 0 to 600 pounds in 100 pound increments

2. 0 to 600 pounds in 100 pound increments

3. 0 to 1000 pounds in a 1000 pound increment
   1000 to 1600 pounds in 100 pound increments

4. 0 to 2000 pounds in a 2000 pound increment

5. 0 to 2000 pounds in a 2000 pound increment

6. 0 to 2000 pounds in a 2000 pound increment

(B) Aluminum Truss

Type A-1, SR-4 electrical strain gages were bonded to the three main longitudinal members at a distance of 2 feet 8 inches from the center of the truss. One gage was placed on the bottom surface of the top member, another on the top surface of the lower member, and the third on the outside surface of the rear member. Deflections at the center of the beam were obtained by means of a 0.001 inch dial indicator and a 1/64 inch division scale attached to a reference stake. A 0.001 inch dial indicator was affixed to the lower longitudinal member at each end of the truss in order to obtain any end support movement. The dead load center deflection was obtained by means of a transit. The truss was loaded in a vertical plane with 50 and 1000 pound weights up to a maximum of 3000 pounds in the following manner:

1. 0 to 700 pounds in 100 pound increments

2. 0 to 1000 pounds in a 1000 pound increment

3. 0 to 1000 pounds in a 1000 pound increment
   1000 to 1600 pounds in 100 pound increments

4. 0 to 2000 pounds in a 2000 pound increment

5. 0 to 2000 pounds in a 2000 pound increment

6. 0 to 2000 pounds in a 2000 pound increment

7. 0 to 3000 pounds in a 3000 pound increment

The truss was also loaded in a horizontal plane by means of a frame and pulley arrangement up to a maximum of 2000 pounds in the following manner:

1. 0 to 1000 pounds in a 1000 pound increment

2. 0 to 1000 pounds in a 1000 pound increment

3. 0 to 2000 pounds in a 2000 pound increment

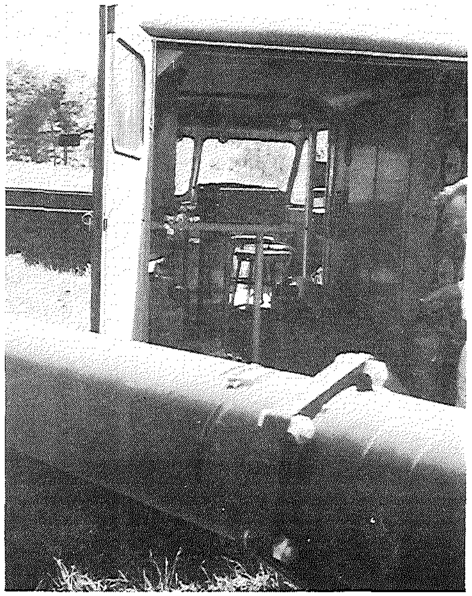
Load deflections, residual deflections and load strains were obtained for each increment of loading. The live load strains were measured with a Baldwin SR-4 strain meter. Each of the two beams was oscillated through a number of cycles of forced vibration, and allowed to vibrate freely, in order to determine the natural frequency of vibration, and the dampening characteristics. A trace showing the frequency, amplitude, and dampening effect of the vibrations was obtained by means of a Brush Recording Oscillograph.

The 50 and 1000 pound weights used in loading the beams were from the Testing and Research Division Scale Checking Truck.

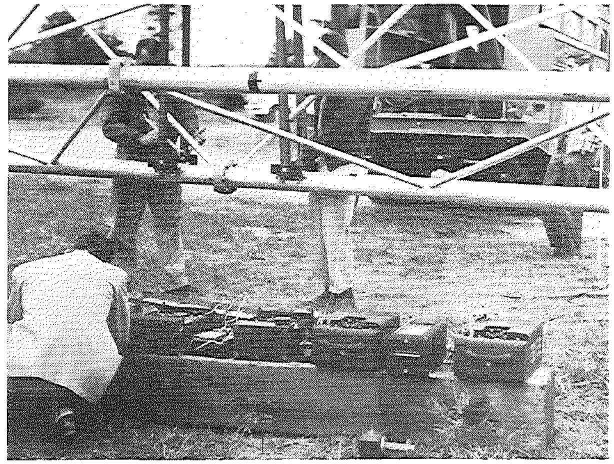
Photographs of the test instrumentation are shown in Figure 3, and photographs of each of the beams loaded with the weights at the center of the span are depicted in Figure 4.

TEST RESULTS

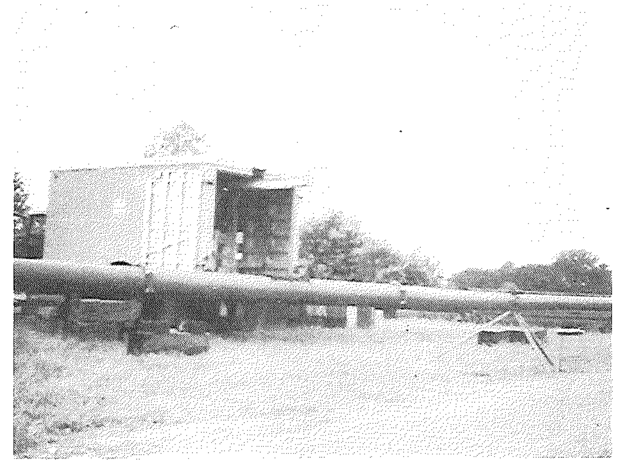
The dead load vertical center deflection was 5.1 inches for the steel beam and 0.45 inches for the aluminum truss. The average live load vertical center deflection



A. STEEL BEAM. VIEW SHOWING POSITION OF STRAIN GAGES ON STEEL BEAM, AND STRAIN MEASURING EQUIPMENT USED FOR OBTAINING STRESSES AND NATURAL FREQUENCY OF VIBRATION.

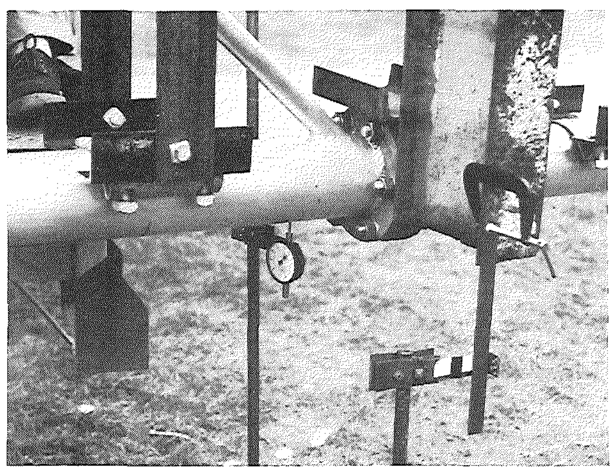


B. ALUMINUM TRUSS. VIEW SHOWING POSITION OF STRAIN GAGES ON ALUMINUM TRUSS, AND STRAIN MEASURING EQUIPMENT USED FOR OBTAINING STRESSES AND NATURAL FREQUENCY OF VIBRATION.

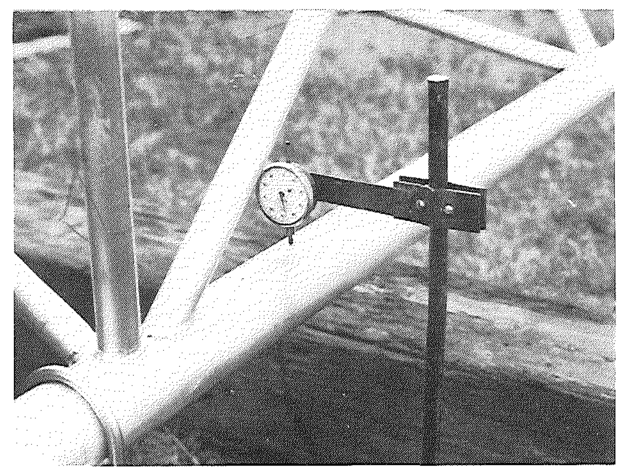


C. STEEL BEAM. VIEW SHOWING TRANSIT USED IN SIGHTING SCALE ATTACHED TO THE BEAM FOR OBTAINING CENTER DEFLECTIONS.

FIGURE 3. INSTRUMENTATION FOR TEST SET UP.



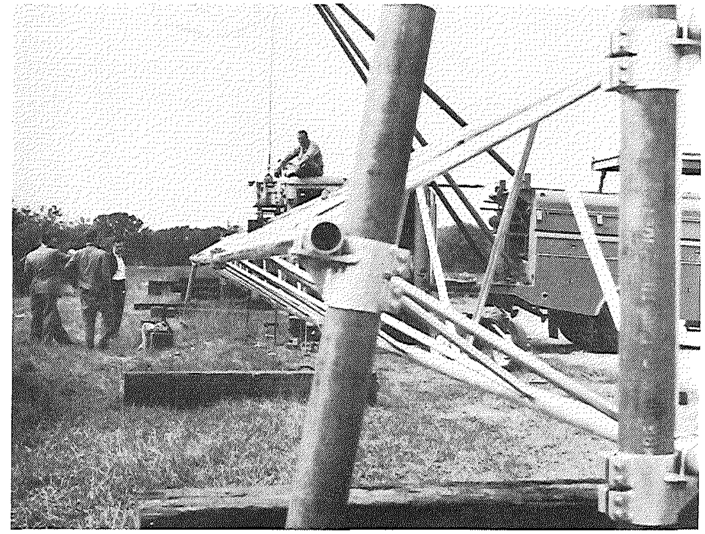
D. ALUMINUM TRUSS. VIEW SHOWING SCALE AND 0.001 INCH DIAL INDICATOR ATTACHED TO THE TRUSS FOR OBTAINING CENTER DEFLECTIONS.



E. ALUMINUM TRUSS. VIEW SHOWING A 0.001 INCH DIAL INDICATOR ATTACHED TO THE TRUSS FOR OBTAINING THE MOVEMENT OF THE END SUPPORTS.

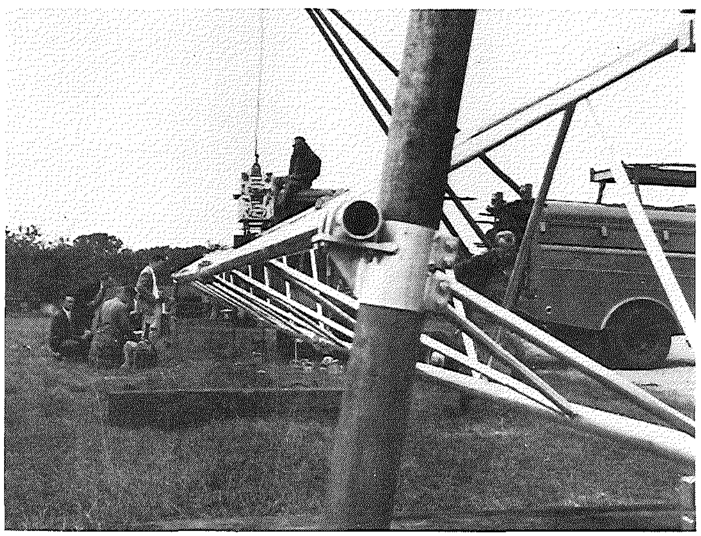
A. STEEL BEAM

STEEL BEAM LOADED WITH 1600 POUNDS AT CENTER SPAN.



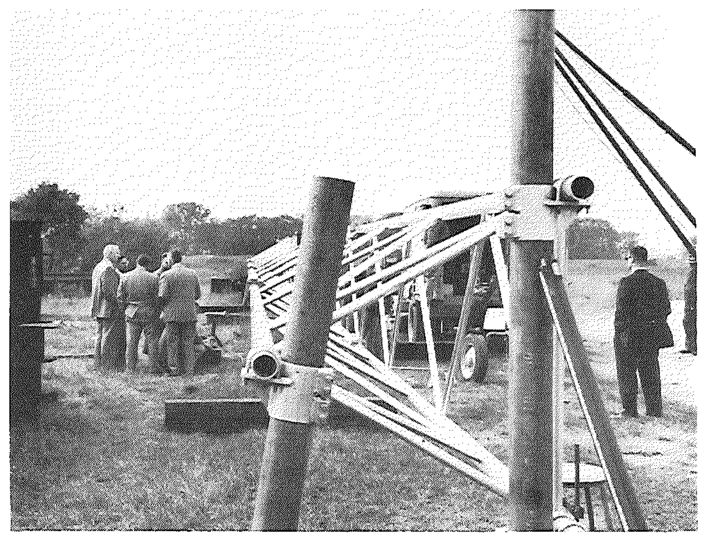
B. ALUMINUM TRUSS

ALUMINUM TRUSS LOADED WITH 2000 POUNDS AT CENTER SPAN.



C. ALUMINUM TRUSS

ALUMINUM TRUSS LOADED WITH 3000 POUNDS AT CENTER SPAN.



D. ALUMINUM TRUSS

ALUMINUM TRUSS LOADED HORIZONTALLY WITH 2000 POUNDS AT CENTER SPAN.

FIGURE 4 STRUCTURES LOADED WITH WEIGHTS AT CENTER SPAN for the steel beam was 0.43 inches per 100 pounds of applied center load while the corresponding value for the aluminum truss was 0.083 inches per 100 pounds. Thus, the aluminum truss had approximately one-fifth of the deflection of the steel beam for a given load. The average live load horizontal deflection for the aluminum truss was 0.10 inches per 100 pounds of horizontally applied load. This test was not run on the steel beam since the stiffness of the steel beam should be the same in the horizontal and vertical planes because of its circular cross-section. Load deflection curves for each of the two beams are shown in Figure 5.

After each cycle of loading, the amount of vertical center set, or the difference between the initial and final zero reading, for each cycle of vertical loading, was recorded. The total accumulated center set for the six cycles of loading for the steel beam was 1.6 inches, while the total accumulated center set for the seven cycles of loading for the aluminum truss was 0.49 inches. This accumulated set for each of the two beams is not what is technically referred to as permanent set, wherein the yield point stress of the material has been exceeded. This set was probably caused by the play in the connecting flanges, and in the end connections. A graphic presentation of the accumulated set after each successive cycle of loading is shown in Figure 6.

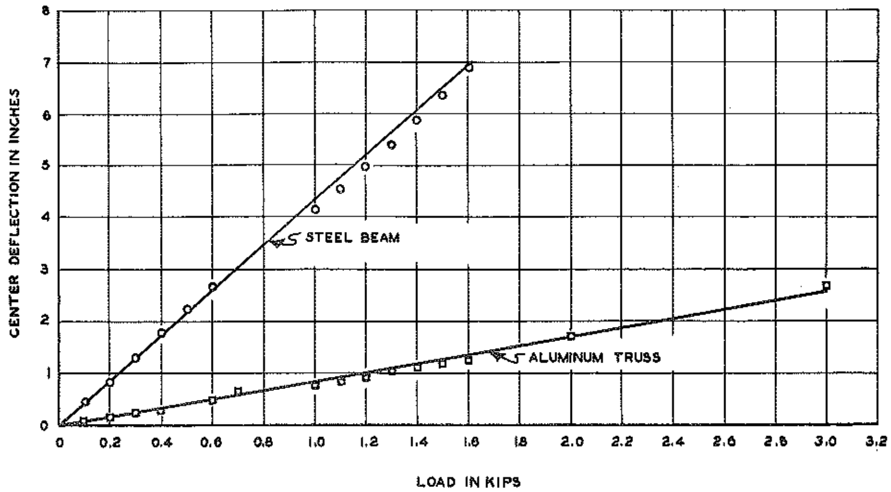
The computed dead load stress for the steel beam was 9,260 p.s.i. at the center of the beam, and 14,230 p.s.i. at the large end of the tapered section. The average live load stress for the steel beam was 487 p.s.i. per 100 pounds of applied vertical center loading, at the center of the beam, and 726 p.s.i. per 100 pounds of applied vertical center loading at a point on the tapered end section, 7-3/4 inches from the flange connection. Since the yield point strength of the material of the center section is 25,000 as compared to 48,000 p.s.i. for the end sections, the stress at the center section is the critical stress. From this data it can be computed that the yield point stress would be reached with a superimposed center load of 3,240 pounds in the vertical direction or 5,130 pounds in the horizontal direction.

The computed dead load stress at the extreme fiber for the aluminum truss at the center of the span was 1095 p.s.i. The average live load stress for the aluminum truss at a point on the top surface of the lower longitudinal member, 2 feet 8 inches from the center of the span was 133 p.s.i. per 100 pounds of applied vertical load, and 97.5 p.s.i. per 100 pounds of applied horizontal center loading. Accordingly, the maximum stress in the lower longitudinal member at the center of the truss would be approximately 173 p.s.i. per 100 pounds of applied vertical center loading. The maximum stress in the rear longitudinal member at the center of the truss would be approximately 224 p.s.i. per 100 pounds of applied horizontal center loading. From this data it may be computed that the yield point stress of the main longitudinal members of the truss would be reached with an applied vertical center load of 19,600 pounds, or by an applied horizontal center load of 15,600 pounds. Load-stress curves for each of the two beams are shown in Figure 7.

The natural damped frequency of vibration was 1.00 cycles per second for the steel beam and 3.57 cycles per second for the aluminum truss. It took 25 seconds for the steel beam to reach an amplitude of vibration equal to one-half that of the initial amplitude, and 1 minute and 37 seconds to reach an amplitude one-tenth that of the initial amplitude. The aluminum truss took 19.6 seconds to reach an amplitude equal to one-half that of the initial amplitude, and 48 seconds to reach an amplitude one-tenth that of the initial amplitude. A typical vibration trace for each beam is shown in Figure 8.

FIGURE 5

LOAD DEFLECTION CURVES



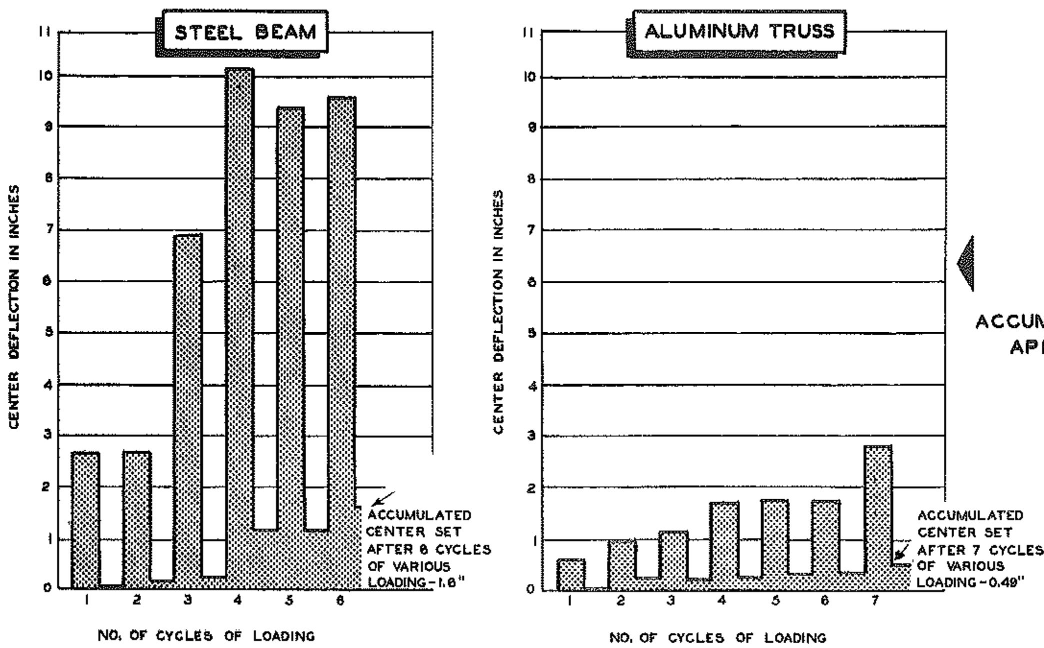
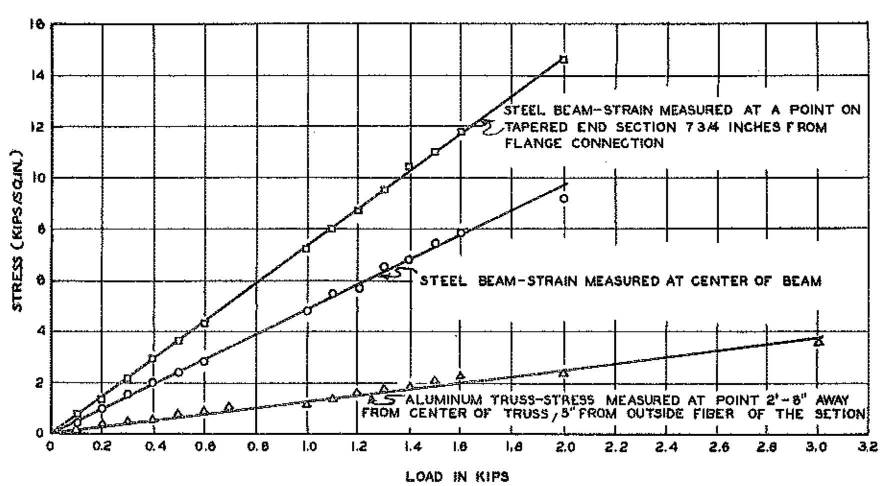


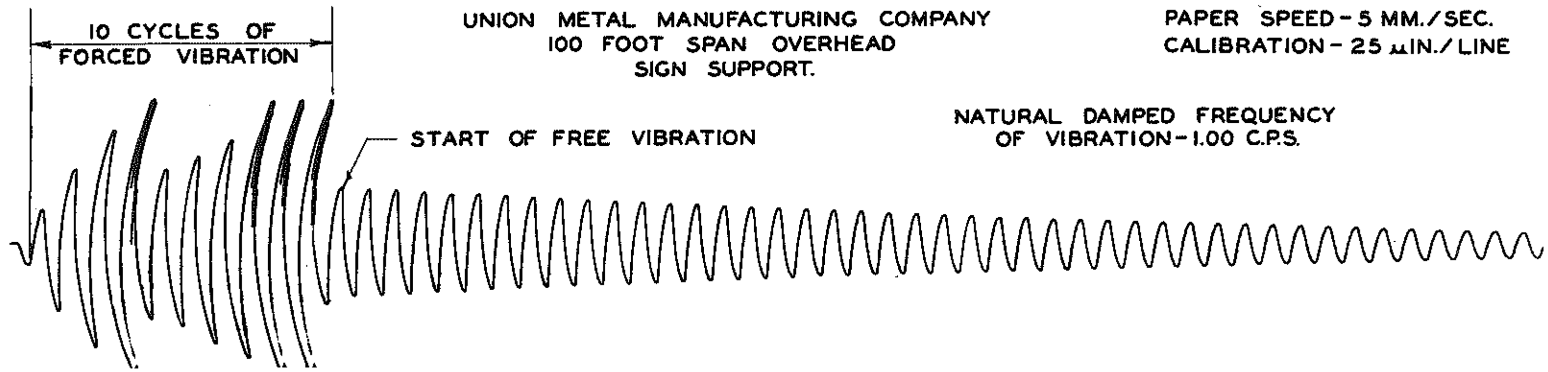
FIGURE 6

ACCUMULATED CENTER SET AFTER APPLIED CYCLES OF LOADING

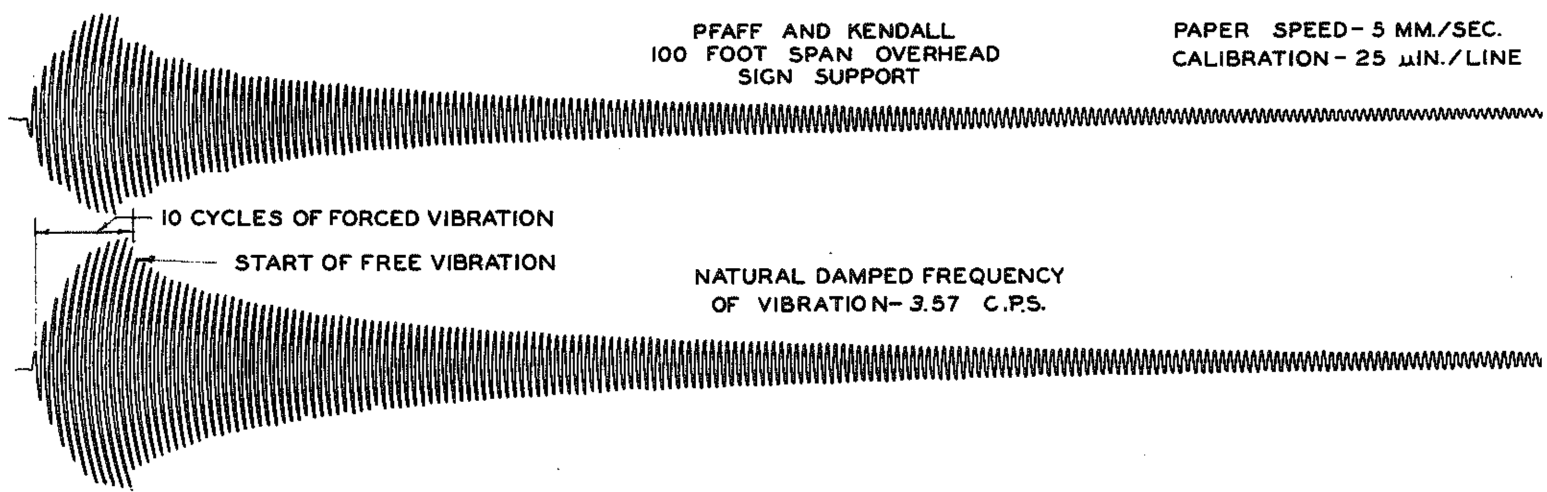
FIGURE 7

LOAD STRESS CURVES





(A.) STEEL BEAM



(B.) ALUMINUM TRUSS

FIGURE 8 TYPICAL VIBRATION TRACES AFTER 10 CYCLES OF FORCED VIBRATION

RAMIFICATIONS OF TEST RESULTS

Both structures were tested similarly under conditions not exactly akin to actual field conditions, in that, short supports were used at the ends of the horizontal member rather than the taller embedded poles. Therefore it was impossible to evaluate the entire bent as a unit, but only to consider the two designs on the basis of the horizontal member. Although both beams were tested with end supports of short stub poles, the results when considered in the light of field conditions would favor the steel beam rather than the aluminum truss. The steel beam is designed for a pin-ended condition at the support while the truss in actual practice receives appreciable fixity at the end support which would tend to decrease deflection and stresses at the center of the span.

Test results indicate that the aluminum truss is very definitely a stiffer structure than that of the steel beam. The center dead load deflection of the steel beam was 11.3 times as great as the center dead load deflection for the aluminum truss. Part of the dead load deflection of the steel beam may have been due to improper cambering. As noted in Figure 1, one of the end sections appeared to be quite crooked. The aluminum truss was 5.2 times stiffer for vertical loading and 4.3 times stiffer for horizontal loading than the steel beam.

Although the stresses in the minor members and the connections of the aluminum truss were not measured, it would appear from the data that the aluminum truss could withstand 6.0 times as much vertical center loading (19,600 compound to 3,240 pounds) and 3.0 times as much horizontal center loading(15,600 compared to 5,130 pounds) as that of the steel beam before the yield stress of the material would be reached. If 0.75 of the yield point strength is considered as the maximum working load, the steel beam would be limited to 2260 pounds of vertical center loading, or 3,840 pounds of horizontal center loading. This compares to 14,700 pounds and 11,700 pounds respectively for vertical and horizontal center loading for the aluminum truss. It should be considered in this respect that when applied loads occur in both directions, for example, the vertical dead load of a sign and the horizontal applied load of the wind force against the sign, the resultant must be considered and the limiting value adjusted depending on the magnitude of the horizontal and vertical components of the resultant.

The natural frequency of vibration of the structure is important in three respects. First, it is a general measure of the stiffness of the structure, the higher the natural frequency the stiffer the structure. Second, generally speaking the structure with the lower natural frequency is more prone to oscillation and also oscillations have less tendency to die out than structures with higher natural frequencies. Third, the natural frequency of vibration is important in order to prevent a resonant condition between the natural vibration pattern of the structure and a periodically applied force.

For cylindrical structures if the product of the diameter in feet and the wind speed in miles per hour is less than 40, the air flow about the cylindrical object is definitely periodic in a steady wind. This eddy current is approximately equal to 0.3 times the ratio of the wind speed in miles per hour to the diameter of the cylinder in feet.[1]

Applying this criteria to the structures under discussion, the product of the diameter in feet and the wind speed in miles per hour will be less than 40 for the steel beam at wind velocities of less than 30 miles per hour and for the aluminum truss for wind velocities of less than 96 m.p.h. If the eddy frequency approximates the natural frequency of the structure resonant vibration might lead to very large amplitudes of vibration.

---

[1] Merriman & Wiggin, American Civil Engineer's Handbook, John Wiley & Sons, Inc., New York; p. 295.

A steady wind velocity of approximately 4 m.p.h. will produce eddy frequencies approximating the natural frequency of the steel beam. For the aluminum truss it appears that a resonant condition could not materialize for the wind velocity would approach zero.

The seriousness of a resonant condition occuring for the steel beam at a wind velocity of 4 m.p.h. may be open to question since the wind force is very small at such a low velocity. However during testing it was noted that a very slight periodic pressure did set up vibrations of fairly large amplitude. Although it was impossible to evaluate the matter of fatigue in this testing, a problem of fatigue damage could occur particularly at connections if wind forces cause long sustained oscillation.

SUMMARY

In evaluating the horizontal members of these structures for their intended use of supporting the dead load of the sign and resisting the wind forces impinging on the sign face, only general limitations may be drawn, for each application requires individual analysis. There are two reasons for this. First, the location of the sign area on the span is a very influential factor in determining the permissible sign area. Second, even though the location of the sign area on the span is determined, the length to height ratio of the sign influences the "shape factor", which in turn effects the design wind force on the sign for a given wind velocity.

Therefore to interpret the test results in terms of permissible sign area the following hypothetical case is considered for a 100 foot span:

1. The wind velocity is 80 m.p.h.
2. Each square foot of sign weighs 3 pounds.
3. The sign area is concentrated at the center of the span.
4. The length to height ratio of sign is 6 : 1("shape factor" = 1.33).

Both structures have been analyzed for this case for an allowable stress of 0.75 of the yield point strength of the material. The steel span would be capable of supporting 85 square feet under these conditions, while the aluminum truss could support an area of 461 square feet of sign area.

The steel structure may support smaller sign areas satisfactorily, if dead load deflection, live load deflection, or large amplitudes of vibratory oscillation which accompanies this structure are not considered as esthetically undesirable. The aluminum truss will support presently anticipated sign areas in any position on the span. The aluminum truss will have much less deflection for a given sign area and in addition a much smaller amplitude of vibratory oscillation.