Design of Aluminum Sign Structures By Electronic Computation

RUDOLPH HOFER, JR., and ALAN H. KNOLL
Aluminum Company of America

The design of overhead sign structures offers an ideal application for electronic computation because the efficiency of a computer is best utilized in the design of similar structures having a great variety of design loading conditions. This type of design work done by slide rule represents the ultimate in inefficient use of design talent.

In setting up a computer program, various suitable geometric configurations are considered for any given combination of span length and wind loading. The computer calculates the force in each member and then selects the lightest available section permitted by specifications. The total metal cost is calculated; this and a calculated fabrication cost make up the estimated total cost of the structure. It is then possible to select a truss for any span length and loading condition which has the correct configuration for the most economical balance of metal and fabrication costs.

•IN 1961 the American Association of State Highway Officials (AASHO) adopted "Specifications for the Design and Construction of Structural Supports for Highway Signs." These specifications, written by a joint AASHO-ARBA Committee, contain allowable design stresses for wrought aluminum alloys 6061-T6, 6062-T6, and 6063-T6 and for aluminum casting alloys 356-T6 and 356-T7. These specifications provide, for the first time, a recognized design and construction code for design and specifying agencies throughout the United States.

The AASHO specifications were adopted to provide for safe, reliable structures and to permit the standardization of designs. Standard designs afford the fabricator the advantages of carrying a minimum number of shapes in inventory and of using standard fabrication techniques. This can result in savings not only to the fabricator but also to his customer in the form of better, less expensive structures.

In 1962, Alcoa began a program designed to provide highway departments with a complete set of aluminum sign structure designs covering most conditions of span and loading. The variation in wind loads throughout the country and the range of span lengths and sign areas made this program a monumental task through any means other than by an electronic computer.

Consideration of the various cross-sections of roadways, including such things as median and shoulder width, led to the conclusion that span lengths for bridge-type structures of from 50 to 140 ft would satisfy most requirements. For example, this would provide a structure over a highway varying from four to twelve lanes. Cantilever and butterfly structures having spans of from 15 to 35 ft, measured from centerline of post, were thought to provide a full range of practical sizes for these types of structures.

Sign areas will vary for different structures having the same span length. Increase in sign area is generally in proportion to increase in span length. It was decided that a 50-ft span could carry a sign area as small as 100 sq ft but that it was highly unlikely

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that a 140-ft span would carry anything smaller than about 400 sq ft and could easily carry as much as 1,000 sq ft of sign area. It was decided to design cantilever and butterfly structures for a sign area covering the full span length and having different sign depths.

The AASHO specifications governing the design of sign structures provide a map that gives the wind speeds in miles per hour for every area of the country. Thus, it is possible to select the design wind load for which a sign structure should be designed. Also provided by the specifications is a map showing the areas of the country in which an ice load is a consideration. Because design wind velocity can vary from 60 mph to a maximum of 120 mph, because only portions of the country are subjected to ice loads, and because some highway departments prefer trusses with walkways, the required number of sign structures can reach well up into the thousands.

Overhead sign structures, subjected to large design wind loads, are generally fabricated as four-chord box trusses. The horizontal-plane trusses carry the wind loads which are applied in either direction; the vertical-plane trusses carry the dead loads, live loads from walkways and ice loads, which are always applied in a downward direction. Consequently, it was decided that the vertical-plane trusses should be Pratt trusses in which the web diagonals normally carry tensile forces. Similarly, it was decided that the horizontal-plane trusses, whose bracing members carry either tension or compression, should be Warren trusses, and the diagonal members should be designed to carry either loading condition. A cost analysis proved these decisions to be economically advantageous.

Another factor of importance, for which a quick solution is possible through the use of a computer, is the correct balance of metal and fabrication costs to arrive at the most economical truss geometry. For example, for any given span length and sign area, the truss cross-section and its number of panel points will have an optimum value. Variation from this optimum will increase the cost of the structure, either in metal cost or cost of fabrication.

By including metal and fabrication costs for different ratios of depth to width of truss for various numbers of panel points, the optimum geometry can be reached. Theoretically, the geometry varies slightly for varying wind loads on any one truss. However, in the interest of standardization, it was deemed advisable to select a constant geometry for all trusses having a given span length, regardless of the wind loading conditions. This geometry was arrived at by trial runs which gave the variation in cost for a fabricated structure having different ratios of width to depth of truss. The selected cross-section and number of panel points per truss were arrived at by choosing the geometry that provided the greatest economy over the entire range of wind loadings. Though this decision will place a small penalty on the theoretical economy for a particular wind loading, it should be more than offset by economy afforded through standardization of fabrication.

Because tubular sections provide a much higher ratio of rigidity to weight of metal than angles or channels, they were chosen to be used for the chords and posts, as well as for the web bracing members. In the case of the chords and posts, this decision was made because these members are designed to resist compressive forces and are subject to column buckling in any plane. Because of the deflection limitations placed on sign structures by the AASHO specifications, and also because of the practical depth of the signs, the trusses have sufficient depth such that the web bracing members are often controlled by limiting values of slenderness ratio and are, therefore, designed on the basis of rigidity rather than stress. Thus, the efficiency of tubular sections is utilized for the entire structure. The more pleasing appearance of tubular members and welded construction is felt to provide an intangible value to the design.

An electronic computer can be used to select, according to such factors, from a list of available sizes the correct tube for each member of a truss. From a practical standpoint, it is desirable to keep the number of tube sizes to a workable minimum so that the fabricator is not faced with the problem of unavailability or of stocking a too-large variety of sizes. In the Alcoa program, trial designs were run in which the computer picked the tube size from a large list included in the input. The designs were then reviewed, with particular attention given to the number of times that each tube was used. The seldom-used sizes were eliminated from the program and the designs were rerun. This resulted in a usable number of tube sizes so that delivery of sections from the mill to the fabricator should not cause unnecessary delay of shipment to the purchaser.

To prepare for a wide variety of sign structure designs, four digital computer programs were written: (a) a program to design the truss portion of bridge-type sign structures, (b) a program to design the supports for bridge-type structures, (c) a program to design the truss portion of cantilever and butterfly-type structures, and (d) a program to design the supports for cantilever and butterfly-type structures. The operation of all four of these programs is basically similar; for purposes of illustration, the details of the program for the design of truss portions of bridge-type structures are described.

The designer begins by selecting a list of tube sections from which he wishes his structure to be fabricated. The properties (diameter, thickness, area, and radius of gyration) of the tubes in this list are fed into the computer. The designer then selects a trial configuration for the structure, including the vertical and horizontal depth of truss and the number of panels in the truss. These are fed into the computer along with the spans, wind load, sign area and estimated values of the deadweight of the structure, ice load on the structure, and area of the structural members exposed to the wind.

The computer proceeds to calculate the design loads for each type of member in the truss. For reasons of simplicity of fabrication and erection, the four chords of the truss are all made identical and of the same section over the entire span length, even though some reduction in section could take place near the ends of the span. Similarly, all diagonals in the vertical faces of the truss are identical, as are the struts in the vertical planes and the diagonals in the Warren trusses in the horizontal planes. In general, the chords are designed by the application of wind and gravity loads producing maximum stress at the center of the span, whereas, the web members in the horizontal and vertical trusses are governed by the shear loads near the ends of the span.

Since the gravity loads from the sign and walkway loadings are applied on one face rather than at the centroid of the truss, the torsional stiffness of a box truss is used to advantage to distribute a portion of this loading to the opposite vertical face. This produces additional shear loads in the horizontal planes of the truss which are accounted for in the design. To insure the torsional rigidity of the box structure, cross diagonals are included at the ends of each shop-assembled section of the truss. These cross diagonals also insure proper fitting of the field chord splices between the subassemblies.

After a design load is calculated for a particular member type, the minimum allowable radius of gyration based on the specification slenderness limit is calculated from the member length. The list of available tube sections is then scanned, starting at the lightest section and proceeding to sections of heavier weight, until a tube is found whose radius of gyration exceeds the calculated minimum radius of gyration. The allowable stress for this trial tube is calculated from the slenderness ratio and the diameter to thickness ratio, using the formulas given in the specification, and is then compared with the actual stress calculated from the design load and the area of the trial tube. If the actual stress exceeds the allowable stress, the trial tube is rejected. The list of tubes is scanned for the next heavier cross-section with an acceptable radius of gyration. This process is repeated until a tube is found whose allowable stress exceeds the actual stress. Because the list of available tubes is searched in order of increasing area and weight, the first section acceptable from a slenderness ratio and stress standpoint is necessarily the lightest tube in the list that can be used. This process is repeated for the chords, the vertical plane diagonals, the vertical plane struts, the horizontal plane diagonals, the horizontal plane struts and, finally, the end cross diagonals. To obtain the maximum economy, the chord and post members have been designed in aluminum alloy 6062-T6 and the web members have been designed in alloy 6063-T6 since they are generally governed by the basis of slenderness rather than strength considerations.

When the lightest acceptable tubes have been selected for each of these members, the dead weight of the truss is calculated. Also calculated are the truss ice load, which is a function of the exposed perimeter of the tubes, and the area of tubular members exposed to the wind. These calculated values of deadweight, ice load and wind area are compared with the corresponding values assumed at the beginning of the design. If any of the three estimates were low, the estimated values are revised and the entire design procedure is repeated. If the estimate for any of the quantities exceeded the calculated value by more than 5 percent, the design may be overly conservative and again the estimates are revised and the design procedure is repeated. The program may go through several cycles of design until the estimated and calculated values for deadweight, ice load and wind area are in agreement. When this point is reached, the estimated cost of the structure is calculated from the weight and unit cost of the metal plus an estimate of the fabrication cost based on the number of joints to be welded.

The following are then punched into a card from the computer memory: (a) the geometry information for the structure, including the span, sign area, vertical truss depth, horizontal truss depth, and number of panels; (b) the loading information, including the applied wind load, the actual dead load of the structure, actual ice load on the structure and actual area of the structures exposed to the wind; (c) the tube size for each of the member types; and (d) the calculated cost of the structure. The information on the card is provided to the designer on a printed sheet.

By selecting several trial geometrical configurations for a given structure and comparing the cost information for each, the designer can manipulate one or more of the geometric parameters to obtain a minimum cost structure. For example, it was found that the cheapest structure tended to be one with a small number of relatively long panels because this reduced the number of joints in the structure and thus lowered the fabricating cost, even though the sizes of the diagonals in the vertical and horizontal trusses increased with a corresponding increase in the metal cost. Similarly, for structures exposed to very light wind loads, the optimum cross-section of the truss tended to be deeper vertically than horizontally; the opposite tended to be true for very heavy wind loads. It was generally found that a square cross-section, that is, one with equal vertical and horizontal depths, was a good compromise when a single cross-section was to be selected for all wind loadings at a given span length.

The computer time required to produce a design for a given set of loading and geometric parameters varies considerably with the span length, loading, and the precision of the original estimates for deadweight, ice load and wind area. After some experience was acquired, these values could be estimated closely enough that one or two passes through the design portion of the program were sufficient. This meant that an average time to produce an acceptable design on a computer such as the IBM 650 or 1620 is on the order of one to two minutes. This time would be faster for short-span lightly loaded sign structures and somewhat longer for long-span heavily loaded structures.

This use of digital computation to produce standard designs for overhead sign structures was economical, efficient, and allowed a much greater degree of refinement in the designs than could have been included had they been prepared by hand. The successful application of this approach to sign structures suggests that similar techniques should be useful in the repetitive design of other types of structures.