THE DESIGN OF A WELDED, ALL ALUMINUM FRAME GREENHOUSE

Thesis for the Degree of B. S.

MICHIGAN STATE COLLEGE

Stuart H. Bogue

1949

The Design of a Welded, All Aluminum Frame Greenhouse

A Thesis Submitted to

The Faculty of

MICHIGAN STATE COLLEGE

of

AGRICULTURE AND APPLIED SCIENCE

by

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Candidate for the Degree of

Bachelor of Science

March 1949

THESIS

Acknowledgement

I would like to extend my appreciation to Dr. William A. Lindley for his invaluable assistance toward the completion of this thesis.

Introduction

Aluminum alloys are produced in practically all of the forms in which metals are used: plate, sheet, bar, rod, wire, tubing, shapes, forgings, castings, and ingot, as well as rivets and screw machine products. Shapes may be the standard structural shapes or they may be of special design which can be produced only by extrusion. The various forms are fabricated into finished shapes and structures by drawing, stamping, spinning, hammering, machining, welding, brazing, riveting, and, for some purposes, soldering. Ease of fabricating and finishing the metal is one of the reasons for the choice of aluminum.

Comparison of costs should be made on the finished article as made from the different possible materials, not on their relative prices per pound. Since the volume of metal is usually substantially the same, the price per pound of aluminum should be divided by the ratio of the specific gravities (approximately three for most of the common metals) when comparing the material costs. In addition, economies frequently result from the greater ease with which aluminum can be fabricated, polished or otherwise finished, and also from the lower cost of distribution made possible by the lightness of the metal.

Frequently, these economies are more than sufficient to overcome an unfavorable cost comparison from the standpoint of metal value alone, as, for example, with common grades of steel. In such comparisons, the higher scrap value of aluminum, when the article is finally discarded, is always an advantage to be considered.

The most generally recognized characteristics of the aluminum alloys are their light weight, resistance to corrosion (both in seacoast and industrial areas,) and high strength. These qualities are largely responsible for the structural applications of the aluminum alloys, particularly in the transportation industry and in architecture. Some of the very high-strength, heavy metal alloys offer similar strength-weight ratios but the thinner sections result in less rigid and less rugged structures and present handling problems during fabrication. In addition, most of these alloys suffer in the cost comparison with the light alloys.

The modulus of elasticity, which is the ratio of stress to strain in the elastic range, varies somewhat, depending on the composition of the material; in general, it increases with increasing amounts of alloying elements from about 10,000,000 to about 10,800,000 pounds per square inch. For most practical purposes, however, the modulus may be taken as 10,300,000 pounds per square inch.

Because of the lower value of this constant as compared with that of steel, it is necessary to use deeper sections in aluminum alloys in order to maintain the same deflection characteristics when they are loaded as beams. It is usually possible to design a structure having the same deflection under load and actually higher ultimate strength than would be obtained with structural steel, and, at the same time, to realize a saving in weight of more than a pound for each pound of aluminum alloy used. The lower modulus of elasticity is an asset when impact loads are to be resisted, since, other things being equal, the lower the modulus, the greater the ability to absorb energy without permanent set. The lower modulus is also advantageous in reducing stresses produced by misalignment, settlement of supports, or other fixed deflections, accidental or intentional.

The modulus of rigidity is about 3,900,000 pounds per square inch for aluminum and its commercial alloys, corresponding to a value of one-third for Poisson's Ratio.

Design Criteria

The new all-aluminum frame greenhouse was designed for durability. A full wind load of twenty-six pounds per square foot and one-half maximum snow load of thirteen pounds per square foot were used to resist bad weather conditions. Since double strength glass is used for the windows a weight of two and thirty-two hundredths pounds per lineal foot was necessary for the computations. Since the design was chosen to eliminate all interior super structure a truss in the form of a gable bent was selected. The various members of the gable bent are to be welded together in order to develop the full strength of each piece. In a riveted structure the members are weakened to a certain extent by the rivet holes. The ends of the truss are welded to a bearing plate that is bolted to a concrete foundation. Since the ends of each truss are bolted down the truss is statically indeterminate. Therefore, to compute the moments and reactions due to the loading, Castigliano's theorem was used. It states that "when a structure is acted upon by an equilibrated force system which produces a total internal strain energy U, the derivative of U with respect to any force gives the displacement in the direction of that force."

The loading on the gable bent was broken into three parts for the sake of computations. The loads were broken down as follows: the vertical side of the greenhouse was considered to resist only a wind load of four hundred and eighty pounds per foot; the horizontal component of the wind and snow load which is two thousand one hundred and eighty pounds per foot; and the vertical component of thirty-two hundred pounds per foot were considered to act on one-half of the roof. It was decided that if the structure was designed to resist the maximum loading on one side it would be sturdy enough.

The first member to be designed was the tee section glazing bar. It was considered to be a continuous beam with five supports and a uniform load on it of four and one-half pounds per foot. The maximum negative moment was found to be larger than the maximum positive moments, therefore, the negative moment governed the design. The section modulus required was 0.144. The tee section chosen was a two inch by one and one-half inch section with a section modulus of 0.195. The section was checked for shear and found to be satisfactory.

The purlin was the next member to be designed. It was designed as a simply supported beam with concentrated loads at a little less than two foot intervals. The loading considered was the snow and wind load, the weight of the glass, the weight of the tee sections, and an assumed weight for the purlin itself. The total loading designed for was two hundred thirty pounds at less than two foot intervals. The maximum moment was used to compute a section modulus of 4.93. A six inch channel section with a section modulus of 5.06 was chosen. The channel was checked for shear on both the X-X axis and the Y-Y axis and found to be satisfactory.

The truss was the last member to be designed. The moments and reactions determined by Castigliano's theorem were used to select a section modulus of 14.99. An H-beam, with a section modulus of 15.06 was selected to make up the gable bent.

The calculations are all contained in the appendix.

Merits of This Design

This aluminum frame greenhouse has many advantages over the iron pipe and wooden frame houses. The most outstanding advantage of this design is the great decrease in maintenance. The aluminum structure will need no painting. Painting a wooden greenhouse serves more purposes than for just looks. Wood must be kept covered so it won't dry out and rot and be a collecting place for dirt. A big problem in the flower business is disease control. These disease organisms thrive in dirty places and are harder to eliminate by fumigation if they have a place to hide. For these reasons a wooden greenhouse must be well maintained at a large cost. The aluminum framework will eliminate the yearly maintainance and make the cleaning comparatively simple. Wooden houses must have metal joints and due to the high humidity required for flowers these joints will rust quickly. The aluminum frame house will not rust either in seacoastal areas or inland areas.

Glass maintainance is also another large item in the greenhouse business. In addition to the regular replacements due to broken panes a greenhouse must be reglazed about every ten years. In the wooden frame house this represents a big project. It consists of removing the old glass, pulling out all the glazing nails, removing the old putty and then the whole procedure must be repeated in reverse to replace the glass. Approximately forty per cent of the reglazing time may be saved with this new aluminum design. Removing the old putty, which was sometimes hard as rock, meant lots of scraping and even shavings were removed from the wooden glazing bars trying to remove the putty. Scraping and nailing are eliminated by the new aluminum glass clip which is spot welded to the aluminum glazing bar. To remove glass simply push the clip in against the glazing bar and pick the glass out; to replace the glass push the clip in, insert the glass and let the clip spring back into place against the glass.

The aluminum design will allow no sagging of the roof after many years as the present houses do unless they are rigidly maintained. A sagging roof can be a large expense due to heat loss even though it may not be noticeable at the time. Glass has a tendency to slip when the roof sags and this is an added worry during the bad weather months.

The perfect greenhouse would be one that had a roof entirely of glass so there would be no shadows inside whatsoever. Since this is impossible, the next best thing is a house that will allow a maximum amount of sunlight through. This aluminum design fulfills this qualification. It is designed to hold glass that is twenty inches square rather than the standard sixteen by eighteen inch glass. The elimination of the interior super structure will also reduce shadow area. Since shade lines are kept to a minimum the sun will penetrate the frost quicker and the winter sun is able to shine through longer.

Inside the greenhouse space is very important, this means that the bench arrangement must be such that a maximum number may be used. In the wooden houses bench arrangement was rather limited because of the interior supports that were necessary. These supports are eliminated in the new design and will allow any bench arrangement which would be the most profitable.

A pleasant appearing greenhouse is almost a prerequisite to be successful in the flower business. The aluminum frame greenhouse would fulfill this requirement to every extent. The gable bent eliminates the need for any unsightly superstructure, the aluminum will never rust or require painting, and most important of all, it will look just as good after ten years of service as it did on the first day.

Welding

Aluminum alloys are designated by numbers rather than by names by Alcoa. An alloy of a given composition is given a number and, in case it is a wrought alloy, the number is followed by the letter S. The temper designation follows the alloy number, separated from it by a hyphen.

The important commercial methods of welding aluminum are: (1) fusion welding, which includes the use of gas, metal arc, automatic and manual carbon arc, and atomic hydrogen, and (2) electric resistance welding, which includes spot; seam; and butt flash welding methods.

The most weldable aluminum material is Alcoa 2S or commercially pure aluminum. In another group of alloys, the strength depends on heat treating but this will not be taken into consideration here. Where it is desirable to use a material with higher tensile strength and suitable for structures, Alcoa 52S is suggested. When fusion welding this alloy, more difficulty is experienced from cracking in the weld zone, and for good results it is important to use butt or edge welds and to eliminate lap or fillet welds.

The metal arc welding process has the advantage that the highly concentrated heat zone obtained prevents excessive expansion of the parts being welded and lessens the distortion. In addition, the preparation of the joints for welding is simple and the rate of welding is faster.

Welding aluminum can be performed in any position, however, the ease of application and the quality of the completed joints are considerably better when the welding is performed in the flat position. Welding in the overhead position is very difficult and should be entirely avoided if possible. Metal-arc welds can be made with standard D. C. motor-generator sets used for welding other materials. Proper polarity may be determined by trial on the joints to be made. Approximate current settings and electrode sizes for welding various thicknesses are as follows: for one eighth inch thickness, a one eighth inch rod may be used with approximately eighty amperes; a one quarter inch weld would require a three sixteenths or one quarter inch rodat two hundred amps; and the same rods may be used for a one half inch weld using a current of about three hundred amperes.

Commercial electrodes with a heavy flux coating are always used. The flux coating has two purposes: to remove the surface oxide from the filler metal and from the parent metal and to stabilize and confine the arc to the end of the electrode. Electrodes may be obtained made from commercially pure aluminum or from an alloy containing ninety-five per cent aluminum and five per cent silicon. The silicon alloy electrodes are generally used, however, as they result in greater freedom from cracking difficulties. The pure aluminum electrodes would be used only where severe corrosive service conditions are expected or to obtain a better color match with some of the aluminim alloys.

The preparation of butt joints for metal-arc welding is comparatively simple. Because of the ease with which penetration can be obtained, no edge preparation is required on material up to one quarter inch in thickness. Heavier materials should be partially beveled to within one quarter of an inch of the bottom of the section. This preparation can sometimes be dispensed with if the material is between one quarter and one half inch in thickness if a weld deposit can be laid down from both sides of the section.

Striking the arc for this welding is very similar to lighting a match. The electrode metal melts very rapidly in the arc and, similarly, solidifies quite rapidly when the arc is extinguished. In view of this fact, it will be found that an attempt to draw the arc by touching the rod to the work will, almost invariably, result in burning fast or freezing the rod to the work. After striking the arc near the point where welding is to start, the arc is brought to the starting point and welding is begun. During the first few seconds of welding the arc may be somewhat unstable due to the lower temperature of the parent metal and during this time an arc slightly longer than normal should be held to assist in bringing the parent metal up to temperature. The arc should be kept as short as possible to improve its stability. An arc length of one eighth to three sixteenths of an inch is most satisfactory and it should never exceed one quarter of an inch. The arc voltage is from twenty-two to twenty-five volts. Considerable molten metal is thrown about in the form of splatter if a long arc length is held. An arc too short will be extinguished frequently by short circuiting of the electrode and the weld pool.

The rate of burn-off of aluminum electrodes is from two to three times the rate obtained on the same size of steel electrodes; furthermore, a considerably shorter arc is held when welding aluminum. In view of this fact an operator who is familiar with arc welding of steel will require some practice in order to produce good weld in aluminum. Weaving of the electrode is not necessary as in welding steel. In welding thick plate the electrode can be moved forward and backward or moved slowly from side to side to build up the desired height in the weld.

The low melting point of aluminum, as well as the high rate of diffusion of heat away from the joint, requires special consideration in choosing the exact current setting to be used. Small parts or material which has been pre-heated require considerably lower values of welding current than would be used in making a similar weld on parts of large size or on cold material. If too high a value of current is used, the operator may find it impossible to keep from burning holes completely through the work. On the other hand, if too low a value of welding current is used, incomplete penetration and a high and narrow bead will be obtained. A good ground connection to the material being welded is very important. A poor ground connection will be indicated by difficulty in starting and maintaining the arc. When the arc is extinguished an insulating fuse flux coating is formed over the tip of the electrode sharply on the work. After this coating has cracked off, the arc may be restruck, using the "match striking" methods.

In making multi-pass welds it is important that the solidified flux be removed from each welded bead before proceeding with successive beads. Failure to remove this flux will result in welding difficulties and with entrapped flux in the welds.

Weld Design

Before the amount of weld needed at each joint can be determined it is necessary to know which load conditions will produce a maximum moment. This was decided by a trial and error method. A loading was placed on the structure and the moments were computed. It was found that the load due to wind caused the greatest stress. The moment due to the dead load was added to that caused by the wind load and the maximum moment was fifty-two thousand foot pounds in joints "b" and "d", the joints where the roof joins the vertical member of the truss. By this same method the maximum moment at the peak joint was found to be sixty-one thousand foot pounds.

The weld at joint "b" was the first to be considered. A complete butt weld between the designed member and the vertical was made and the rest of the strength was provided by a cover plate on both the top and the bottom of the flange. The butt weld would resist a moment of twenty-two thousand foot pounds; therefore, this left thirty thousand to be taken by the cover plates. A width of five inches was arbitrarily selected and after finding the moment of inertia of the plate, a thickness of one-half inch was found to be satisfactory. The value per inch of a half inch weld is two thousand four hundred and seventy pounds. With a plate stress of sixty thousand pounds, twenty-four inches of weld are needed to prevent failure. However, twenty-eight inches was provided for a margin of safety. Nine inches of plate with a three inch "V" notch was used on each side of the joint. This will provide a rigid connection for each of the lower joints and yet it is not too conservative.

Since the joint at the peak has a larger maximum moment it will require a thicker plate and more weld area. The butt weld between the two H-sections will take twenty-two thousand foot pounds as before, leaving almost forty thousand to be taken by the plate. By the same method of calculation a five eighths inch plate was found to be necessary. A five eighths inch weld with a value of three thousand pounds per inch of weld was used. With a plate tension of seventy-eight thousand pounds it is shown that about twenty-five inches of weld were necessary. As before, twenty-eight inches was provided. A five eighths inch plate, nine inches long, with a four inch "V" slot was used.

A welded connection was also used for the column anchorage. The maximum moment that a six inch H-section can resist was chosen as the design limit for this connection. This moment was found to be two hundred and eleven thousand inch pounds.. The size of bolt necessary was first determined by finding the bolt stress caused by this moment. The size bolt necessary was a one and one-half inch steel bolt. The bolts will be anchored in the concrete at the time of pouring, allowing about twelve inches to protrude above the surface of the concrete. Next the size weld desired must be chosen. A three eighths inch weld was chosen with a value of less than ninteen hundred pounds per inch of weld. With this value and the maximum bolt stress of ninteen hundred pounds, a little over five inches of weld were required. This value must be checked for shear from direct pull and shear from flexure and also the resultant shear on the throat of the weld. It was not found to be sufficient therefore a length of ten inches was chosen and found to stay within the limiting stress. A four by four by three-eighths inch angle was chosen to complete the connection. It was checked and found to be sufficient to take the stress. The angles must be ten inches high in order to provide the necessary weld area.

Computations and sketches are contained in the appendix.

An estimate was made on the electrode consumption for the construction of this greenhouse. There were about fifty-four pounds of three eighths inch electrodes necessary for the eighteen butt welds. There are about forty feet of three eighths inch fillet weld in the column anchorage. This will require about forty-two pounds of electrodes. In the cover plate welds at joints "b" and "d" there are about one hundred and twelve feet of one-half inch weld but three passes are necessary, therefore, the requirement here is about one hundred seventeen pounds. The top cover plate needs four passes to fill the five eighths inch fillet weld and since there are fifty-six feet of weld it will take almost ninety pounds of electrodes. These figures will give the prospective builder a rough estimate of the amount of each size electrode necessary for the construction of this greenhouse.

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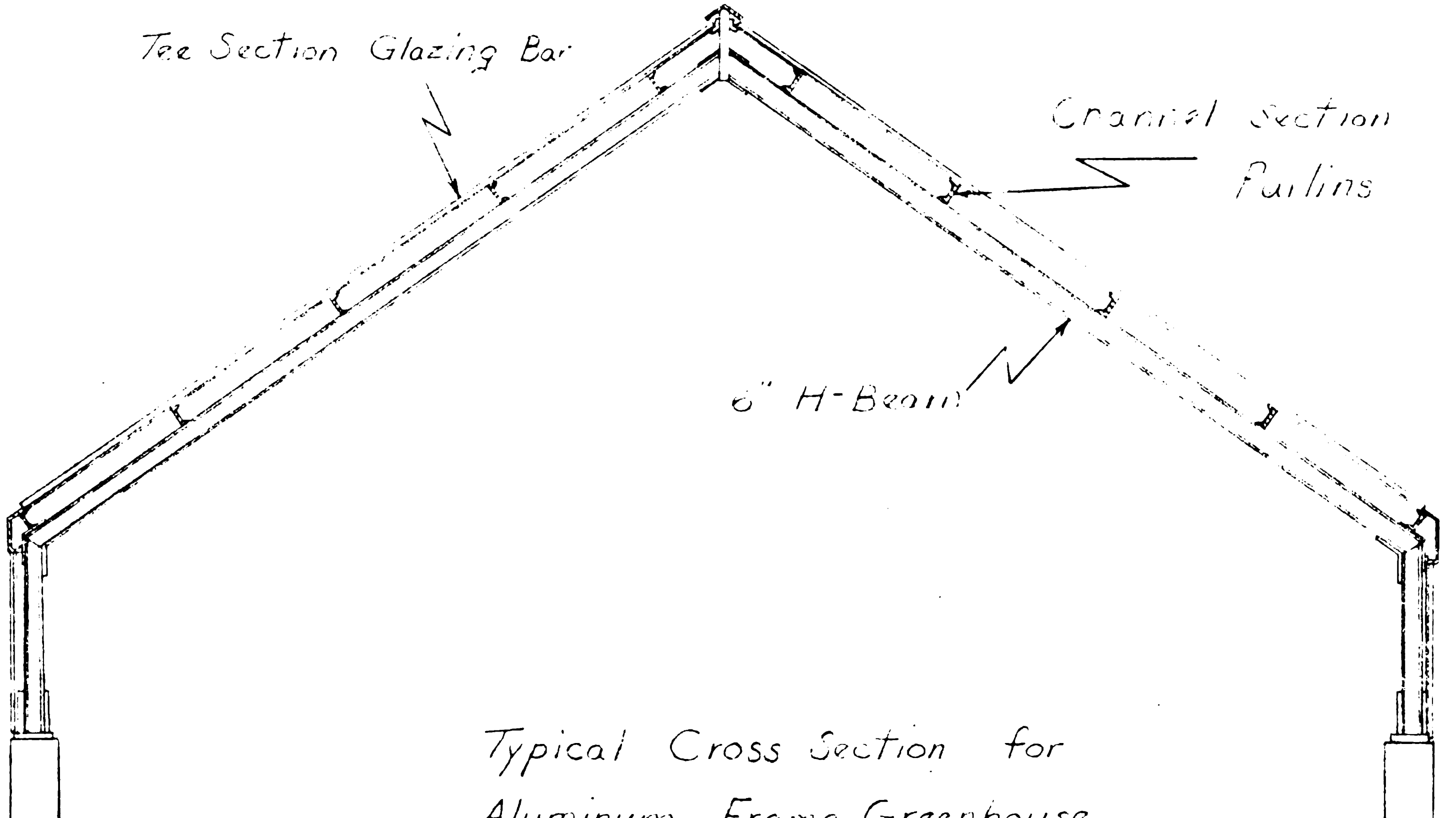
Graphic Statics - - - - - - - - - - - - Charles W. Malcolm

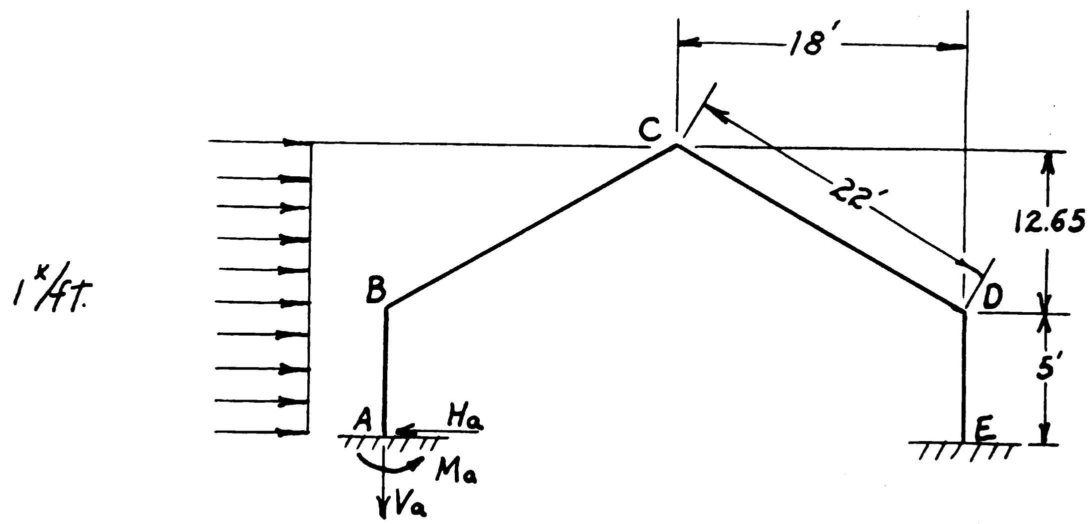
Statically Indeterminate Structures - - - L. C. Maugh

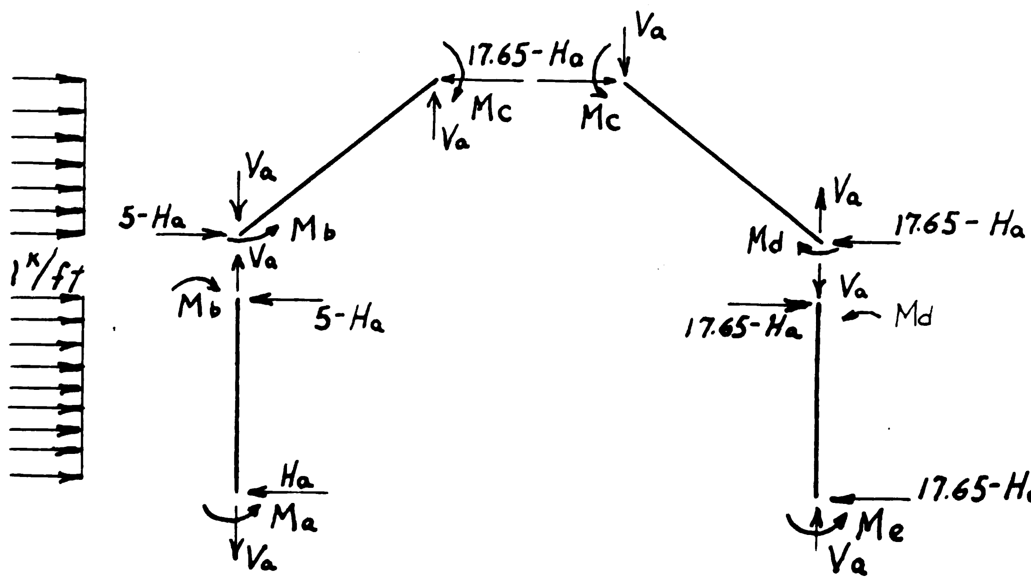
Welding and Brazing Alcoa Aluminum - - - - - - - - 1945

Appendix

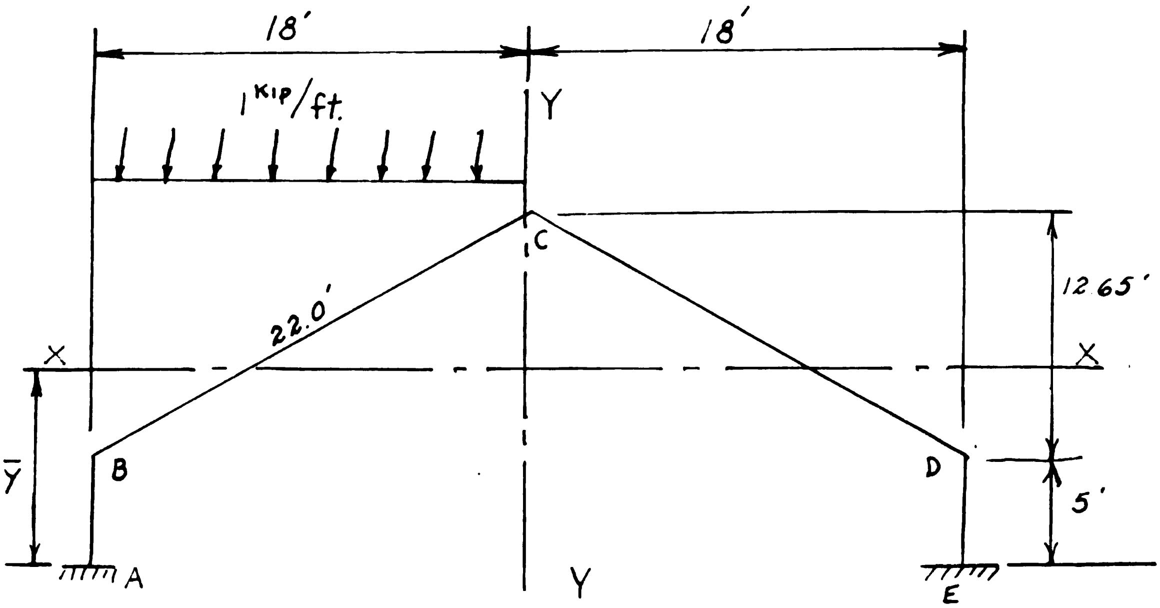


Typical Cross Section for
Aluminum Frame Greenhouse





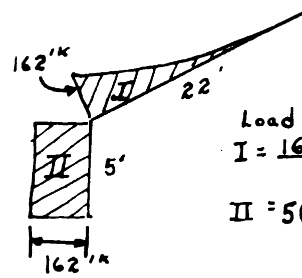
Solution for Moments in Gable Bent



E & I constant

$$\bar{y} = \frac{5(2.5) + 11.325(22)}{27.0} = \frac{12.5 + 249.1}{27.0} = 9.69'$$

$A = 10 + 44 = 54$



Load:

$I = \frac{162(22)}{3} = -1188$

$II = 5(162) = -810$

-1998

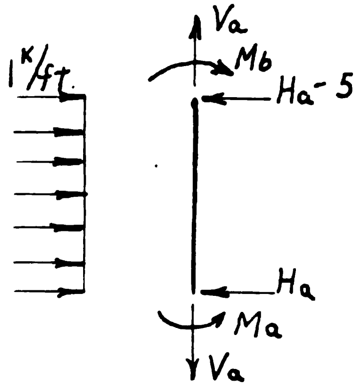
$$I_{x-x} = 2\left[\tfrac{1}{12}(5)^3 + 5(7.14)^2 + \tfrac{1}{12}(22)(12.65)^2 + 22(1.635)^2\right]$$
$$= 2[10.41 + 258.4 + 293.6 + 58.8] = 1242$$

$$I_{y-y} = 2\left[\tfrac{1}{3}(22)(18)^2 + 5(18)^2\right]$$
$$= 2[2376 + 1620] = 7992$$

$$M_{x-x} = (-1188)(-1.53) + (-810)(-7.19)$$
$$= 1818 + 5820 = 7638$$

$$M_{y-y} = (-1188)(-13.5) + (-810)(-7.19)$$
$$= 16040 + 5820 = 30620$$

AB



$$M_{x_1} = -M_a + H_a X - \frac{1(x^2)}{2}$$

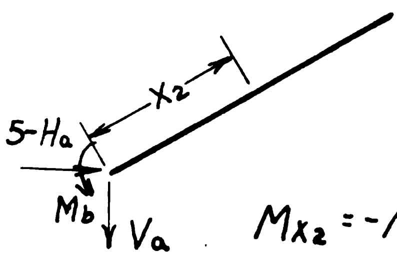
$$\frac{\partial M}{\partial M_a} = -1$$

$$\frac{\partial M}{\partial H_a} = X$$

$$\frac{\partial M}{\partial V_a} = 0$$

$$M_b = M_a - 5H_a + 12.5$$

BC



$$M_{x_2} = -M_b - (5-H_a)(.575X) - V_a(.818X) - (.575X)^2(\tfrac{1}{2})(1)$$

$$M_{x_2} = -M_a + 5H_a - 12.5 - 2.875X + .575H_aX - .818V_aX - .165X^2$$

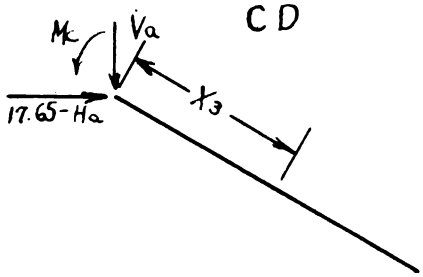
$$\frac{\partial M_{x_2}}{\partial M_a} = -1$$

$$\frac{\partial M_{x_2}}{\partial H_a} = 5 + .575X$$

$$\frac{\partial M_{x_2}}{\partial V_a} = -.818X$$

$$M_c = M_a - 17.65H_a + 18V_a + 155.65$$

CD



$$M_{x_3} = -M_c - V_a X_3(.818) + (17.65 - H_a)(.575 X_3)$$

$$= -(M_a) + 17.65 H_a - 18 V_a - 155.65 - .818 V_a X_3$$

$$+ 10.15 X_3 - .575 H_a X_3$$

$$= -M_a + 17.65 H_a - 18 V_a - 155.65 - .818 V_a X_3$$

$$+ 10.15 X_3 - .575 H_a X_3.$$

$$\frac{\partial M_{x_3}}{\partial M_a} = -1$$

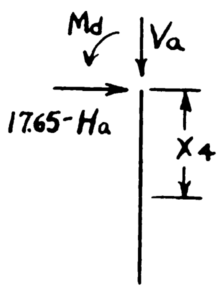
$$\frac{\partial M_{x_3}}{\partial H_a} = 17.65 - .575 X_3$$

$$\frac{\partial M_{x_3}}{\partial V_a} = -18 - .818 X_3$$

$$M_d = M_a - 17.65 H_a + 18 V_a + 155.65 + 18 V_a - 223.1 + 12.65 H_a$$

$$= M_a - 5 H_a + 36 V_a - 67.45$$

DE



$$M_{x_4} = -M_d + (17.65 - H_a)(X_4)$$

$$= -M_a + 5 H_a - 36 V_a + 67.45 + (17.65 - H_a) X_4$$

$$= -M_a + 5 H_a - 36 V_a + 67.45 + 17.65 X_4 - H_a X_4$$

$$\frac{\partial M_{x_4}}{\partial M_a} = -1$$

$$\frac{\partial M_{x_4}}{\partial H_a} = 5 - X_4$$

$$\frac{\partial M_{x_4}}{\partial V_a} = -36$$

$$U = \int \frac{M^2 dx}{2EI}$$

$$\frac{dU}{dM_a} = \int \frac{M \frac{\partial M}{\partial M_a}}{EI} dx \qquad \frac{dU}{dH_a} = \int \frac{M \frac{\partial M}{\partial H_a}}{EI} dx \qquad \frac{dU}{dV_a} = \int \frac{M \frac{\partial M}{\partial V_a}}{EI} dx$$

Omitting EI

$$\frac{dU}{dM_a} = 0 = \int_0^5 (-M_a + H_a x - \tfrac{x^2}{2})(-1)\, dx$$

$$+ \int_0^{22} (-M_a + 5H_a - 12.5 - 2.875x + .575 H_a x - .818 V_a x - .165 x^2)(-1)\, dx$$

$$+ \int_0^{22} (-M_a + 17.65 H_a - 18 V_a - 155.65 - .818 V_a x_3 + 10.15 x_3 - .575 H_a x_3)(-1) dx$$

$$+ \int_0^5 (-M_a + 5H_a - 36 V_a + 67.45 + 17.65 x_4 - H_a x_4)(-1)\, dx$$

$$= \left[M_a x - \frac{H_a x^2}{2} + \frac{x^3}{6}\right]_0^5 + \left[M_a x - 5H_a x + 12.5x + 1.438x^2 - .288 H_a x^2\right.$$

$$\left. + .409 V_a x^2 + .055 x^3\right]_0^{22} + \left[M_a x - 17.65 H_a - 18 V_a - 155.65 x + .409 V_a x^2\right.$$

$$\left. - 5.08 x^2 + .288 H_a x^2\right]_0^{22} + \left[M_a x - 5 H_a x + 36 V_a x - 67.45 x - 8.83 x^2\right.$$

$$\left. + .5 H_a x^2\right]_0^5$$

$$= 54 M_a - 523 H_a + 972 V_a + 1987.7 = 0$$

$$M_a - 9.68 H_a + 18 V_a + 36.80 = 0 \qquad (1)$$

$$\frac{dU}{dH_a} = 0 = \int_0^5 (-M_a + H_a X - \frac{X^2}{2})(X)\,dX + \int_0^{22} (-M_a + 5H_a - 12.5 - 2.875X$$

$$+ .575 H_a X - .818 V_a X - .165 X^2)(5 + .575 X)\,dX + \int_0^{22} (-M_a$$

$$+ 17.65 H_a - 18 V_a - 155.65 - .818 V_a X + 10.15 X - .575 H_a X)$$

$$(17.65 - .575 X)\,dX + \int_0^5 (-M_a + 5H_a - 36 V_a + 67.45 + 17.65X$$

$$- H_a X)(5 - X)\,dX = \left[-\frac{M_a X^2}{2} + \frac{H_a X^3}{3} - \frac{X^4}{8} \right]_0^5 +$$

$$\left[-5 M_a X + 25 H_a X - 62.5X - 10.78 X^2 + 2.88 H_a X^2 - 2.05 V_a X^2 - \right.$$

$$\left. .826 X^3 - .288 M_a X^2 + .11 H_a X^3 - .157 V_a X^3 - .0237 X^4 \right]_0^{22}$$

$$\left[-17.65 M_a X + 311.5 H_a X - 317.8 V_a X - 2750 X - 2.05 V_a X^2 + 134.35 X^2 \right.$$

$$\left. - 10.15 H_a X^2 + .288 M_a X^2 + .157 V_a X^3 - 1.95 X^3 + .11 H_a X^3 \right]_0^{22}$$

$$+ \left[-5 M_a + 25 H_a X - 180 V_a X - 337.25 X + 10.40 X^2 - 5 H_a X^2 + .5 M_a X^2 \right.$$

$$\left. + 18 V_a X^2 - 5.88 X^3 + .333 H_a X^3 \right]_0^5$$

$$= -523.2 M_a + 63.13.4 H_a - 9419 V_a - 36,062 = 0$$

$$M_a - 12.06 + 18.0 V_a + 68.95 = 0 \qquad (2)$$

$$\frac{dU}{dV_a} = 0 = \int_0^5 (-M_a + H_a X - \frac{X^2}{2})(0)dx + \int_0^{22} (-M_a + 5H_a - 12.5 - 2.875X +$$

$$.575 H_a X - .818 V_a X - .165 X^2)(-.818X)dx + \int_0^{22} (-M_a + 17.65 H_a - 18 V_a$$

$$-155.65 - .818 V_a X + 10.15X - .575 H_a X)(-18 - .818X)dX$$

$$+ \int_0^5 (-M_a + 5H_a - 36 V_a + 67.45 + 17.65X - H_a X)(-36)dX$$

$$= [.409 M_a X^2 - 2.05 H_a X^2 + 5.12 X^2 + .78 X^3 - .16 H_a X^3 + .22 V_a X^3$$

$$+ .034 X^4]_0^{22} + [18 M_a X - 317.8 H_a X + 324 V_a X + 2802X + 14.72 V_a X^2$$

$$-27.6X^2 - 2.05 H_a X^2 + .409 M_a X^2 + .22 V_a X^3 - 2.77 X^3 + .16 H_a X^3]_0^{22}$$

$$+ [36 M_a X - 180 H_a X + 1296 V_a X - 2429X - 317.9X^2 + 18 H_a X^2]_0^5$$

$$= 971.9 M_a - 94.21 H_a + 25417 V_a + 17463 = 0$$

$$M_a - 9.70 H_a + 26.19 V_a + 17.97 = 0 \qquad (3)$$

Solving (1) & (2)

$H_a = 13.50^k$

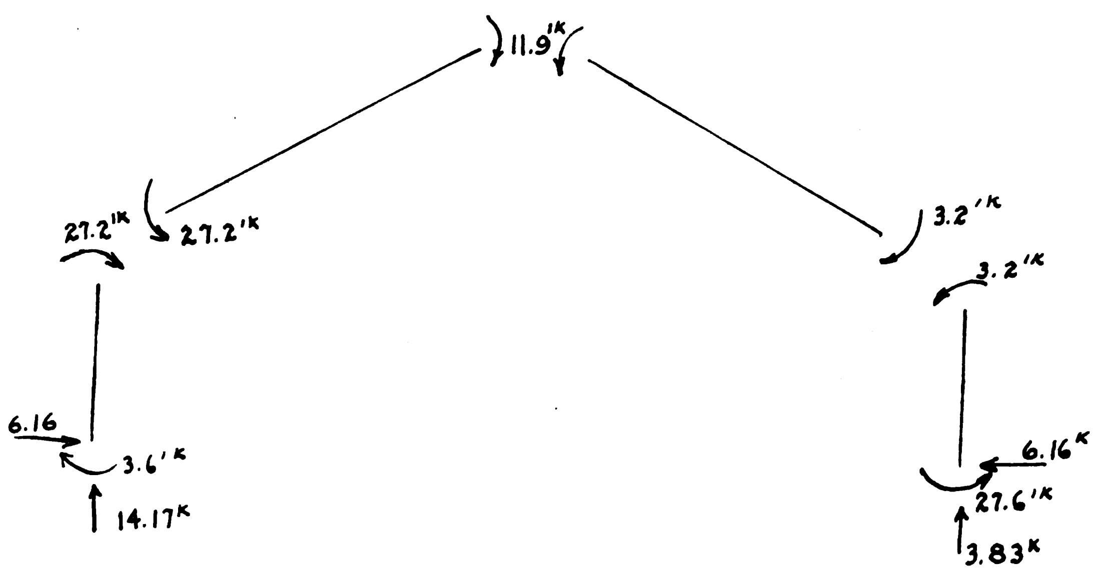
(2) & (3) $V_a = 2.33^k$

$M_a = 52.03$ ft.-k.

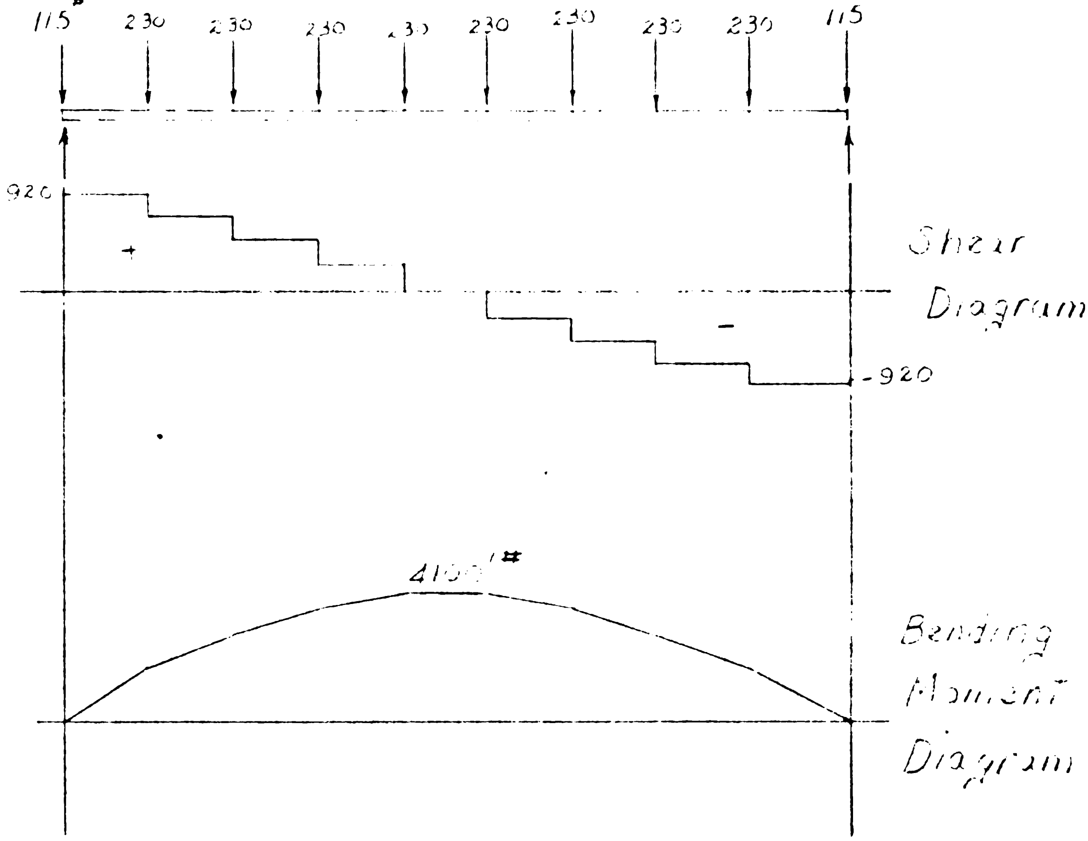
$$m_i = \frac{-1998}{54} + \frac{30620\,X}{7992} + \frac{7638\,Y}{1242}$$

$$= -37.0 + 3835\,X + 6.15\,Y$$

	X	Y	3835X	6.15Y	$\frac{\theta}{A}$	m_i	m_s	M
A	-18	-9.69	-69.0	-59.6	-37	-165.6	-162	+3.6
B	-18	-4.69	-69.0	-28.8	-37	-134.8	-162	-27.2
C	0	+7.96	0	+48.9	-37	+11.9	0	-11.9
D	+18	-4.69	+69.0	-28.8	-37	+3.2	0	-3.2
E	+18	-9.69	+69.0	-59.6	-37	-27.6	0	+27.6



Design of Channel Section



$$\text{Max. Mom.} = 4100'\# = 49{,}200''\#$$

$$Z = \frac{M}{S} = \frac{49200}{10{,}000} = 4.92$$

Try a 6 × 2.034'' Channel $Z = 5.06$

$I_{x-x} = 15.18$ $\qquad I_{y-y} = 0.87$

$$S_{x-x} = \frac{VQ}{Ib} = \frac{920 \times 2.15}{15.18 \times .314} = 415 \text{ psi} \qquad S_{y-y} = \frac{920 \times .627}{.87 \times 6} = 111 \text{ psi}$$

$$S_{x-x} = \frac{49200}{5.06} = 9750 \text{ psi} \qquad S_{y-y} = \frac{2770}{.54} = 5130 \text{ psi}$$

Therefore the channel is safe.

Design of Tee Section

Uniform Load = 4.5 #/ft.

Max + mom. = $.077\, w l^2$

Max - mom = $.107\, w l^2$

Max shear = $.607\, w l$

Max. Mom. = $.107\, w l^2$

= $.107 \times 4.5 \times 25$

= 120'# = 1440''#

$Z = \frac{M}{S} = \frac{1440}{10000} = .144$

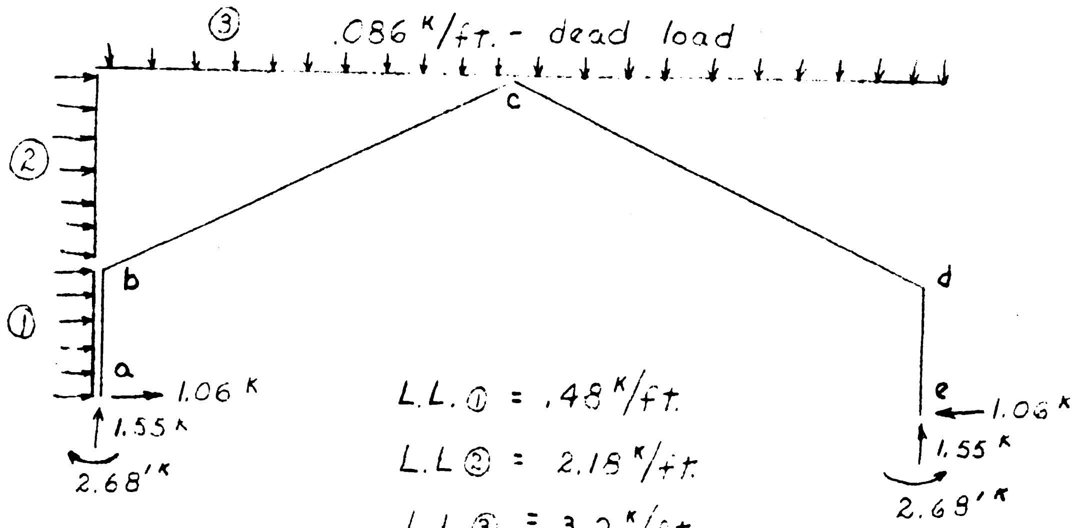
Try a 1½" × 2" Tee Z = .135

$V = .607 \times 5 \times 45$

= 136#

$S = \frac{VQ}{Ib} = \frac{136 \times .197}{.269 \times .188} = 530$ psi

Therefore the section is safe.



L.L. ① = .48 K/ft.

L.L ② = 2.18 K/ft.

L.L. ③ = 3.2 K/ft.

Glass = 600 #/truss

Tee-Sect. = 136 #/truss

Channel = 300 #/Truss

H-beam = 460 #

$\Sigma M_b = 2.68 - (5 \times 1.06) = 2.62'^K$ due to dead load

$\Sigma M_c = (1.06 \times 17.65) + (.086 \times 18 \times 9) - 2.68 - (1.55 \times 18) = 2'^K$

$\Sigma_b = (2.33 \times 5) + (4.12 \times 5) + 4.75 + 20.2 - (5 \times 0.48) - 2.62$

$= 52'^K$ Max. Mom. due to W.L. + D.L.

$\Sigma M_c = (2.33 \times 17.65) + (4.12 \times 17.65) + 4.75 + 20.2 - (17.65 \times .48 \times 8.82)$

$- 2.62 = 61.33'^K$ - due to W.L. + D.L.

W.L. $①_H$ = $4.86 \times .48 = 2.33^K$

W.L. $②_H$ = $8.59 \times .48 = 4.12^K$

W.L. $①_M$ = $9.9 \times .48 = 4.75'^K$

W.L. $②_M$ = $42.15 \times .48 = 20.2'^K$

Weld Design for Column Anchorage

Use 7000 psi for design purposes.

Section Modulus of a 8" × 31.3" H-Beam = 15.06

$M_R = 14{,}000 \times 15.06 = 211{,}000''\#$

Bolt Stress $= \dfrac{211{,}000}{11} = 19{,}200\#$

Net area needed $= \dfrac{19200}{20{,}000} = 1\square''$

Root diam of a $1\frac{1}{2}''$ bolt = 1.283

$1.283 - 0.0626 = 1.22''$

Net area furnished $= \dfrac{\pi \times \overline{1.22}^2}{4} = 1.17\square''$

<u>Use a $1\frac{1}{2}''$ steel bolt</u>

Weld Connection:

Try a $\frac{3}{8}''$ fillet

$L_{needed} = \dfrac{19{,}200}{2 \times 1960} = 5.17''$

Mom. on one weld $= \dfrac{19200 \times 2.5}{2} = 24{,}000''\#$

Guess weld length at 10"

$$S = 1.66\left(1100 - 5\frac{10}{.375}\right) = 1795 \text{ psi}$$

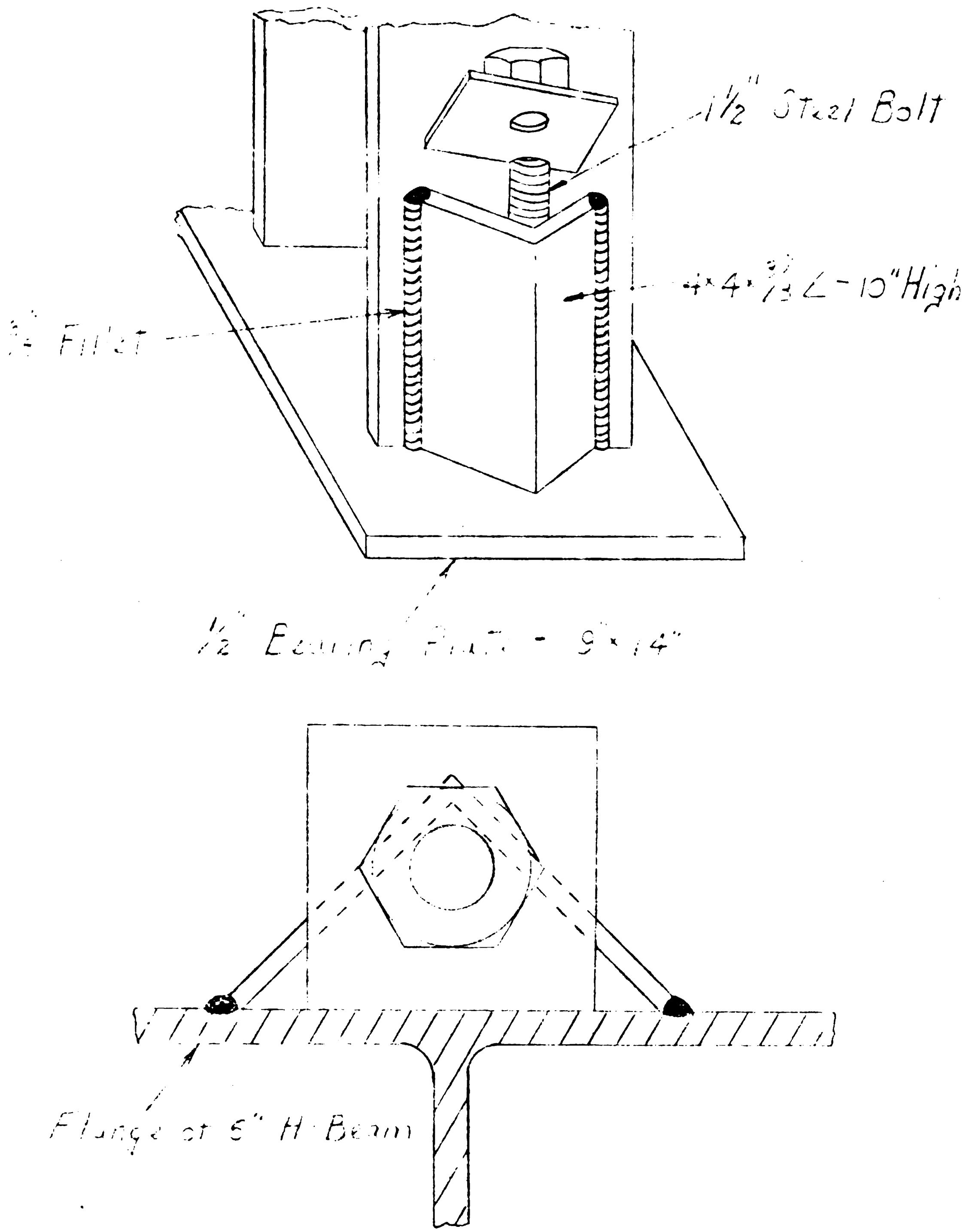
Shear from direct pull $= \dfrac{9600}{10} = 960$ psi

Shear from flexure $= \dfrac{19{,}200 \times 4}{\frac{1}{12} \times 10^3} = 922$ psi

Resultant shear on throat of weld:

$$\sqrt{960^2 + 922^2} = 1330 \text{ psi} < 1960 \text{ psi}$$

Use a $4 \times 4 \times \frac{3}{8}''$ ∠ − 10" high



Column Connection To Foundation

Weld Connection at "b" & "d"

Max. Mom. = $52'^{k}$

I (for butt weld) $= \frac{1}{12} \times .313 \times 6^3 + 2(6 \times 3^2)$

$= 113.63 \ in^4$

Mom. resisted by butt weld $= \frac{7000 \times 113.63}{3} = 22.1'^{k}$

$52'^{k} - 22'^{k} = 30'^{k}$ To be taken by weld

$S = \frac{M}{f} = \frac{29900 \times 12}{10,000} = 35.9$

$I = Ak^2$

$2(t \times 5)3^2 = 35.9$

$t = 0.4''$ Use $\frac{1}{2}''$ plate

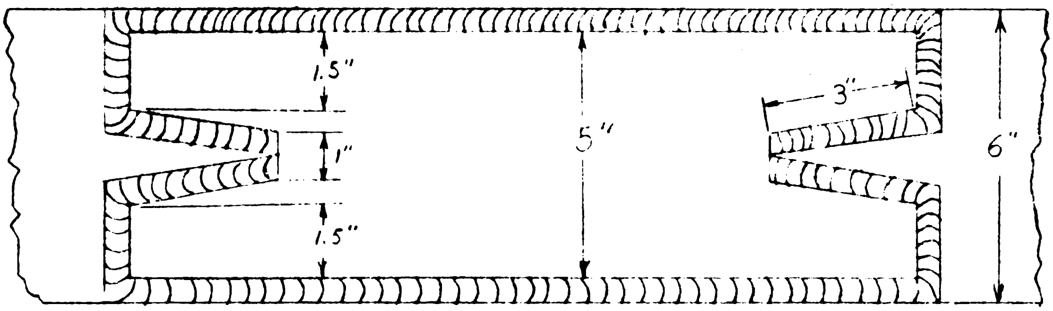
$T = \frac{M}{d} = \frac{30}{.5} = 60,000^{\#}$

Value of $\frac{1}{2}''$ weld $= \frac{1}{2} \times .707 \times 7000 = 2470^{\#}$

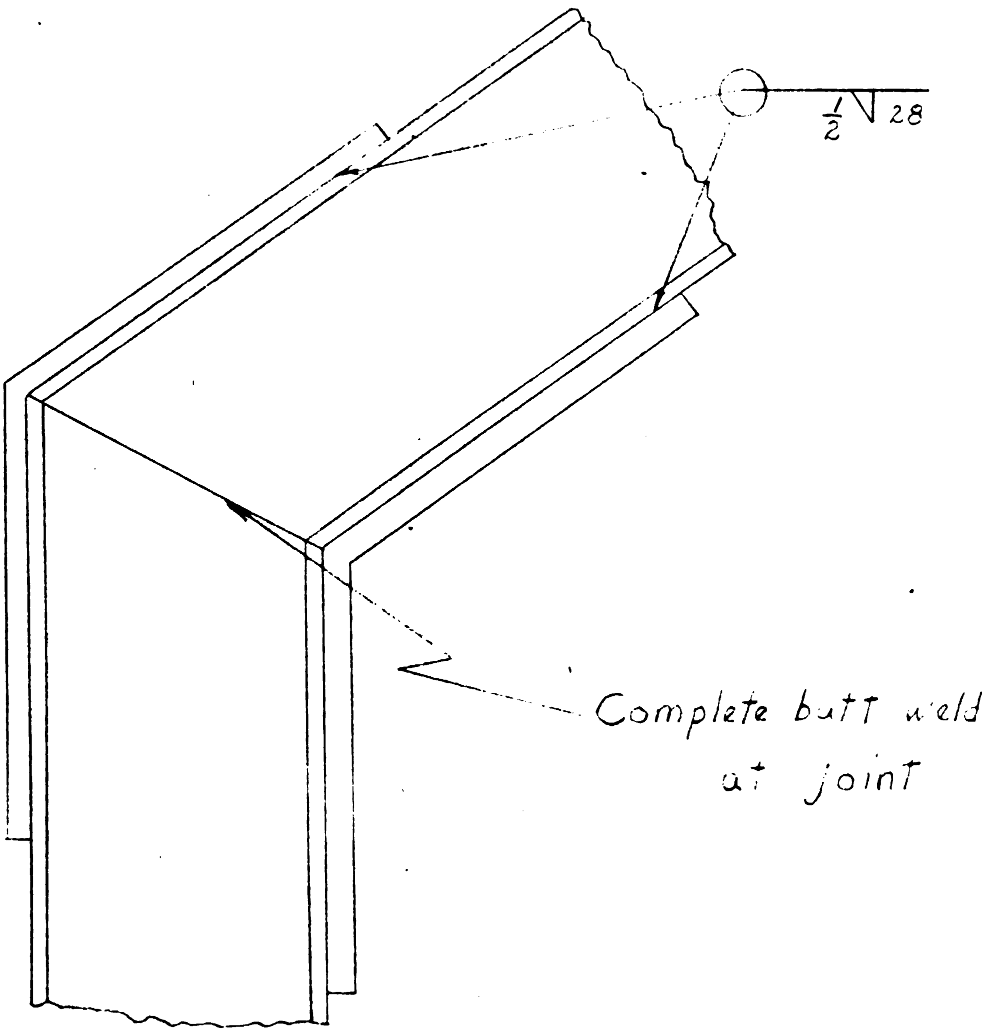
Length needed $= \frac{60,000}{2470} = 24.3''$

However 28" will be provided

Outside Cover Plate at Joint "b" & "d"



Inner & outer plates are the same.



Weld at Peak Connection ("C")

Max. Mom. at "C" = 61.33'K

I (butt weld) = 113.63 in^4

61.33 - 22.1 = 39.23'K to be taken by plate

$$S = \frac{M}{f} = \frac{39,230 \times 12}{10,000} = 47.1$$

$I = AK^2$

$2(t \times 4.5)3^2 = 47.1$

$t = 0.582''$

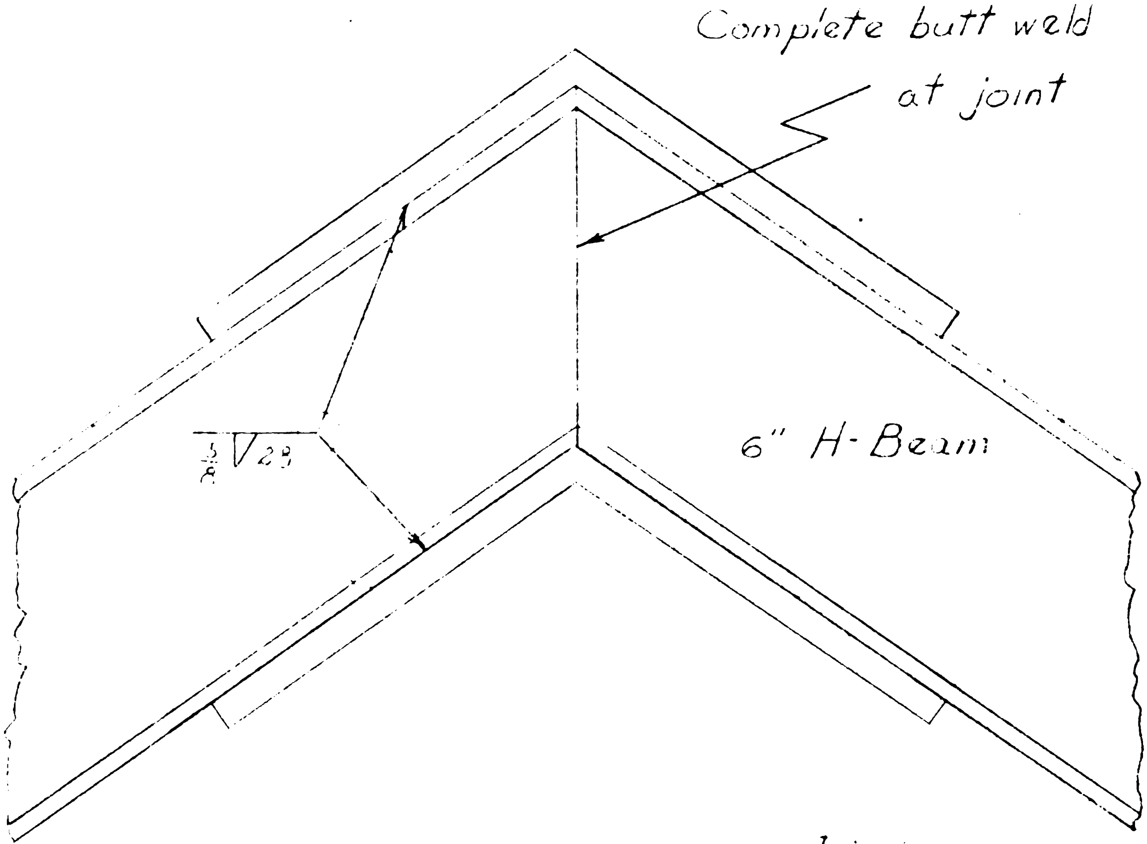
Use 5/8" plate

$$T = \frac{39,000}{.5} = 78,000\#$$

Value of 5/8" weld = $5/8 \times .707 \times 7000 = 3090\#/''$

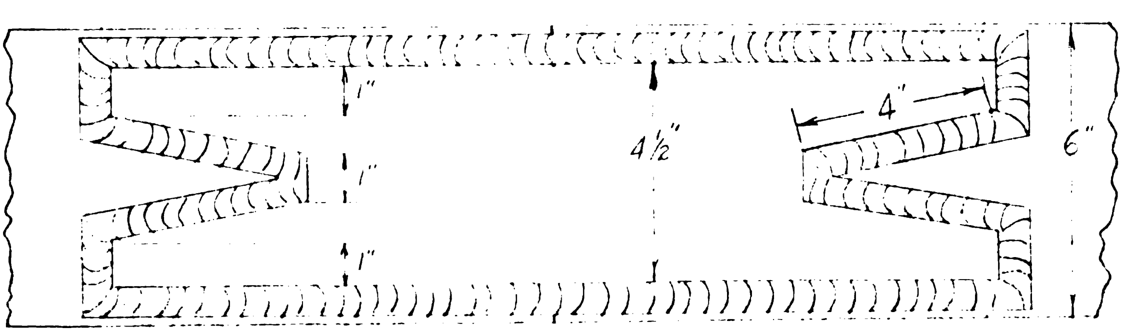
$$\text{Length needed} = \frac{78000}{3090} = 25.2''$$

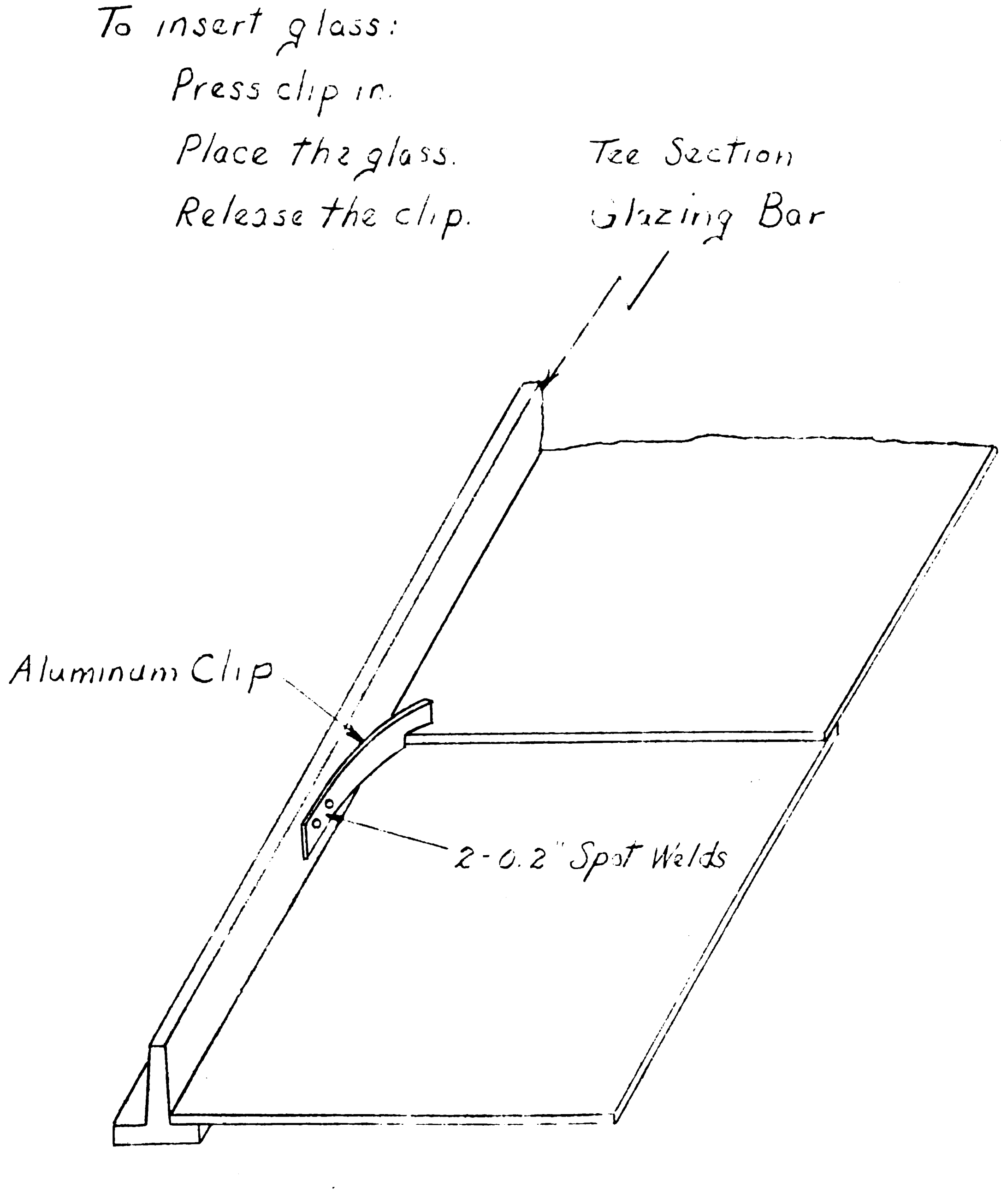
However 28" will be provided

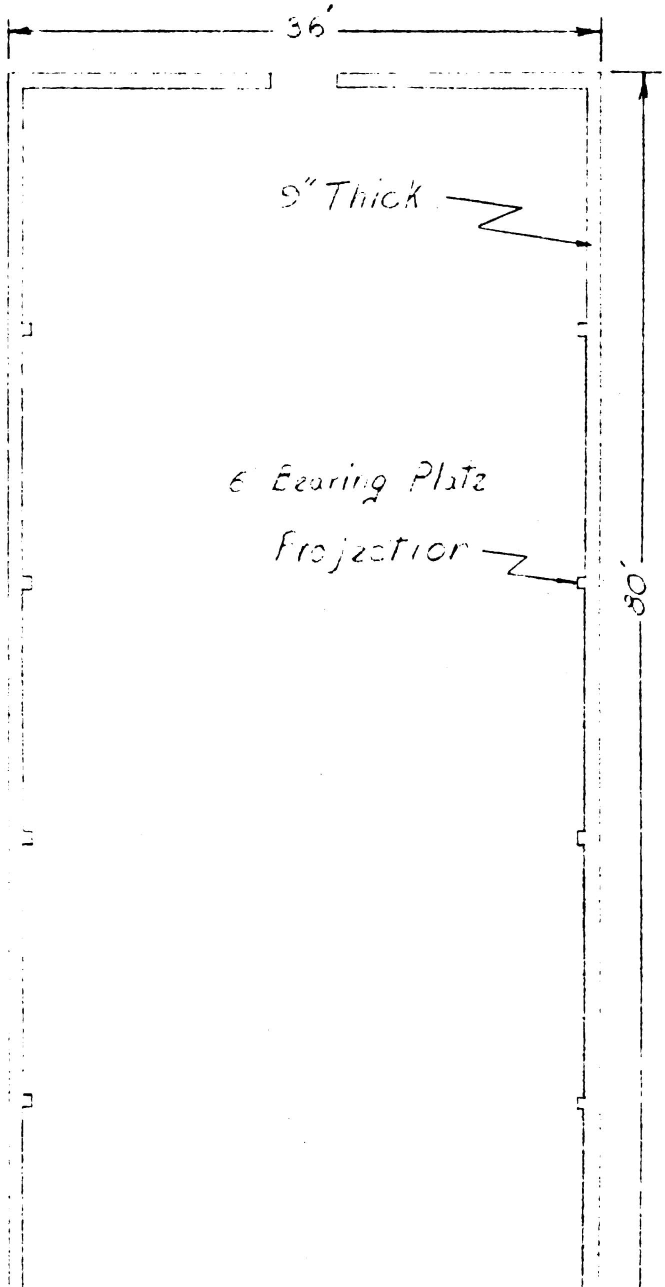


Connection at Peak Joint

Inner plate is the same as the outer.




To insert glass:
Press clip in.
Place the glass.
Release the clip.
Tee Section
Glazing Bar
Aluminum Clip
2-0.2" Spot Welds



Plan View of Concrete Foundation