THE DEVELOPMENT OF A LABORATORY TECHNIQUE FOR MODEL CONSTRUCTION

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THE DEVELOPMENT OF A LABORATORY TECHNIQUE FOR MODEL CONSTRUCTION

Submitted to the Faculty of
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CONTENTS

15630

CONTENTS

CONTENTS

Part VI

Part VII

LIST OF FIGURES

CONTENTS

LIST OF FIGURES

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INTRODUCTION

Present day structural design is based upon theory composed of numerous assumptions, some of which have been proved rigidly by experimental data while others have been shown to be adequate only so long as a large enough safety factor is introduced. The strength and stability of the majority of our structures which have been built in the last thirty years attest the overall adequacy of the theory being used. However, as stated above, this theory is padded in numerous places with high safety factors to insure adequacy in instances where experimental data is lacking. Of course, information which is lacking could be obtained by trial and error -- building a structure, loading it, and observing whether or not the structure supported the loads to which it was subjected. If a person lived long enough and had unlimited resources, he might obtain some very important information in this way. However, as has been done in the past and as will probably be done in the future, designers have attempted to make models of the structures they wished to investigate and, by subjecting those models to loads which simulated the actual loading, learn something about the action of the prototype. Model analysis has proved very useful in some instances.

In the field of rigid frames, for example, little is known about the stresses at the knees. Practically all the information we have at this time came from the results of some full and quarter scale tests conducted several years ago by the U. S. Bureau of Standards, Lehigh and Columbia Universities,

and the University of Illinois. These tests were very expensive, and are not likely to be repeated for checking purposes in the near future. The results of these tests disagreed radically with the stresses predicted by theory. Although a new theory was evolved, to date it has not been checked. The small scale testing that has been done up to this time has not yielded, in general, satisfactory results.

In an effort to help solve this problem, E. J. Scullen designed and constructed at Rensselaer Polytechnic Institute in 1950, as a master's thesis, a model testing frame which could accommodate intermediate scale models (approximately one twenty-fifth to one fifteenth scale.) It was hoped that by testing intermediate scale models, accurate information could be obtained at much less expense than by testing large scale models.

The object of our thesis, then, was to develop a technique for constructing the intermediate scale models. The prime requirement of any technique would be to produce a model which could be expected to simulate the action of its prototype. The technique should be inexpensive. It should be simple, so that master craftsmen are not required to build the model. The technique should facilitate rapid construction of a model. Last of all, the technique should be flexible, lending itself to the fabrication of models of varied shapes.

In the attainment of the object as presented above, the authors constructed many different models and tested these models by various means to determine their suitability for model analysis.

I. CONSIDERATION OF MATERIALS TO BE USED

The problem of building a suitable model for laboratory analysis is a matter not only of the techniques and methods that might be used, but also a matter of what material should be used. Therefore, it is necessary first of all to look at the various materials readily available, and from these, to pick one or two that seem to possess the greatest possibilities for success.

Those materials which seemed to us to offer the best possibilities were: aluminum, steel, plastic, and wood.

An understanding of the problem of using the loading frame with the high loads which it will be desirable to apply will bring to mind a question about the feasibility of using wood and plastic. Wood, of course, is readily available, but the difficulty of fabricating suitable models such that reasonable values could be predicted for their prototypes is a major problem. Also, knowing that eventually it will be desirable to build welded structures, the making of suitable joints with wood that would resemble welded joints presents a problem of questionable solution. The possibility of using plastic is equally as difficult as using wood, not only because of the problem of putting joints together and the low loads plastics are capable of carrying, but of great importance is the fact that residual, stress free models are very difficult to make.

This then brings us to aluminum and steel. These two metals were chosen in preference to other metals due to the

great deal of information that is known about them, such that the problem of making models might be simplified by using techniques already recognized as acceptable. It was decided to use aluminum first, primarily because of a ready supply on hand, along with the fact that the equipment available was best suited for handling that material. The most recognized characteristics of aluminum are its light weight, resistance to corrosion, and high strength, which make it highly desirable for this work. However, there are several properties of aluminum which tend to hinder the possibility of success. These are: (1) the fact that the melting point of aluminum is very close to the welding temperature such that great care is needed to avoid melting the parent material while welding, and; (2) the coefficient of thermal expansion of aluminum is slightly more than twice that of cast iron or steel with the resulting effect that care must be taken to consider expansion and to control it carefully in order to avoid distortion. Secondly, we decided to try steel as a material for a possible second method even if aluminum should work out. This would prove to be very helpful, if successful, since with the higher strength of steel it would be possible to build models which would be capable of carrying the full load of the loading frame.

Thus, with this in mind we started with aluminum as our first material and proceeded as the following pages indicate.

II. ALUMINUM MODULUS CHECK

In the fabrication of models from aluminum by brazing, soldering, or welding it is necessary to heat the aluminum, the temperature required depending upon the method used. Aluminum alloys which derive their strength from alloying and subsequent tempering* are annealed by reheating (if the reheating temperature is high enough) and lose their strength. Aluminum alloys which derive their strength from alloying alone are not appreciably changed by heating them to temperatures below their melting points. Of the alloys tested, 61ST6 is one of the former, while 52SO is one of the latter. We were interested in finding out what happened to these alloys, with respect to their structural strength, specifically their moduli of elasticity, when they were heated to temperatures required for brazing, soldering, or welding. As stated in The Aluminum Company of America's literature, "Alcoa Aluminum and Its Alloys," and "Welding and Brazing Alcoa Aluminum," the results of heating these alloys could be determined for each case only by individual tests. We, therefore, elected to test various heated and unheated samples by using electric strain gage equipment.

A. Electric Strain Gage Equipment**

1. General

The electric strain gage equipment used was

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* Engineering Physical Metallurgy (Chapter 4) - Heyer
** For a detailed description and for operation procedure, see Baldwin instruction book, bulletin 312, entitled "Type L Portable Strain Indicator."

composed of, essentially, bonded wire strain gages, type SR-4, and an electric indicating device for measuring strains, in micro-inches, produced in those strain gages by some type of loading applied to the material upon which the gages were mounted. The indicating device, Baldwin Type L, indicates strains resulting from the loading by measuring the change in electrical resistance produced in the bonded gages.

Leading to the indicator are two sets of wires, one set from the active gage and one set from the compensating gage. The active gage is mounted on the test piece or model which is to be loaded; the compensating gage is mounted on a piece of the same material as that on which the active gage is mounted, is placed near the active gage, but is not loaded. The purpose of the compensating gage is to correct the strain reading for temperature prevailing in the vicinity of the active gage.

2. Operating Procedure

a. Check calibration of indicating device if equipment is being used for the first time.*

b. Check batteries; if the pointer remains in the red part of the dial, new batteries are needed.

c. Connect leads from compensating and active gages to their respective terminals.

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* See Calibration Check Procedure below.

d. Turn battery switch to ON position, and allow 10 seconds for tube warm-up.

e. Set the correct value of gage factor, as supplied by the gage manufacturer, on the gage factor dial.

f. Bring the pointer to zero, and read the indicator dial. This is the zero reading.

g. Load the test piece, bring the pointer to zero, and read the indicator dial. This is the loaded reading. The difference between the zero reading and the loaded reading is the strain produced in the test piece by the load, in micro-inches.

For best results, use hot soldered joints in connecting lead wires to gages, and make both lead wires to any one gage the same length. Also, place the compensating gage as near as possible to the active gage.

3. Calibration Check

If the indicating equipment is being used for the first time, it is best to check its calibration before using it. A brief check procedure follows:

a. Connect the active and compensating gages to the equipment as above, and set the gage factor dial.

b. Take a zero reading.

c. Connect a resistor of known value, (R_c), in parallel with the active gage. A resistor of

about 500,000 ohms is satisfactory.

d. Read the indicator dial, and subtract the zero reading from this second reading to obtain a value in micro-inches which we will call "e".

e. If R_g designates the resistance of the active gage, which is approximately 120 ohms, then R_c referred to in "c" above equals R_g divided by e times the gage factor, G.

$$\text{ie, } R_c = \frac{R_g}{(e)\ (G)}$$

This computed value of R_c should equal the value of the known resistor.

B. Preparation of Samples

Strips of 61ST6 aluminum about 9 inches long and about 1 inch wide were cut from sheet aluminum 0.091 inches thick. The cutting was done on a metal cutting bandsaw. The edges of the pieces were sanded to remove cutting burrs. Similar strips 0.271 inches thick were cut from 52S0 stock. Two samples each of 61ST6 and 52S0 were then heated with an oxy-acetylene torch, with an effort being made to simulate the welding and soldering temperatures. As an index to the correct temperature, the pieces were heated until the flame impinging upon the aluminum became tinted with yellow. This was an arbitrary temperature measuring index (which later proved inaccurate) adopted after observing the flame while actually joining pieces of aluminum. The heated pieces were then air cooled.

Another strip of 61ST6 was heated in an electric furnace to the actual temperature required for welding, then allowed to cool in air.

An electric strain gage of the SR4 type was then mounted on the centerline of each piece at about its mid-length.

C. Explanation of the Gage Mounting Procedure

1. Clean the surface upon which the gage is to be mounted. For this purpose, light grinding or sanding with emery cloth may be employed.

2. Degrease the surface with carbon tetrachloride (acetone may be used).

3. Mount the gage:

a. Scribe lines to indicate gage orientation.

b. Coat test surface with a layer of Duco household cement and allow it to dry about 20 minutes.

c. Coat test surface with a second liberal coat of Duco cement and allow it to dry until it becomes slightly tacky.

d. Press gage into position with proper orientation and gradually press out the excess cement with the fingers. Watch the corners of the gage particularly.

e. Keep a slight pressure on the gage until the cement will hold the gage to the surface (about 3 minutes required).

f. Cure the gage:

(1) Cure gages under a slight pressure - about

1 pound will be sufficient.

(2) Directly on top of the gage, place a layer of waxed paper, then a piece of sponge rubber, then the weight. This combination allows the slight pressure of the weight to hold the gage in place while curing.

(3) Allow gages to cure at room temperature for at least 24 hours. If curing is taking place in an atmosphere of high humidity, allow a longer curing time.

(4) As an alternative to (3) above, an infra-red heating bulb may be placed near the gages, such that a temperature of 150° is maintained, in which case only about 5 hours curing time is required.

4. Cover gages with a light coating of Ceresin wax to keep out moisture. (If testing is being conducted in a laboratory, in all probability no wax coating will be required.)

D. Check of Mounted Gages

After gages have been cured, it is necessary to check them before straining them. The resistance of a strain gage should be about 120 ohms. The leakage resistance to ground should be infinite. By using an ohmeter, check the above resistances. The gage resistance, in order to be satisfactory, should be within 2 ohms of 120 ohms. The resistance to ground should be at least 50 megohms.

E. Testing of Samples and Results (See Figures 1 and 2)

The samples were loaded as cantilevers, one end being held with a "C" clamp to a rigid support while the other end received the load.

Loading was accomplished by suspending an empty beer can, into which shot was placed, from a knife edge which rested in a deep scribe mark at the end of the test piece. Loads were varied by varying the amount of shot placed in the can. The shot was weighed on a laboratory balance for accuracy.

Representative results of these tests are shown on the next few pages.

Modulus Check

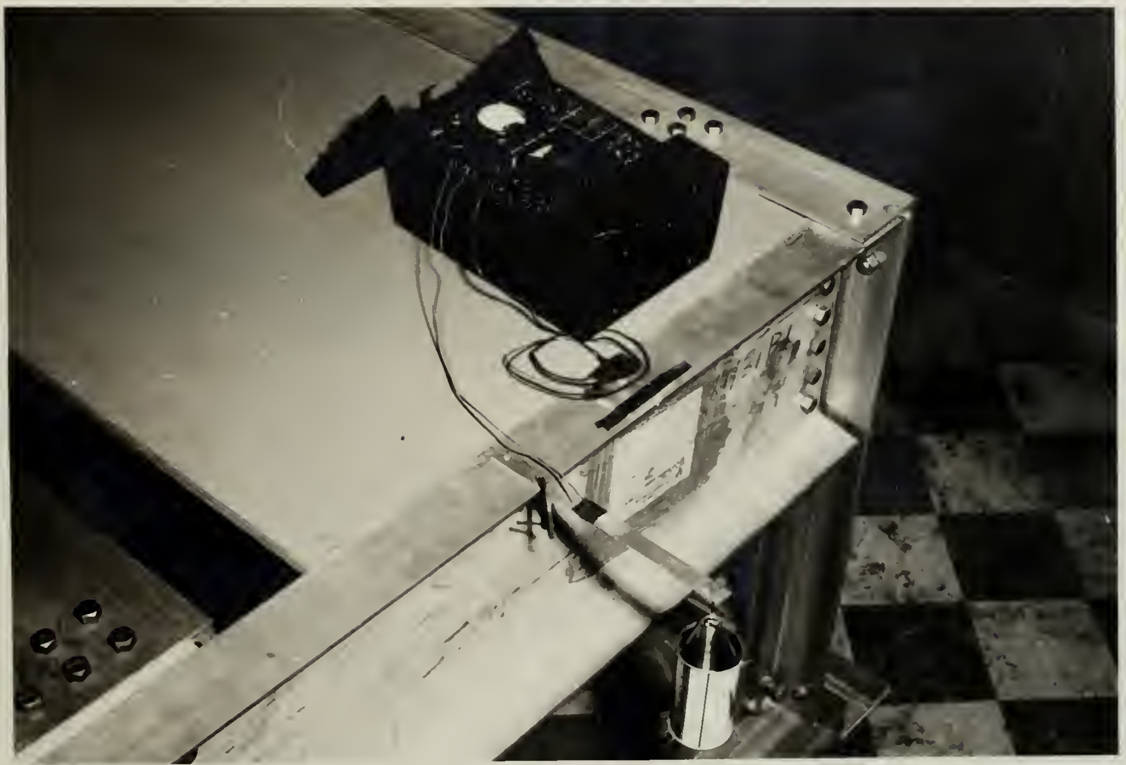


Figure 1

Method of Loading For "E" Check

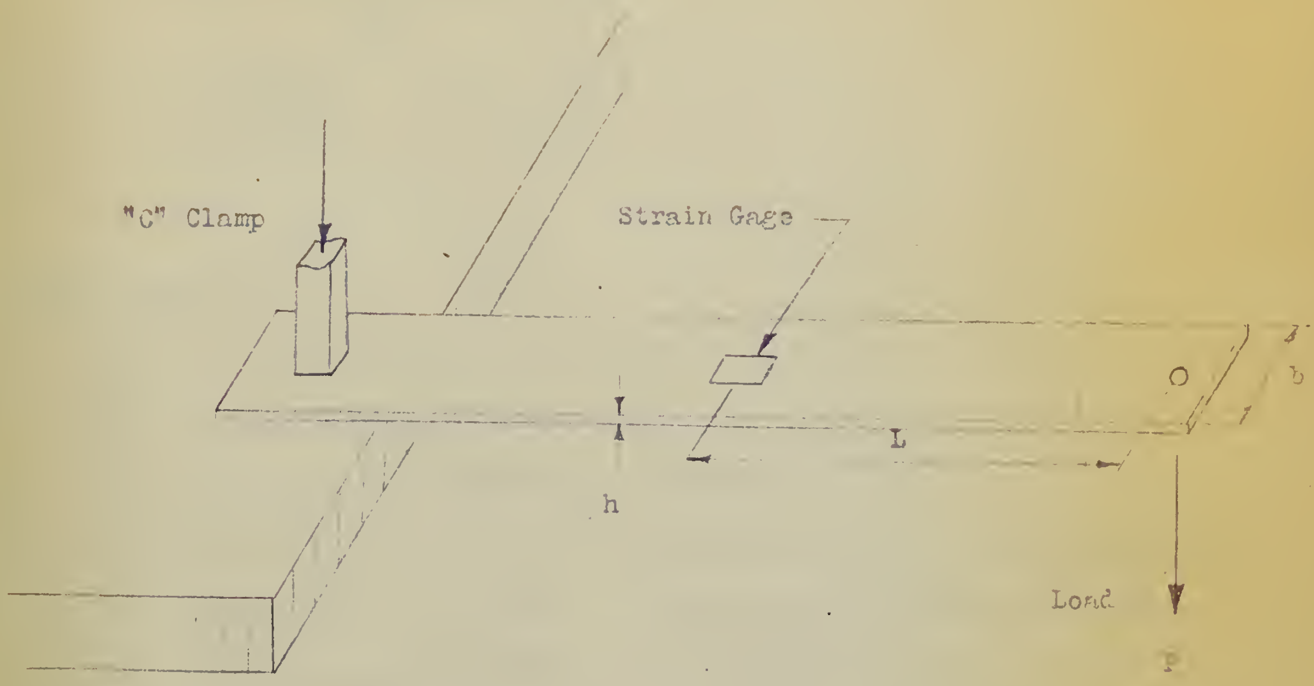


Figure 2

Form of Computations for "E" Check

Computations:

$$I = \frac{bh^3}{12}$$

$$f = \frac{Mc}{I} = \frac{(P)(L)(h/2)}{\left(\frac{bh^3}{12}\right)} = \frac{6\ PL}{bh^2}$$

$$E = K\ \frac{\text{Stress}}{\text{Strain}} = K\ \frac{f}{e} = \frac{6\ PL}{\frac{6\ h^2}{e}}\ K$$

Terms Defined:

I, moment of inertia, inches^4

b, width of test piece, inches

h, thickness of test piece, inches

f, bending stress in extreme fiber of test piece, lbs/inch^2

e, unit strain indicated by SR-4 gage, micro-inches/inch

E, a number proportional to the modulus of elasticity

L, distance from point of application of load to the center of the strain gage, inches

M, bending moment, inch lbs.

K, a constant which corrects the strain indicated by the SR-4 gage to the value actually existing at the extreme fiber of the test piece.

P, load applied, pounds

Heated 61ST6 Aluminum

Dimensions of Test piece:

$b = 0.817$ inches

$I = 5.21 \times 10^{-5}$ inches^4

$h = 0.091$ inch

$L = 5.34$ inches

$E = \frac{P}{e}(.00466)$

Strain Reading

P, lbs.	Zero	Loaded	e	E	f
.25	0924	1043	119	9.78	1165
.50	0924	1161	237	9.82	2330
.75	0923	1281	358	9.78	3490
1.00	0923	1400	477	9.78	4660
*1.25	0923	1519	596	9.78	5840
*1.50	0923	1637	714	9.80	7000

* Strains recorded are those existing 10 minutes after the load was applied. Immediately upon applying the load, the strain was somewhat higher, but gradually decreased to the above values. After 10 minutes, there was no significant change in the strain reading.

Unheated 61ST6 Aluminum

Dimensions of test piece:

$b = 0.837$ inches

$I = 5.33 \times 10^{-5}$ inches^4

$h = 0.0915$ inches

$L = 5.375$ inches

$E = \frac{P}{e} (.00457)$

	Strain Reading				
P, lbs.	Zero	Loaded	e	E	f
.25	1498	1617	119	9.60	1143
.50	1497	1735	238	9.60	2281
.75	1496	1853	357	9.60	3430
1.00	1494	1970	476	9.60	4570
*1.25	1493	2086	593	9.62	5700
*1.50	1493	2201	708	9.68	6860

* Strains recorded are those existing 10 minutes after the load was applied. Immediately upon applying the load, the strain was somewhat higher, but gradually decreased to the above values. After 10 minutes, there was no significant change in the strain reading.

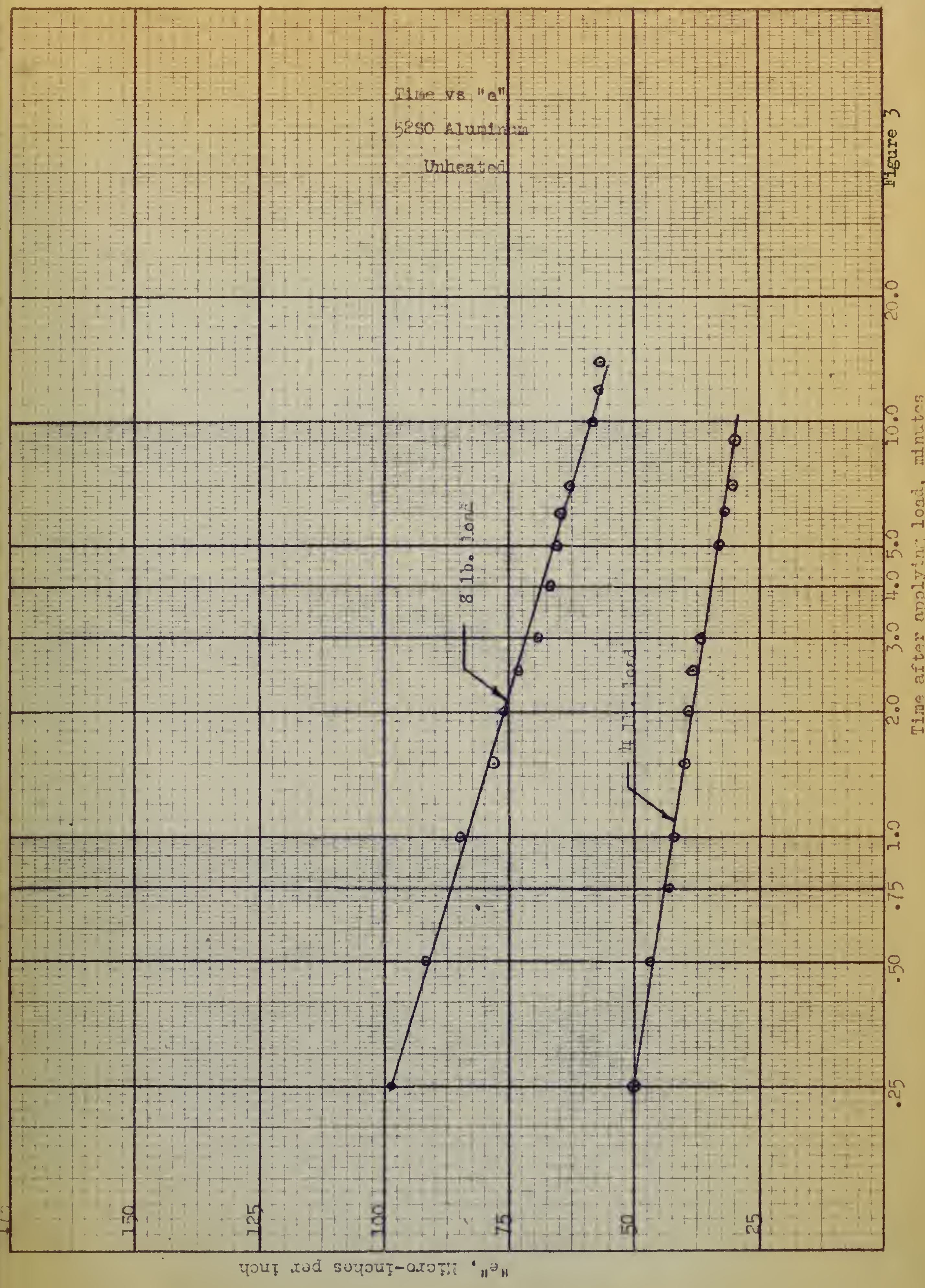
F. Conclusions on "E" Check

As shown on the preceding pages, the torch heating of the 61ST6 strips changed their value of "E" about 2%. Consistent, stable strain readings were obtained as long as the stresses were below about 5000 psi. For stresses above about 5000 psi, strains fluctuated with time.

Stressing of the 52SO strips, heated and unheated, produced strains which varied radically with time, even at low values of stress. As shown on figures 3 and 4, this variation appears almost linear on a semi-log graph plot. This action appears similar to creep, only in a reversed direction, the test piece seeming to gain strength (i.e., become strained less) the longer the load of constant value remains on it. The authors consulted with members of the Metallurgy Department in an effort to explain this action, but were unable to find a satisfactory answer.

The authors concluded from the results of the above tests that 52SO definitely would not be suitable for a model material, but that 61ST6 would probably be satisfactory.

In an effort to determine the cause of poor results in beams #1 through #7, strips of 61ST6 were placed in an electric furnace to find out the actual temperature required for fusion. It was determined that 1125° F. was required for fusion of the parent metal with the eutecrod filler. The temperature left the metal in a very soft distorted condition after being heated for about 15 minutes. When an effort was made to subject a strip to a flexural load, it collapsed.


Time vs "e"
52SO Aluminum
Unheated
Figure 3
8 lb. load
4 lb. load
.25
.50
.75
1.0
2.0
3.0
4.0
5.0
10.0
20.0
Time after applying load, minutes
175
150
125
100
75
50
25
"e", Micro-inches per inch

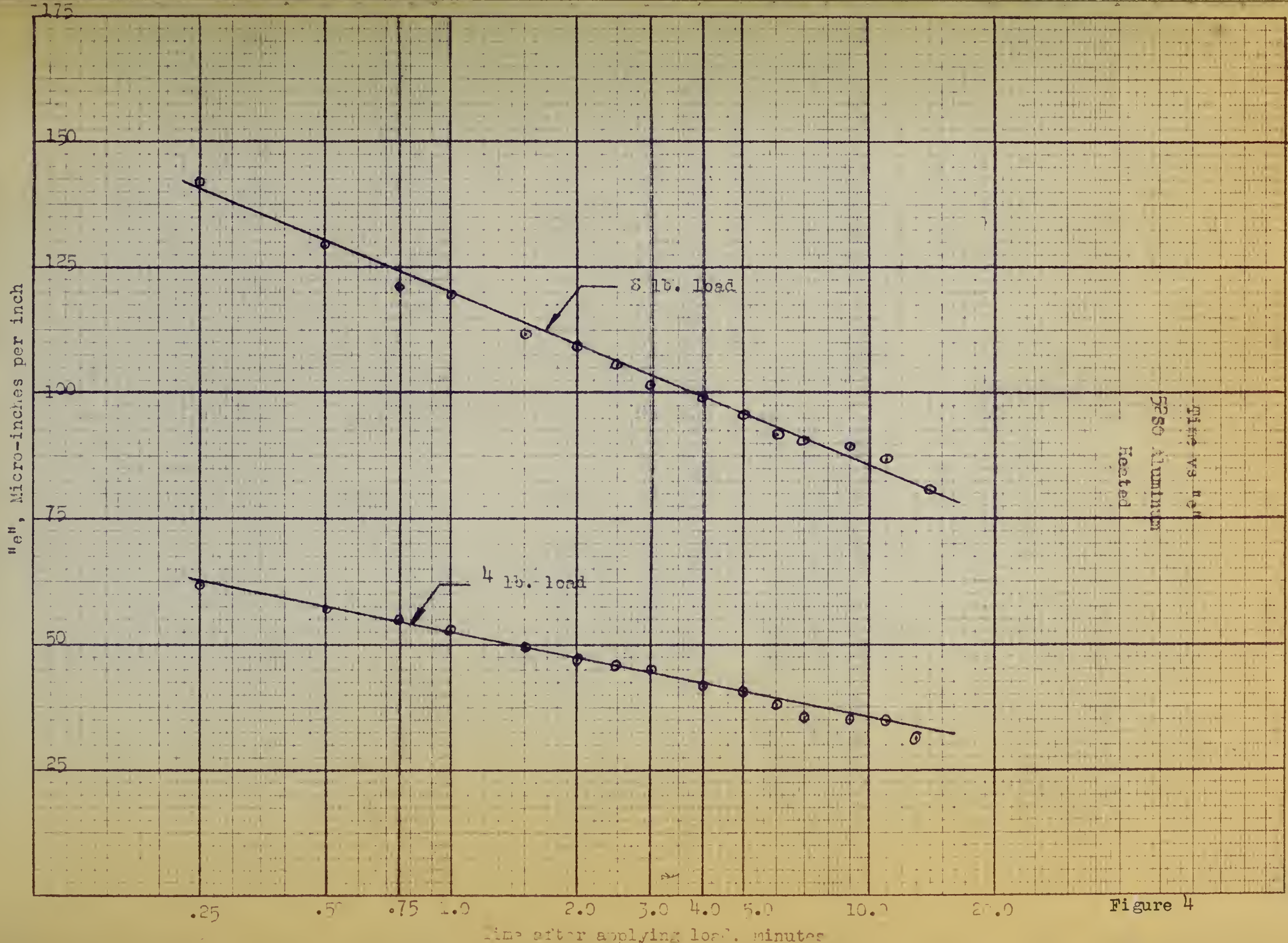

Time vs "e"
52S0 Aluminum
Heated
8 lb. load
4 lb. load
"e", Micro-inches per inch
175
150
125
100
75
50
25
.25
.50
.75
1.0
2.0
3.0
4.0
5.0
10.0
20.0
Time after applying load, minutes

Figure 4

Thus, it was impossible to get strain reading with any meaning from these pieces. The authors concluded that, since these strips had been rendered useless for structural purposes by the temperature required for fusion, at least in the vicinity of the weld when a torch was being used to supply the heat, a similar condition of softness and distortion existed. It was seen, then, that the amount of torch heating given the 61ST6 strips, as determined arbitrarily by the slight discoloration of the flame as it impinged upon the surface of the aluminum, was in reality considerably below the temperature required for fusion during welding with eutecrod. This accounts for the closeness of the valves of "E" as determined in the previous test. (The actual temperature was probably near that required for soldering with the alladin rod.) Welding was then discarded as a method of making aluminum models, and our efforts were concentrated upon the lower temperature alladin soldering method.

III. FABRICATION OF TEST BEAMS

The two materials used for the making of the test beams were steel and aluminum, with the reasons for this choice as dictated in part I. This section is dedicated to the methods and techniques used, and the problems encountered in the fabrication of the test beams. It is divided into two sub parts based on the material used.

A. Aluminum

Aluminum was our first choice for the reasons previously explained. It is best perhaps to begin with the ways the material was prepared.

1. Preparation of Material

The aluminum for the beams was obtained from sheet aluminum of the 61ST6 type, and of varying thicknesses. A metal cutting bandsaw was used to obtain the desired sizes, with great care being taken to insure that straight pieces were obtained. Of interest at this point, would be the fact that it is necessary to be certain that a sharp blade is used in the saw if a straight cut is to be obtained. The sawed edges were next ground down to a smooth finish on a disc sand-wheel and burrs left from this sanding were taken off with a belt sander. This process insured that the extreme edge was not only clean, but also smooth such that close fitting tolerances were obtained when joining pieces. In the making of wide-flange beams in which the web of the beam is butted against the middle of the flange, it is felt by the authors

that even the thin aluminum oxide present at the joint should be cleaned off. This was accomplished by using a fine emery cloth and cleaning the center of the flange along which the web would touch. The surfaces of the web near the edges were also cleaned up for a short distance, using emery cloth, to insure that the fillet of joining material would have a good surface on which to adhere.

2. Jigs

Making a jig to hold the pieces together while joining them was one of the most difficult problems encountered. We will explain not only the most successful method used, but also the others that were tried. It can be easily understood that the problem of jigging is not just one of holding the materials, but also a problem of holding them extremely accurately in their correct relation to each other. For example, in the making of wide-flange beams it is necessary that the web be held exactly in the center of the flange. The problem of jigging is applicable to all the different methods of joining the materials; therefore, it is only necessary to present it once.

At the beginning, the most important problem of jigging seemed to be one of being able to insure that the pieces were held in exact alignment. It was with this in mind that the first jig was made.

This jig was constructed using three pieces of aluminum angle, lined with asbestos along the outside against

which the main material would be held, as shown in Figure 5. Angle A and angle B were clamped together to hold the flange securely. Then angle C, which was a cut down angle to give the maximum torch clearance, was used in conjunction with angle A to hold the web securely. As can be seen in the sketch, this method not only gave assurance that the web and the flange were at right angles, but also afforded clear access for measurement to insure that the web was at the midpoint of the flange. The several disadvantages that became apparent in using this method were as follows: (1) in spite of the asbestos lining, too much heat was lost through contact with the metal jig, such that the heating of the piece was irregular and thus the welding temperature, which is very critical, was hard to regulate; (2) the two pieces which were to be joined were both held clamped together, and although of the same material, they warped because of the unequal expansion due to localized heating; and (3) most important, as there was no support for the upper part of the flange, there was a tendency for it to distort to one side or the other due to the concentrated heating near the centerline. Therefore, in the method of welding using eutecrod, as will be explained later, the temperatures required are too high; however, in the soldering method, with the slightly lower temperatures, it might be possible to use the above procedure. The method finally used, as will be explained, seems to be a much more practical way of solving the problem.

Jig # 1

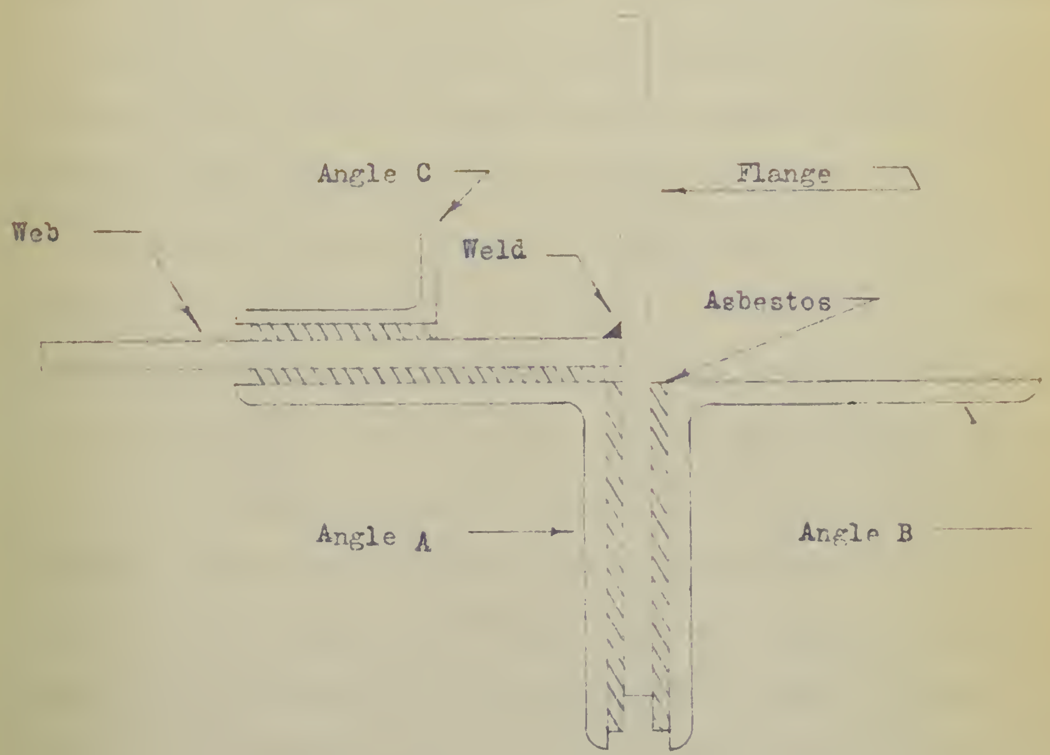


Figure 5

The second jig was made with the idea in mind of being able to support both flanges and the web at the same time to overcome any tendency of these members to warp due to lack of support. We then constructed a jig, the cross section of which is shown in Figure 6. The two angles were made about 30 inches long, which of course limited the length of beam it was possible to make. The angles were lined with asbestos and one was fixed to a base plate to prevent movement. The other angle was made a sliding variety which was held in place by clamping it to the fixed angle with "C" clamps to provide the pressure needed to hold the beam while welding it. The correct location of the web was obtained by using a piece of sheet aluminum bent on a brake such that it held the web up between the two flanges as shown in the sketch. In the process of welding, the two upper welds were placed, the beam was turned over, and the two other welds were placed. This method, at first, seemed to be the solution to all jigging problems; however, one of the problems encountered in the first jig was present along with a new one. The old problem was that of controlling the heat, and still hadn't been solved. The new problem was as follows. In clamping the two angles together we tried to put just enough pressure to cause the joints to be tight, but not really forced together. This appeared fine from the standpoint of expansion, but still proved inadequate. From the sketch it can be seen that there is no easy way to provide support on top of the web, and still leave room in

Jig # 2

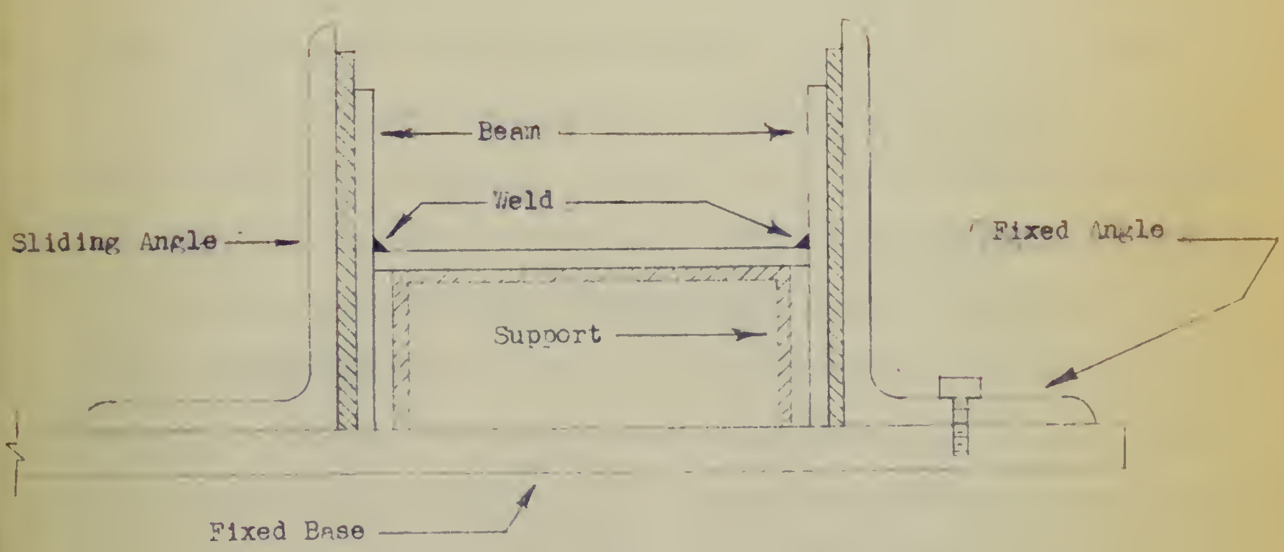


Figure 6

which to use the acetylene torch. Therefore, due to no top support, and the fact that the web was bound to be held by the flanges with more pressure in some places than others, there was a definite tendency for the web to rise off its support and buckle upwards when the heat was applied. The flanges seemed to stay in line, but the method resulted in a beam whose web was not exactly centered between the flanges. Therefore, this beam could not be expected to check according to the deflection theory being used.

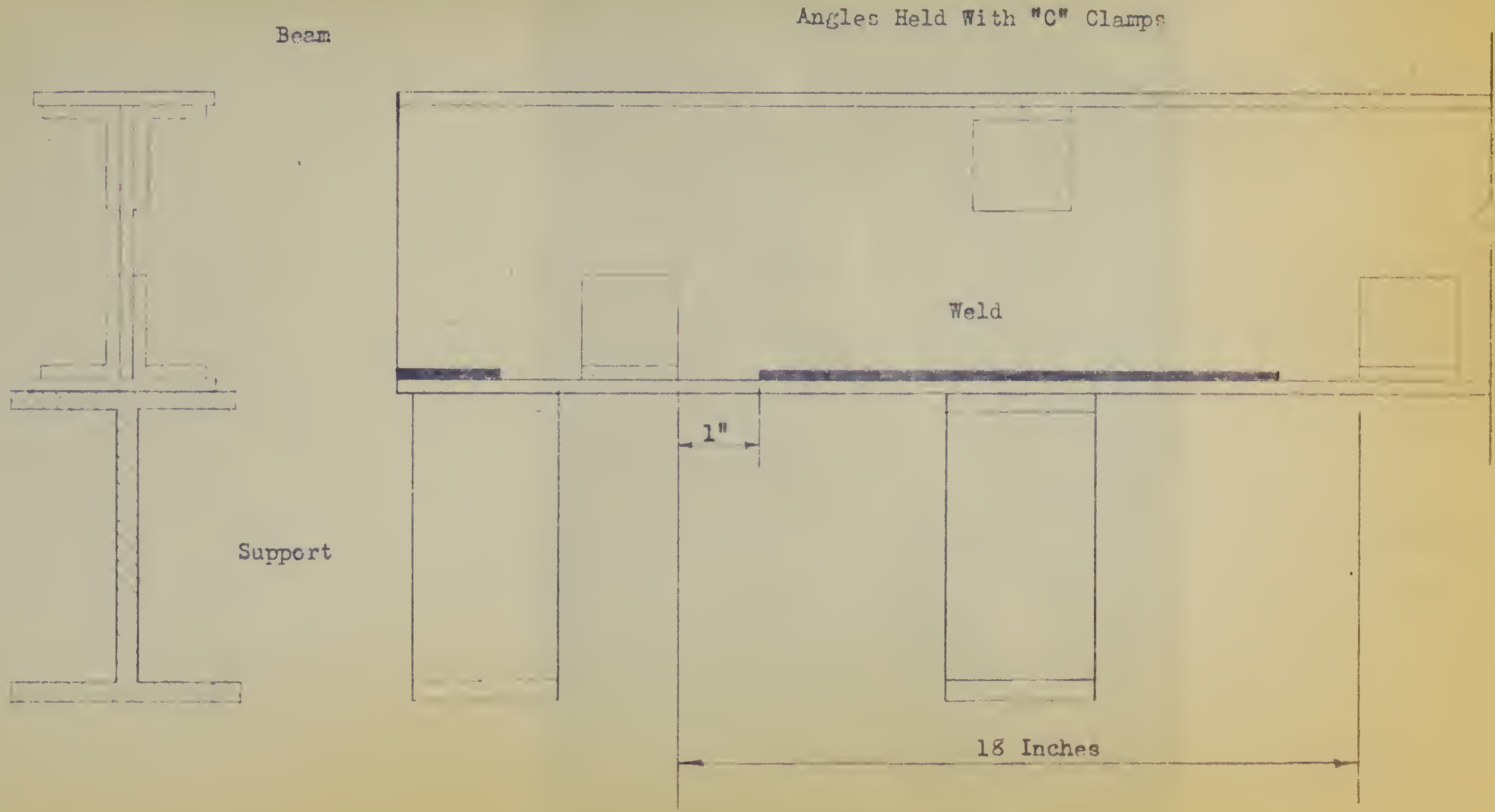
Our third design, which eventually led to our final and very successful method, came as an effort to eliminate the defects that were noted in our previous jigs. First of all we wanted to eliminate the heat loss due to contact of other materials with those we were welding. It was also necessary to find some way to support the flanges and web such that they would be held in the proper orientation with respect to each other. These problems were solved by using 1-inch by 1-inch steel angle cut in 3/4-inch lengths. The flange and the web were held at right angles by clamping pieces of the angle to both the web and the flange along one side leaving the other free for welding. Then by adjusting the location of the angle on the flange the web could be placed in the proper location. This arrangement of angles was made along the whole length of the beam, the weld being placed down the free side. However, the flange and the web, which were clamped rigidly together, distorted due to the heating. This resulted in beams which would not check out.

Finally, we used the same method as described in the previous paragraph, but clamped one piece of angle to each side of the flange, directly opposite each other, leaving enough clearance between the angles to insert the web and hold it firm and perpendicular. (See Figures 7 and 8.) The pairs of angles were placed about one foot apart.

A clamp preventing the web and flange from separating, but allowing longitudinal movement, was placed along the beam at each set of angles. The whole beam was then supported on pedestals placed at the mid-point between the angles. This was done such that the beam reaction at the support would keep the joint between the web and the flange tight. The welding was done next, welding first on one side of the web for a length of about 8 inches, then on the other side of the web. It is important not to weld any closer than 2 inches to the angles. The purpose of welding on the opposite side immediately was to utilize the heat that had already been put into the pieces. This also minimized distortion, since stresses resulting from heating on both sides of the web tended to be cancelled out. After the whole beam was welded this way, it was necessary to take off the angles and clamps and weld up the remaining spaces. This method gave us consistent results on all beams constructed, as the results in the following sections will indicate.

3. Check of the Loading Device

It was felt by the authors that a check of the vertical loading frame (see Figure 9) was necessary in order



Jig # 3 Modified

Figure 7

Jig #3 Modified

Figure 8

Vertical Loading Frame

Figure 9

to insure that accurate results would be obtained. Therefore, an extruded "T" beam was obtained and subjected to a load test on the loading frame. The method used to check our procedure consisted of loading the beam and comparing the actual and computed deflections. This set up is shown in Figure 10.

The beam, when in the loading frame, was supported on knife edges which were rounded on the underneath side so that no restraint was placed on them. The load consisted of lead shot placed in a bucket. It was applied to the beam by means of a knife edge, attached to a yoke (see Figure 11) which supported the bucket. The deflection was measured by a 1/10,000 of an inch direct reading dial, placed underneath the mid-point of the span. The dial holder is shown in Figure 11 and was made such that it would also serve as a dial holder for taking readings on the horizontal loading frame.

A comparison of the actual deflections, under load, with the deflections computed by conventional formulae show an average difference of 1.4%. This check was considered close enough to allow the use of this vertical loading frame for future model tests.

to insure that accurate results would be obtained. Therefore, an extruded "T" beam was obtained and subjected to a load test on the loading frame. The method used to check our procedure consisted of loading the beam and comparing the actual and computed deflections. This set up is shown in Figure 10.

The beam, when in the loading frame, was supported on knife edges which were rounded on the underneath side so that no restraint was placed on them. The load consisted of lead shot placed in a bucket. It was applied to the beam by means of a knife edge, attached to a yoke (see Figure 11) which supported the bucket. The deflection was measured by a 1/10,000 of an inch direct reading dial, placed underneath the mid-point of the span. The dial holder is shown in Figure 11 and was made such that it would also serve as a dial holder for taking readings on the horizontal loading frame.

A comparison of the actual deflections, under load, with the deflections computed by conventional formulae show an average difference of 1.4%. This check was considered close enough to allow the use of this vertical loading frame for future model tests.

Method of Loading for Beam Tests and Form of Computations

All Dimensions are in inches.

Computations:

Moment of Inertia,

$$I_{flange} = 2\left(\frac{bt^3}{12}+btc^2\right), \qquad I_{web} = \frac{t(d-2t)^3}{12}$$

I Total equals I flange + I web.

Deflection,

$$D = \frac{PL^3}{48\,EI}$$

D- Deflection in inches
L- Span length in inches
E- Modulus of Elasticity
I- Moment of Inertia
P- Load in pounds

Stress

$$f = \frac{Mc}{I}$$

f- Stress in psi
M- Moment in inch-pounds
I- Moment of Inertia
c- As shown above

Figure 10

Loading Yoke and Deflection

Dial Holder

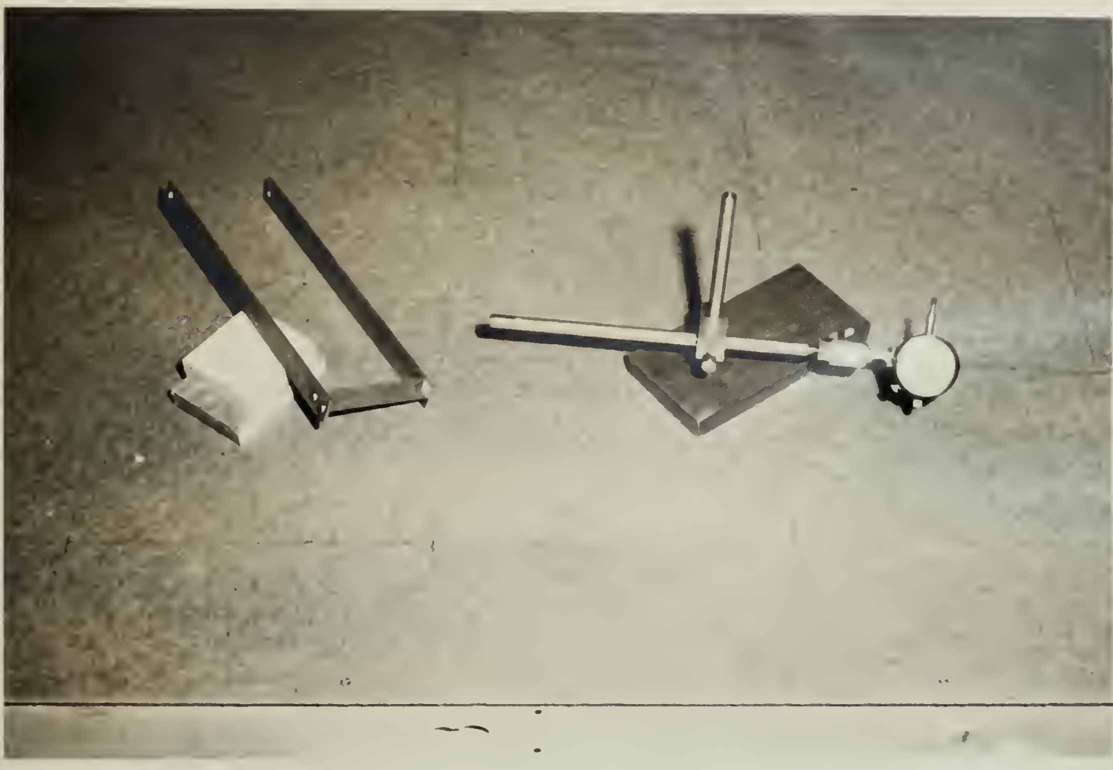


Figure 11

Extruded "T" Beam

(Beam #1)

Dimensions of Beam
(See Figure 10)

b = 1.24 inches
t = .128 inches
d = .87 inches
L = 34 inches

Neutral Axis was computed to be .227 inches above the base.

Moment of inertia (I) = .0158 inches^4

Deflection (D) = 5.18 P (10^{-3})

Stress (f) = 345 P

Load	Dial Reading Zero	Dial Reading Loaded	Act. Def.	Comp. Def.	% Dif.	Stress
1.6	.07551	.08330	.00801	.00830	0	551.0
2.16	.07566	.08679	.01128	.01123	.45	745.0
3.0	.07555	.09170	.01604	.01555	3.05	1035.0
4.0	.07560	.09708	.02153	.02073	3.72	1380.0
5.0	.07560	.10160	.02600	.02590	.38	1720.0
7.0	.07561	.11201	.03641	.03630	.32	2320.0
9.0	.07561	.12314	.04753	.04670	1.74	3100.0
11.0	.07561	.13320	.05759	.05700	1.02	3800.0
13.0	.07561	.14382	.06821	.06730	1.33	4480.0
15.0	.07561	.15489	.07928	.07775	1.93	5180.0

4. Technique of Joining Flanges to Web

There were three methods used by the authors in fabricating models from aluminum. They were eutecrod welding, soldering, and furnace brazing. It is in this section that we will discuss the three methods and the results of the tests run on the models constructed by each method.

a. Eutecrod Welding

(1) Welding difficulties

The difficulty in welding with eutecrod is the high temperature required for fusion, which approaches the melting temperature of aluminum. In actual practice the two temperatures differ only by about 50 degrees and great care must be exercised not to bridge this differential. The parent material will warp and disintegrate vary quickly when the melting point is approached. Another important point to consider is that, in the vicinity of the weld, the yield strength of the material has decreased considerably, resulting in the material no longer being homogeneous. These two facts are very important and must be considered in view of the final results desired.

(2) Flux

The flux used was supplied by the eutecrod company to be used in conjunction with their rod. It is a powder that is mixed with

water to form a paste, which is spread on the joint to be welded. Care must be exercised in applying the flux, insuring that only the surfaces at the joint are covered. This is true because, if too much is used, the flux allows the eutecrod to run as it melts, covering a weld area that is too large. This point is not essential in making a good weld but it appears to help.

(3) Method of welding (See Figure 12)

The actual method used in welding is similar to that used in any torch welding, with a modification. The big change adopted was in the way the heat from the torch was applied to the joint. Rather than directing the flame almost perpendicular to the joint, we found it better to shoot the flame parallel to the joint, heating with the side of the flame. Using this method, it was found that there was better control of the heat, giving effective preheating with less chance of overheating. The rest of the welding procedure is the same, i.e., feeding in welding rod as the temperature gets high enough, and moving along fast enough to give an even fillet.

Method of Welding

Figure 12

(4) Test Samples and Results

In order to be sure of the amount of load eutecrod welding would sustain, a series of test samples were made. They were of the form as shown in Figure 13 with the dimensions and results as shown below.

Shear test

a = 1 inch
L = 2 inches
b = 3/4 inch
h = .091 inch

Under a load (P) of 1590 pounds, the parent material broke across the 3/4 inch dimension.

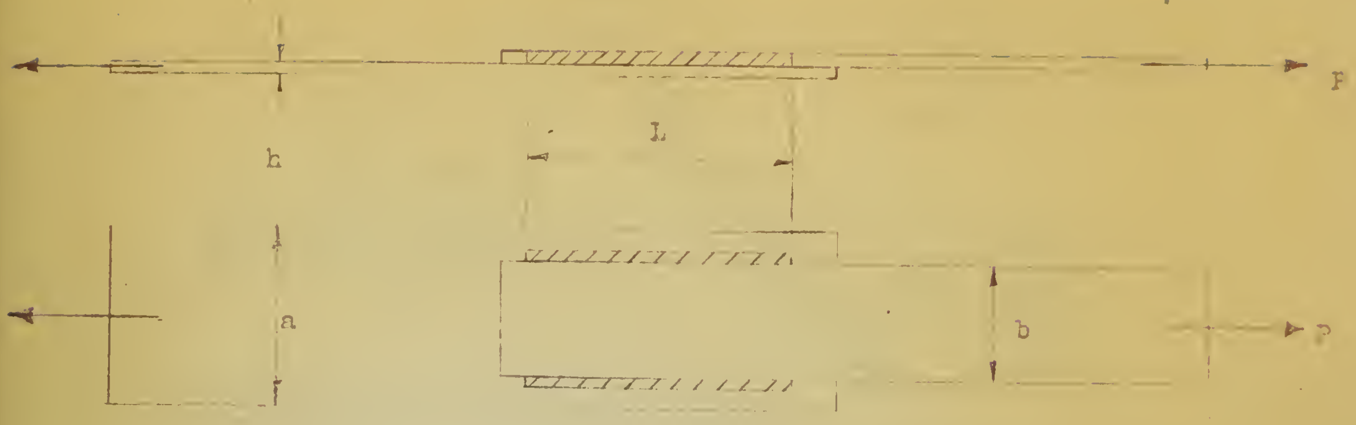
Tension test

a = 1 inch
b = 3/4 inch
h = .091 inch

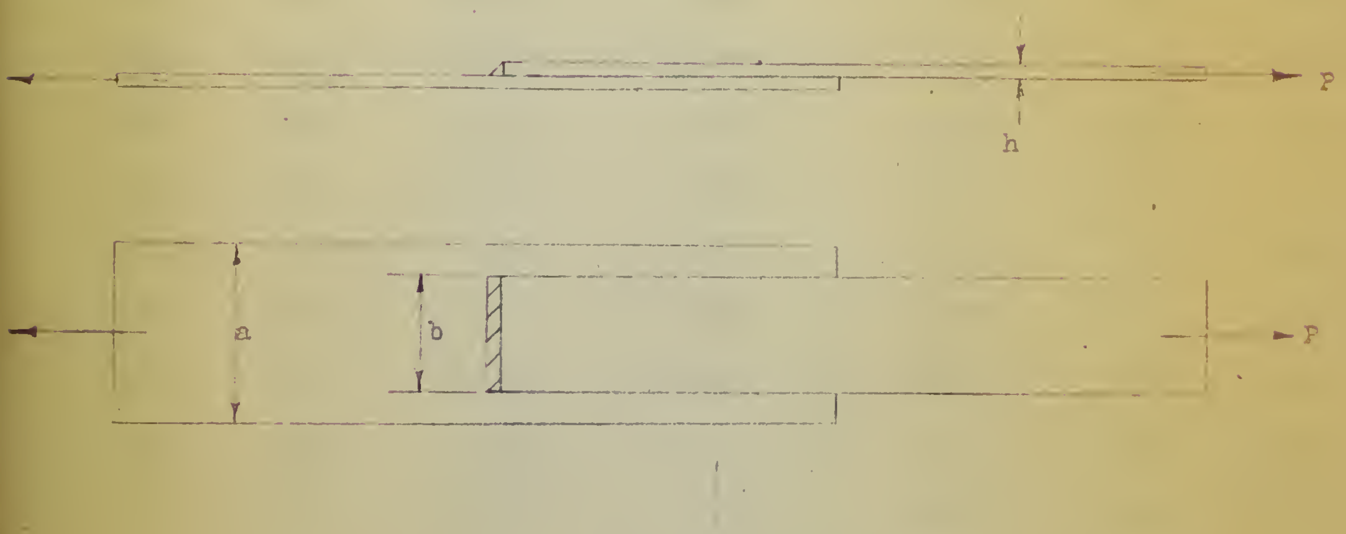
Under a load (P) of 980 pounds, the weld broke.

The results of these tests were definite proof that any welds made with eutecrod were sufficiently strong to withstand more load than the parent material, and therefore, strong enough to carry the loads we would use.

Shear and Tension Test Specimen



Shear Test



Tension Test

Figure 13

(5) Aluminum welded beam tests and results

Beam #4

Beam #4 was constructed, using the eutecrod welding method, in jig #2. It was tested on the vertical loading frame with the results as given below.

Dimensions of Beam (See Figure 10)	
	b = 2.0 inches
	t = .093 inches
	c = 1.32 inches
	d = 2.73 inches
	L = 24 inches

Moment of Inertia (I) = .7750

Deflection (D) = $.0371 \times 10^{-3}$ P

Stress (f) = 10.2 P

Load	Dial Reading Zero	Loaded	Act. Def.	Comp. Def.	% Diff.	Stress
10	.2800	.2831	.0031	.00037	87.0	102.0
26.6	.2800	.2845	.0045	.0010	78.0	272.0
35.0	.2821	.2859	.0038	.0013	66.0	357.0
50.6	.2823	.2875	.0052	.0019	63.0	516.0
60.0	.2826	.2882	.0056	.0022	61.0	612.0
75.6	.2828	.2901	.0073	.0028	62.0	771.0
85.0	.2829	.2916	.0087	.0032	63.0	867.0
100.6	.2831	.2928	.0097	.0037	62.0	1020.0
110.0	.2832	.2936	.0104	.0041	61.0	1121.0
125.6	.2836	.2946	.0110	.0047	57.0	1280.0
135.0	.2839	.2949	.0110	.0050	55.0	1379.0
150.6	.2839	.2976	.0137	.0056	59.0	1537.0

Load	Zero	Loaded	Act. Def.	Comp. Def.	% Diff.	Stress
160.0	.2844	.2981	.0137	.0059	57.0	1631.0
185.0	.2849	.2997	.0148	.0068	54.0	1889.0
215.5	.2850	.3004	.0154	.0080	48.0	2195.0

Beam #4 was warped and distorted which accounts for the high percentage error. These high errors indicate that the whole method was entirely inadequate for a simple laboratory technique. The next attempt at eutecrod welding was Beam #7.

Beam #7

Beam #7 was constructed using the eutecrod welding method in jig #3. It was tested on the vertical loading frame with the results as follows:

Dimensions of Beam (See Figure 10)	
	b = 1.03 inches
	t = .063 inches
	c = .55 inches
	d = 1.16 inches
	L = 12 inches

Moment of Inertia (I) = .0455

Deflection (D) = .0791 x 10^{-3} P

Stress (f) = 36.2 P

Load	Zero	Loaded	Act. Def.	Comp. Def.	% Diff.	Stress
1.6	.2337	.2341	.0004	.000127	67.5	58.0
5	.2337	.2347	.0010	.000396	60.4	181.0
12.2	.2337	.2357	.0020	.000963	52.0	442.0
19.85	.2335	.2364	.0029	.00157	48.3	719.0
27.85	.2338	.2373	.0035	.00220	37.0	1005.0
35.7	.2338	.2379	.0041	.00283	31.0	1290.0
42.65	.2340	.2389	.0049	.00337	31.2	1540.0
51.1	.2340	.2400	.0060	.00403	32.8	1850.0
58.85	.2341	.2410	.0069	.00465	32.6	2130.0
66.35	.2343	.2416	.0073	.00525	28.7	2400.0
74.65	.2341	.2428	.0087	.00590	32.2	2750.0
110.00	.2339	.2470	.0130	.00870	33.1	3980.0
160.0	.2340	.2518	.0175	.01265	28.0	5800.0

Load	Zero	Loaded	Act. Def.	Comp. Def.	% Diff.	Stress
185.0	.2343	.2540	.0197	.01462	25.8	6700.0
235.0	.2350	.2603	.0253	.01860	26.5	8500.0
259.8	.2362	.2644	.0282	.0205	27.4	9370.0
283.0	.2362	.2680	.0318	.0223	29.9	10,500.0

The readings taken on Beam #7 were consistently better than those on Beam #4, but the percentage error was still much too high to accept this method as a way for building models. It appears that, due to the localized heating, there is a definite zone of softening in the area of the weld which caused the beam to act irregularly.

b. Aluminum Soldering

The method of using aluminum solder as a means of constructing our model beams was investigated at the same time as the eutecrod method. The two methods are very similar, and their similarities along with the differences will be presented in this section.

(1) Characteristics of Solder

Alladin soldering is not as strong as eutecrod welding. However, once the limitations were discovered, it was possible to use it with considerable success. The solder melts at a much lower temperature than does welding rod. This most important characteristic makes it much easier to use since the melting point of the parent material is not approached. However, since there is no direct fusion of material, the strength of the joint is definitely decreased. The sample pull test results will indicate this much more clearly. The rod used was an alladin rod. This particular rod required no flux. Therefore, it was necessary to insure that all oxides were cleaned off the aluminum prior to soldering. In addition, a reducing flame was used to prevent the formation of any oxides while soldering.

The method of cleaning the aluminum was the same as that outlined under eutecrod welding. Of the two size rods available, the 1/16" rod was preferred to the 1/8" rod due to the size of the sections being joined. There was only one difficulty encountered, other than those mentioned under eutecrod welding. It was noticed that the solder already placed tended to ball up in some places along the joint when placing solder on the opposite side. This occurred only in a few locations, however, and was patched up easily by reheating and soldering.

(2) Method of Soldering

The technique of heating the joint in preparation for soldering was the same as outlined under the method of eutecrod welding. Since the solder requires a lower temperature than eutecrod, the size of the flame used was considerably smaller. The pressure settings on the cylinder regulators were 5 lbs. and 2 lbs. for oxygen and acetylene respectively. The main difference in soldering is when the filler rod is added. As the torch is held in position for heating the joint, it is best to hold the filler rod in the outer fringe of the flame to keep it

in a soft condition. Then, when the reflected flame turns orange, quickly remove the torch and wipe the filler rod along the joint. It will be possible only to run the joint for about 1 to 2 inches, as the metal cools quickly. However, in our method of using the torch to preheat as well as weld, it will be necessary just to heat the joint a second or two until it will be hot enough again to make another run. This procedure is continued until the whole length of weld is completed.

(3) Test Samples and Results (See Figure 13)

A series of tests on samples, similar to those run using eutecrod, were run using solder. Since there is quite a range of temperatures at which the solder will flow and still not affect the parent material, we ran two sample tests. The first was on a model soldered at a very high temperature such that there was almost fusion. The second was run at the lowest possible temperature such that there was no fusion. The results of these two tests were considered as limits of the possible strength a soldered joint would take. In all future tests, we kept our horizontal shear definitely below that indicated by the lowest test.

Test #1 (Fusion of material and solder noted)

Shear test	a = 1	inch
	L = 2	inches
	b = 3/4	inch
	h = .091	inch

Under a load (P) of 1176 pounds the solder failed in shear

Tension test	a = 1	inch
	b = 3/4	inch
	h = .091	inch

Under a load (P) of 85 pounds, the solder failed.

Test #2 (Low temperature)

Shear test	a = 1	inch
	L = 2	inches
	b = 3/4	inch
	h = .091	inch

The load built up to 50.5 pounds, then the solder yielded suddenly within the joint, although no cracks were visible. It was impossible to make the specimen take any more load. The horizontal shear was 12.6 lbs./inch.

The authors concluded from these tests that if the alladin solder method were to be used it would be necessary to keep the loads down such that the horizontal shear would be less than 12 lbs./inch, except where we were interested in the beam behavior at higher loads.

(4) Aluminum soldered beam tests and results

Beam #2

Beam #2 was constructed using the alladin solder method in Jig #1. It was tested on the vertical loaded frame.

Dimension of Beam (See Figure 10)

b = 1.03 inches
t = .064 inches
c = .55 inches
d = 1.16 inches
L = 14 inches

Moment of inertia (I) = .0455

Deflection (D) = $.1256 \times 10^{-3}$ P

Stress (f) = 42.3 P

	Dial Reading					
Load	Zero	Loaded	Act. Def.	Comp. Def.	% Diff.	Stress
15.1	.600	.5975	.0025	.0019	24.0	640.0
45.75	.600	.5925	.0075	.0057	24.0	1940.0
84.0	.600	.5860	.0140	.0105	25.0	3580.0
100.60	.600	.5835	.0165	.0126	23.6	4260.0
116.35	.600	.5810	.0190	.0146	23.1	4930.0
131.6	.600	.5785	.0215	.0165	23.1	5570.0
156.6	.600	.5742	.0258	.0196	24.0	6640.0
166.35	.600	.5725	.0275	.0209	24.0	7060.0
174.65	.600	.5709	.0291	.0219	24.8	7400.0
188.75	.600	.5684	.0316	.0237	25.0	7999.0
202.75	.600	.5658	.0342	.0255	25.5	8560.0
210.85	.600	.5632	.0368	.0265	27.9	8960.0

The error in Beam #2 was believed to have resulted from the fact that the beam was warped and untrue. We, therefore, constructed beam #3.

Beam #3

Beam #3 was constructed using the alladin soldering method in Jig #1. It was tested on the vertical loading frame.

Dimensions of Beam (See Figure 10)

b = 1.03 inches
t = .064 inch
c = .55 inch
d = 1.15 inches
L = 23 inches

Moment of Inertia (I) = .0452

Deflection (D) = $.558 \times 10^{-3}$ P

Stress (f) = 73.2 P

Load	Dial Reading Zero	Loaded	Act. Def.	Comp. Def.	% Diff.	Stress
1.6	.1559	.1568	.0009	.0008	11.0	117.0
5.0	.1554	.1601	.0047	.0028	40.3	366.0
12.2	.1554	.1649	.0095	.0068	28.4	893.0
19.8	.1553	.1692	.0139	.0111	20.1	1455.0
27.8	.1555	.1741	.0186	.0159	15.0	2040.0
35.70	.1556	.1789	.0233	.0199	14.6	2610.0
43.50	.1556	.1839	.0283	.0243	14.2	3190.0
51.25	.1563	.1893	.0330	.0286	13.3	3750.0
58.75	.1575	.1978	.0403	.0328	18.5	4300.0
83.75	.1605	.2440	.0835	.0418	49.3	6130.0

Beam #3 was made considerably longer than Beam #2. This, along with the fact that a zero reading was taken after each load, had a noticeable affect on the results. While these results were better, it was decided to try a new method. We next built beam #5.

Beam #5

Beam #5 was constructed using the alladin soldering method in Jig #2. It was tested on the vertical loading frame.

Dimensions of Beam (See Figure 10)

b = 2.0 inches
t = .091 inches
c = 1.28 inches
d = 2.75 inches
L = 33 inches

Moment of Inertia (I) = .7715

Deflection (D) = $.097 \times 10^{-3}$ P

Stress (f) = 13.7 P

Load	Dial Reading Zero	Loaded	Act. Def.	Comp. Def.	% Diff.	Stress
1.6	.09037	.09056	.00019	.00016	15.8	21.9
5.0	.09041	.09110	.00069	.00048	30.4	68.5
13.0	.09041	.09193	.00143	.00126	11.9	178.0
20.5	.09041	.09337	.00296	.00199	32.8	280.0
27.7	.09062	.09395	.00333	.00269	19.2	379.0
34.65	.09041	.09505	.00464	.00336	27.6	473.0
42.50	.09060	.09619	.00559	.00412	26.3	583.0
50.25	.09060	.09752	.00692	.00487	29.6	689.0
58.05	.09081	.09870	.00789	.00563	33.2	795.0
65.20	.09090	.09959	.00869	.00632	27.3	895.0
73.60	.09102	.10071	.00969	.00713	26.7	1010.0
81.90	.09113	.10169	.01056	.00794	24.8	1120.0

Beam #5 was made longer than Beam #3, and of larger section. We made these changes to discover if perhaps length or size of section had a major effect on the results. The irregular results proved nothing other than it didn't appear to be acting as a beam. We next built beam #6.

Beam #6

Beam #6 was constructed using the alladin soldering method in Jig #2. It was tested on the vertical loading frame.

Dimensions of Beam (See Figure 10)	b = 2.01 inches t = .091 inches c = .96 inches d = 2.10 inches L = 26 inches

Moment of Inertia (I) = .424

Deflection (D) = $.0864 \times 10^{-3}$ P

Stress (f) = 15.7 P

Load	Dial Reading Zero	Dial Reading Loaded	Act. Def.	Comp. Def.	% Diff.	Stress
1.6	.05533	.05543	.00010	.00014	40.0	25.1
10.0	.05545	.05626	.00081	.00085	4.9	157.0
18.4	.05546	.05645	.00199	.00157	21.1	289.0
25.9	.05550	.05834	.00284	.00221	22.2	407.0
33.65	.05580	.05968	.00388	.00287	26.0	528.0
41.65	.05605	.06040	.00435	.00355	18.4	653.0
48.80	.05608	.06110	.00502	.00417	16.9	765.0
64.55	.05610	.06384	.00774	.00557	28.0	1010.0
73.80	.05665	.06533	.00868	.00636	26.8	1158.0

Beam #6 didn't eliminate the errors although the percentage error was less than that occurring in beam #5.

Beam #8

Beam #8 was constructed, using the alladin solder method in Jig #3. It was tested on the vertical loading frame.

Dimensions of Beam (See Figure 10)	b = 1.03 inches
	c = .55 inches
	d = 1.16 inches
	t = .063 inches
	L = 24 inches

Moment of inertia (I) = .0454

Deflection (D) = $.634 \times 10^{-3}$ P

Stress (f) = 76.7 P

Load	Zero	Loaded	Act. Def.	Comp. Def.	% Diff.	Stress
1.6	.2825	.2835	.001	.00101	1.0	122.5
5.0	.2825	.2857	.0032	.00317	.94	383.0
12.2	.2825	.2912	.0087	.00773	11.5	931.0
19.85	.2825	.2964	.0139	.0126	9.35	1520.0
27.85	.2830	.3023	.0198	.0177	10.60	2130.0
35.70	.2830	.3077	.0247	.0227	8.10	2740.0
43.50	.2833	.3130	.0300	.0276	8.00	3330.0
51.25	.2835	.3183	.0350	.0325	7.13	3930.0
58.75	.2835	.3234	.0399	.0373	6.52	4500.0
65.90	.2835	.3286	.0451	.0408	9.53	5050.0
74.20	.2841	.3341	.0503	.0470	6.50	5680.0
82.35	.2840	.3399	.0558	.0521	6.71	6320.0
90.65	.2847	.3459	.0619	.0575	7.1	6950.0

The percentage error as indicated in beam #8 averages less than 10 percent. This indication that our methods and

techniques were improving convinced us that we should continue with our tests with only slight changes in our methods. It should be noticed that the beam is 24 inches long and of such a section that a large deflection is obtained. It is felt that a large deflection is necessary so that any errors that do occur are not a significant part of the deflection. It should also be noted that the horizontal shear on this beam reached 36.2 lbs./inches which is considerably above the absolutely safe value as determined by test. Therefore, in any future tests, a horizontal shear maximum of 10 lbs./inch can be assumed to be absolutely safe. With the above considerations in mind we constructed beam #9.

Beam #9

Beam #9 was a "T" beam constructed using the alladin solder method in Jig #3 modified. It was tested on the vertical loading frame.

Dimensions of Beam (See Figure 10)

b = 1.453 inches
c = .8244 inches
d = 1.0938 inches
t = .091 inches
L = 54 inches

Moment of inertia (I) = .02375

Deflection (D) = 1.38×10^{-2} P

Stress (f) = 468 P

Horizontal Shear (H) = $\frac{VQ}{I}$ = .623 P

The neutral axis was computed to be .268 inches above the base.

	Dial Reading					
Load	Zero	Loaded	Act. Def.	Comp. Def.	% Diff.	Stress
1.6	.16340	.18820	.0248	.0221	10.9	747.0
2.0	.16340	.19210	.0287	.0276	3.8	935.0
3.0	.16340	.20710	.0437	.0414	5.24	1405.0
4.0	.16340	.22010	.0567	.0552	2.45	1870.0
5.0	.16340	.23420	.0708	.0690	2.54	2340.0

The error in beam #9 was not as great as that in beam #8. The horizontal shear at 5 lbs. was 3.115 lbs./inches. We stopped loading at 5 lbs. as we wanted to put another flange on the "T" beam to see the effect. Therefore, we soldered a flange on beam #9 to get beam #10.

Beam #10

Beam #10 is beam #9 with another flange soldered on.

Dimensions of Beam (See Figure 10)	
	b = 1.453 inches
	c = .548 inches
	d = 1.188 inches
	t = .091 inches
	L = 54 inches

Moment of inertia (I) = .08873

Deflection (D) = 3.7×10^{-3} P

Stress (f) = 90.3 P

Horizontal Shear (H) = .408 P

Load	Zero	Loaded	Act. Def.	Comp. Def.	% Diff.	Stress
1.6	.1320	.1382	.0062	.0059	4.8	144.5
2.0	.1319	.1397	.0078	.0074	5.1	180.5
3.0	.1320	.14285	.01085	.0111	2.3	271.0
4.0	.1320	.1469	.0149	.0148	0.6	361.0
5.0	.1320	.1500	.0180	.0185	2.8	451.0
6.0	.1320	.1541	.0221	.0222	0.4	542.0
7.0	.1320	.1580	.0260	.0259	0.4	631.0
8.0	.1320	.1620	.0300	.0296	1.3	722.0
9.0	.1320	.1658	.0338	.0333	1.5	811.0
10.0	.1320	.1697	.0377	.0370	1.9	903.0
18.0	.1321	.1998	.0678	.0666	1.8	1628.0

The small amount of difference between computed and actual deflections as evidenced by the percentage error was considered excellent. The horizontal shear obtained was 7.35 lbs./inches at 18 lbs. In view of the results, it was decided to construct a beam of larger cross section, to see if there would be any effect on the accuracy.

Beam #11

Beam #11 was constructed using the alladin solder method in Jig #3 modified. It was tested on the vertical loading frame.

Dimensions of Beam (See Figure 10)

b = 1.234 inches
c = 1.193 inches
d = 2.477 inches
t = .091 inches
L = 54 inches

Moment of Inertia (I) = .4128

Deflection (D) = $.798 \times 10^{-3}$ P

Stress (f) = 40.5 P

Horizontal Shear (H) = .1623 P

Load	Dial Reading Zero	Dial Reading Loaded	Act. Def.	Comp. Def.	% Diff.	Stress
5	.0964	.1001	.0037	.0040	8.1	202.0
10	.0965	.1041	.0076	.0080	5.3	404.0
15	.0965	.1083	.0118	.0120	1.7	616.0
20	.0965	.1122	.0157	.0160	1.9	807.0
25	.0965	.1164	.0199	.0199	0.0	1015.0
30	.0967	.1208	.0243	.0239	1.6	1215.0
35	.0967	.1250	.0283	.0279	1.4	1417.0
40	.0967	.1290	.0323	.0319	1.2	1620.0
45	.0968	.1333	.0366	.0359	1.9	1823.0
50	.0969	.1380	.0412	.0399	3.2	2020.0
55	.0969	.1419	.0450	.0439	2.4	2230.0

The results of Beam #11 proved that our methods and techniques of constructing models were satisfactory. This beam was made with the idea in mind of using it for checking stresses and calibrating the horizontal loading frame. (See Figure 14.) These tests are explained in section IV.

Beam #11 on Horizontal

Loading Frame

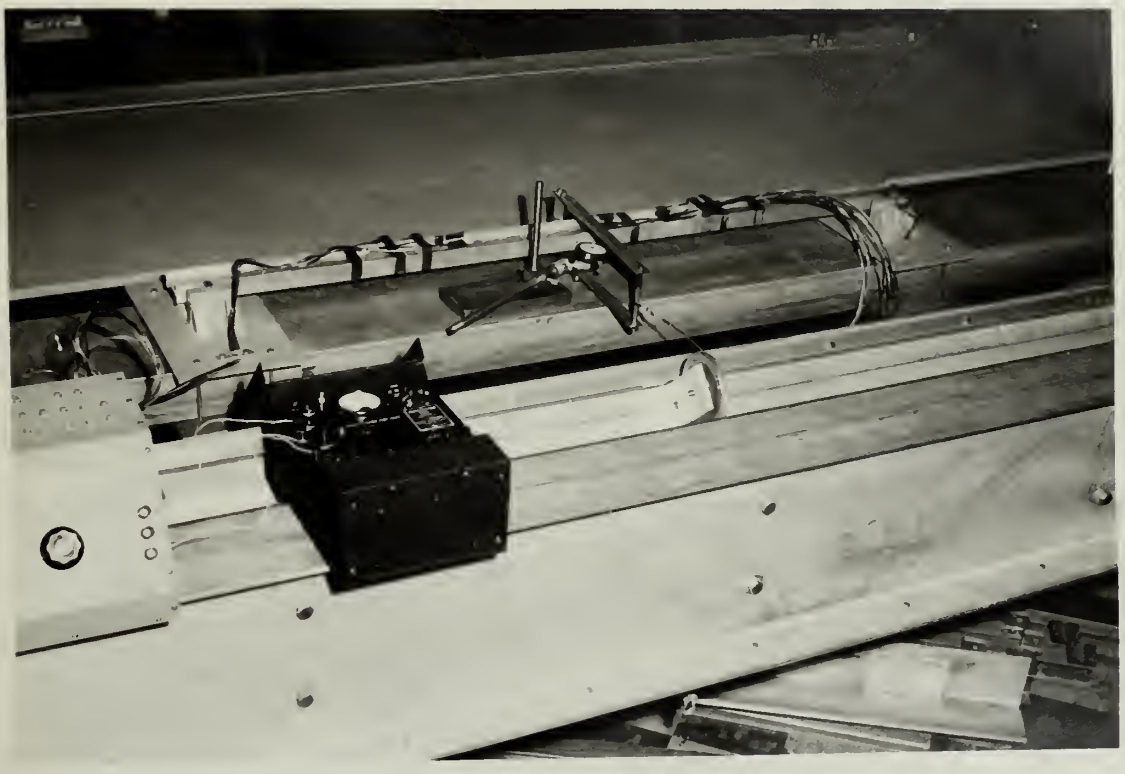


Figure 14

c. Furnace Brazing

The third method of constructing beams by furnace brazing was not successful. The furnace used was the same one that was mentioned in the "E" check discussion.

The beam constructed was 24 inches long, 1-1/2 inches deep, .091 inches thick and the flanges were 1-1/4 inches wide. The beam was held together in the manner discussed for Jig #3 modified, with clamps holding the flanges together. The joining material used was eutecrod. In order to get a thin foil, the eutecrod was rolled to a thickness of about .008 inches. It was inserted in the joint and held in place by the clamping action of the "C" clamps. Flux was placed along all the surfaces that were to be joined. The furnace temperature used was 1125° F. This was the temperature, found from tests, that was necessary for the materials to fuze. The jigged beam was placed in the furnace and allowed to remain for 15 minutes. At the end of the required time, the furnace was shut off and allowed to cool before inspecting the beam.

The whole beam was completely distorted and warped. (See Figure 15.) The flanges were welded to the web for only about 2 inches at one end. It was impossible to test the beam because of its condition.

Furnace Brazed Aluminum Beam

Figure 15

This method is impractical for use with aluminum. The eutecrod will not flow by itself until a temperature of about 1125° F. is reached. This temperature is above the melting point of the alloy used, and the beam will not even support its own weight. Thus, with the jigging system used, the weight of the clamps alone caused the whole beam to be pulled out of shape. Therefore, the authors felt it a waste of time to attempt any further tests.

B. Steel.

For the fabrication of steel models, we selected hot rolled strip steel, 1-1/2 inches wide and 0.056 inches thick. This particular size material was selected from the available stock at a local steel yard because it would require the least cutting in the fabrication of a model. Hot rolled strip was chosen in preference to cold rolled strip because of its being relatively free of residual stresses.

1. Preparation of Material

A hacksaw was used to cut the strip steel into the desired lengths. The rounded edges of the pieces were ground flat on a mechanical disc sander. Next, the scale on the edges and sides, where the pieces were to be joined, was removed by using emery cloth which gave a bright surface. Care should be exercised in grinding the edges to insure that a smooth, flat surface is obtained. Irregularities will cause a poor joint.

2. Jigs

Jigs used for making steel models were the same as those used for making aluminum models, as given in section III-A-2 above; consequently, they need not be discussed again in this section.

3. Techniques of Joining Flanges to Webs

a. Silver soldering with an oxyacetylene torch

In joining the pieces of steel together to form a model, we wanted a strong joint, which could be obtained without heating the steel into its critical range. Heating to a low temperature was desirable also to avoid large expansions and accompanying distortions. Silver soldering seemed to possess all of the above desirable characteristics. The "Easy Flow" solder we used flowed freely at 1175° F., which is well below steel's critical temperature, and it possessed a tensile strength of approximately 65,000 psi.

(1) Joint thickness

In the "Welding Handbook" of the American Welding Society, a graph is shown expressing the strength of a soldered butt joint, using silver solder to join stainless steel, as a function of the joint thickness. With a joint thickness of 0.003 inches, the joint strength was 117,000 psi, while with a

thickness of 0.024 inches, the strength was 47,000 psi. This shows the desirability of having a close fitting joint between the pieces being joined.

(2) Heating and fluxing

Before the joint was heated, a coating of flux* was painted on the surfaces to be joined, its purpose being to prevent oxidation of the solder and steel surfaces being joined, to dissolve any oxides that might form during heating, and to assist the flowing of the alloy. The flux also serves as a temperature indicator, in that the joint should be heated until the flux remains fluid if the torch flame is removed for an instant.

The models we made consisted of tee and wide-flange sections. In joining the web to the flange, the torch was held in a position so that the flame (a slightly reducing flame was used) was approximately parallel to the axis of the joint being soldered. (See Figure 12.) By directing the flame in this manner, the material in the vicinity of the torch tip was heated to the soldering temperature,

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* A Borax and Boric Acid mixture.

while the material away from the torch tip in the direction of the flame became preheated to a relatively high temperature. When the correct temperature was reached, as indicated by the fluid flux, the silver solder rod was touched to the joint. The solder flowed freely along the joint until the joint became too cool. By moving the torch slowly and applying solder from the rod at about every inch, a strong joint was obtained throughout the length of the pieces.

If the joint is dirty, or if the flux is rubbed off at a point along the joint, no amount of heating will cause the solder to adhere to the pieces. In this event, wait until the pieces cool, clean and reflux the spot, then reheat and solder it.

(3) Test samples and results

In order to check the strength of the silver solder joint in shear and tension, test samples of joints were prepared and tested. (See Figure 13.)

Shear test	Tension test
a = 1 inch	a = 1 inch
L = 1 inch	b = 1 inch
b = 3/4 inch	h = .056 inch
h = .056 inch	

Two inches of joint tested in shear was

stronger than the parent metal, while one inch tested in tension broke at 2830 pounds. The strength of the joint was seen to be more than sufficient for our purposes.

(4) Beam tests and results

Beam #12

Beam #12 was a "T" beam constructed by using silver solder rod and an oxyactelylene torch, in Jig #2. It was tested on the vertical loading frame with the results as given below:

Dimensions of beam (See Figure 10)	
	b = 1.5 inches
	t = .056 inches
	d = 1.56 inches
	L = 22 inches

The neutral axis was computed to be .417 inches above the base.

Moment of Inertia (I) = .0905

Deflection (D) = .0817 P x 10^{-3}

Stress (f) = 69.3 P

Load	Dial Reading Zero	Dial Reading Loaded	Act. Def.	Comp. Def.	% Diff.	Stress
10	.4107	.4132	.0015	.00082	83.0	690.0
25	.4110	.4141	.0031	.00204	52.0	1735.0
50	.4110	.4170	.0060	.00408	47.0	3470.0
75	.4107	.4186	.0089	.00612	45.5	5200.0
100	.4108	.4220	.0112	.00817	37.1	6930.0
125	.4110	.4242	.0132	.01020	29.4	8670.0
150	.4111	.4259	.0148	.01223	21.0	10400.0

This beam was distorted from heating. The web was not exactly centered on the flange. The joint, however, appeared to be very good.

b. Furnace Brazing (See Figure 16)

In an effort to overcome the distortion of the material being joined resulting from localized heating with a torch, furnace brazing was tried. The bonding alloy was silver solder, in the form of a thin foil or sheet 0.005 inches thick. The pieces to be joined were prepared as stated in section III-A-1. Flux was applied to the surfaces for the purpose previously stated. Finally, strips of the foil were inserted in the joint between the pieces to be united, and the whole assembly clamped rigidly together. The pieces could be clamped rigidly together since there would be no differential expansion between the model components while in the furnace. The assembly was then inserted in the furnace.

(1) The furnace

The furnace used was a Lindberg type, belonging to the Metallurgy Department. It was an automatically controlled, electric furnace, equipped with a blower for circulating the air within it. Prior to inserting the model, the temperature was raised to 1175° F.

The model was left in the furnace for 15 minutes at the 1175° temperature, then

Furnace Brazed Steel Beam

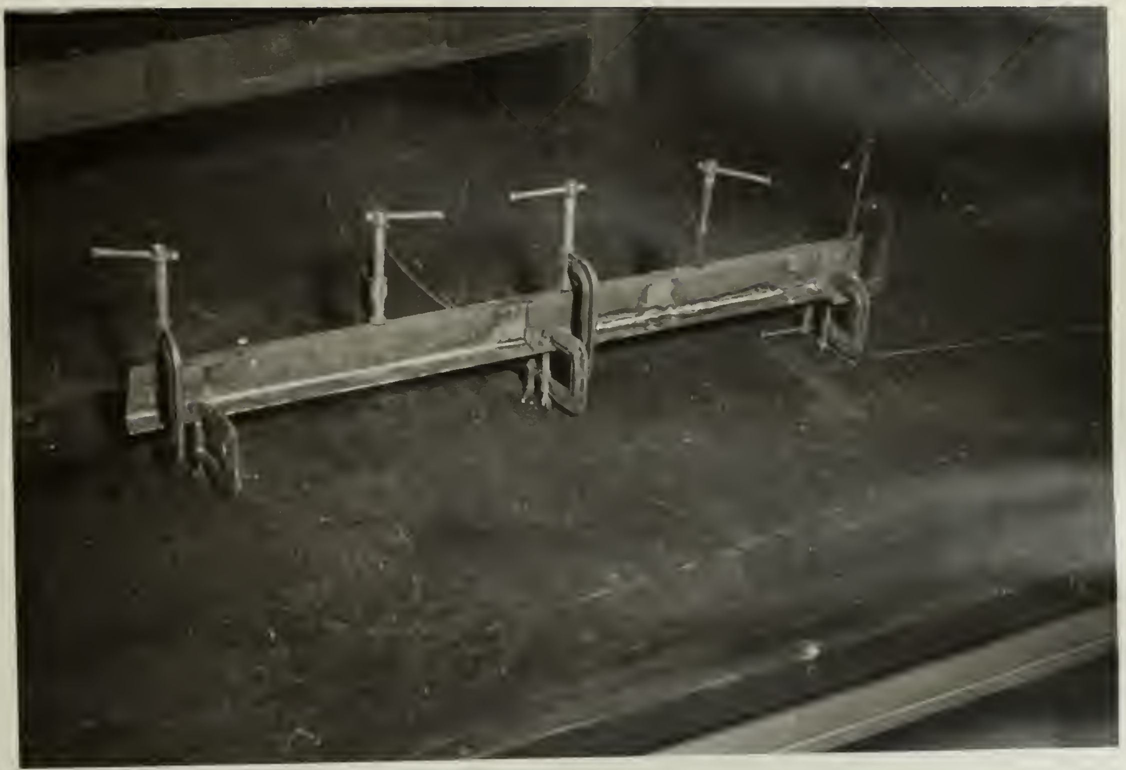

Figure 16

taken out and allowed to cool in air.

(2) Patching the model

The model referred to in the above paragraph was a wide-flange section, about 22 inches long. Near one end, the flange was not joined to the web for a distance of about 2 inches. It is presumed that this bad joint was caused by an uneven web which allowed too large an opening to be filled by the solder. This spot was patched by placing another strip of foil in the opening, fluxing it, and reheating the area with a torch.

See following pages for the results of the testing of these models.

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See following pages for the results of the testing of these models.

(3) Beam test and results

Beam #13

Beam #13 was a "T" beam fabricated by furnace brazing with silver solder using Jig #3 modified, and clamping the pieces rigidly together with "C" clamps. It was tested on the vertical loading frame with the following results.

Dimensions of Beam (See Figure 10)	
	b = 1.5 inches
	t = .056 inches
	d = 1.56 inches
	L = 16 inches

The neutral axis was computed to be .417 inches above the base.

Moment of Inertia (I) = .0905

Deflection (D) = .0315 P x 10^{-3}

Stress (f) = 50.4 P

Load	Zero	Loaded	Act. Def.	Comp. Def.	% Diff.	Stress
10	.1520	.1476	.0044	.00315	28.5	504.0
35	.1581	.1478	.0103	.0110	6.8	1765.0
60	.1600	.1478	.0122	.0890	55.0	3030.0

The erratic results were thought to have been caused by buckling of the web as the load was applied. The beam showed very little distortion, and the joint appeared sound.

Beam #14

Beam #14 was a wide flange section which was furnace brazed using silver solder. Jigging method #3 modified, with the assembly clamped rigidly together, was used.

Dimensions of Beam (See Figure 10)

b = 1.5 inches
t = .056 inches
d = 1.61 inches
L = 22 inches

Moment of Inertia (I) = .1172

Deflection (D) = .0631 P x 10^{-3}

Stress (f) = 37.8 P

Load	Zero	Loaded	Act. Def.	Comp. Def.	% Diff.	Stress
110	.18440	.19490	.0150	.00695	33.8	4160.0
185	.18450	.20180	.01730	.01169	32.0	6990.0
60	.18530	.19130	.00600	.00380	36.5	2270.0

This beam appeared to be distortion free and unwarped throughout its length. The joint, after it was patched, appeared to be satisfactory. The cause of the bad test results could be attributed only to the imperfect joint, which, even after being patched, probably was not strong enough.

Types of Beams Constructed

Figure 17

IV. Check of Beam #11 by Electric Strain Gages

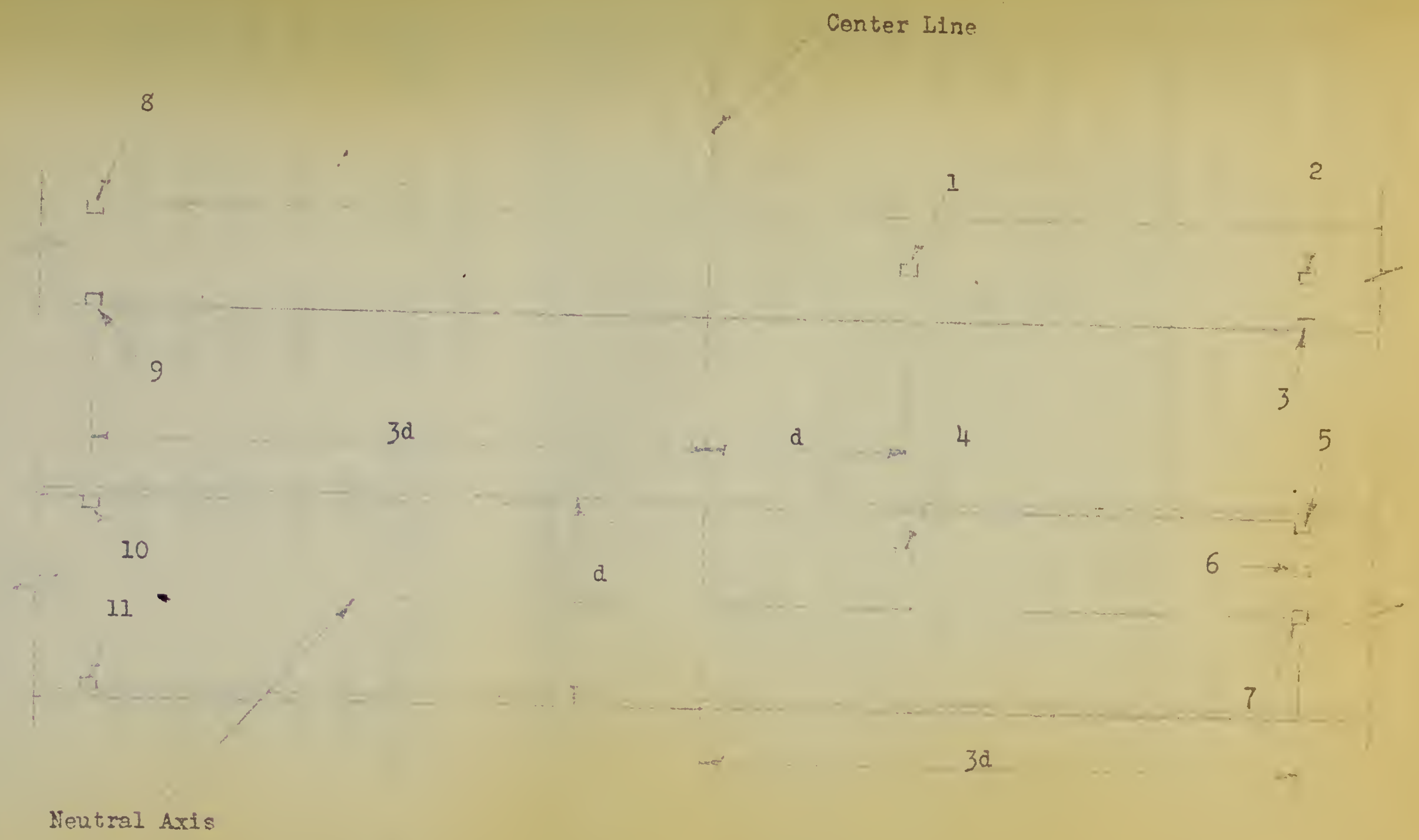
Beam #11 was found to be very satisfactory when loaded on the vertical loading frame. The average variation between the computed and actual deflections of this model under load was less than two percent. It could be presumed, then, that as a whole the model was acting as a wide-flange beam should. However, in order to check this beam further and in particular to find out something about the stress distribution at various sections along its length, several SR-4 electric strain gages were mounted on it.

A. Location of Gages

A total of 11 gages were mounted on the web and flange of the beam as shown in Figure 18. Gages #1 and #4 were located at a distance of one beam depth away from the centerline of the beam, where the load was applied. According to the St. Venant principle, the stress at this section should be as given by the elastic theory. Gages #2, #3, #5, #6, and #7 were placed at a distance of three beam depths away from the load on one side of the mid-point while gages #8, #9, #10, and #11 were placed at a like distance on the other side of the mid-point. By locating the gages at these sections and placing some on the flange and others at different distances from the neutral axis on the web, we attempted to obtain a representative set of stress values.

B. Loading and Results

As stated previously, this beam had already been checked on the vertical loading frame. Since it was antici-



Alladin Soldered Beam # 11, Showing Strain Gage Location

Figure 18

pated that models made by our technique would be tested eventually on the horizontal loading frame, it was necessary first of all to check the action of the horizontal loading frame. (See Figure 19.) It was feared that there would be some friction losses caused by the change in direction of application of the load over a pulley.

Beam #11 was placed upon the loading frame in a horizontal position with steel ball bearings, sandwiched between glass plates, supporting it. (See Figure 14.) The same loading yoke that was used for vertical loading was supported at the center of the beam on ball bearings. The flanges at the end of the beam were pushed snugly against the vertical knife edge supports, making sure that the flanges were bearing along their whole length against the knife edges. A load of known value was applied, then, at the end of a steel cable, which passed over the pulley and was attached to the yoke. The results of this loading are shown below:

	Dial Reading					
Load	Zero	Loaded	Act. Def.	Comp. Def.	% Diff.	Stress
10	.0745	.0826	.0081	.0080	1.25	405.0
20	.0745	.0900	.0155	.0160	3.1	810.0
30	.0745	.0979	.0234	.0240	2.5	1215.0
40	.0745	.1058	.0313	.0320	2.2	1620.0
50	.0745	.1138	.0393	.0400	1.75	2025.0

Horizontal Loading Frame

Figure 19

A comparison of the actual and computed deflections shows that the friction losses are negligible since the actual differences are no greater than those occurring with vertical loading. These encouraging results showed that the horizontal loading frame, with all of its advantages in accommodating large models and in the ease of applying diversified loads, could be used for future tests.

Leads from the SR-4 gages were connected with the indicating device, and values of strains read for different loads. The results of these loadings are shown on the next few pages.

Form of Computations for Stresses at Various Sections Along

Beam #11

Computations:

Section at "d" distance from the center (See Figure 18)

$M = (\frac{P}{2})\ (24.5) = 12.25\ P \qquad I = .4128$

Computed $f = \frac{Mc}{I} = \frac{(12.25\ P)(c)}{.4128} = 29.6\ Pc$

Actual $f = eE = e \times 10^{-7}$

Section at 3 "d" distance from the center

$M = (\frac{P}{2})\ (19.56) = 9.78\ P$

Computed $f = \frac{Mc}{I} = \frac{(9.78\ P)(c)}{.4128} = 23.7\ Pc$

Actual $f = eE = e \times 10^{-7}$

Terms Defined:

I, moment of inertia, inches^4

M, bending moment, inch lbs.

P, load, lbs.

f, stress, lbs./inch^2

c, distance from neutral axis of beam to center of gage

e, strain indicated by SR-4 gage, micro-inches/inch

E, modulus of elasticity of aluminum, lbs./inch^2

Values of c:

gage 1, 1.238	gage 5, .88	gage 9, 1.238
gage 2, 1.238	gage 6, .45	gage 10, .88
gage 3, 1.238	gage 7, 0	gage 11, .93
gage 4, .47	gage 8, 1.238	

P = 10 lbs.

Gage	1	2	3	4	5	6	7	8	9	10	11
Zero	0622	0113	0732	1900	0370	1361	1453	1052	1884	0798	0260
Loaded	0598	0091	0709	1887	0350	1351	1452	1022	1860	0779	0273
e	24	22	23	13	20	10	1	30	24	19	13
Act. f	240	220	230	130	200	100	10	300	240	190	130
Comp. f	367	293	293	138	207	106	0	293	293	209	220
% Diff.	34.5	24.9	21.5	5.8	3.4	5.7		2.4	18.1	9.0	41.0

P = 20 lbs.

Gage	1	2	3	4	5	6	7	8	9	10	11
Zero	0622	0113	0732	1900	0370	1361	1453	1052	1884	0798	0260
Loaded	0561	0064	0686	1871	0332	1340	1454	0998	1835	0761	0288
e	61	49	46	29	38	21	1	54	49	37	28
Act. f	610	490	460	290	380	210	10	540	490	370	280
Comp. f	735	587	587	277	415	213	0	588	588	417	441
% Diff.	17.0	16.5	21.7	4.7	8.5	1.4		8.2	16.7	11.2	36.4

P = 30 lbs.

Gage	1	2	3	4	5	6	7	8	9	10	11
Zero	0622	0113	0732	1900	0370	1361	1455	1052	1884	0798	0260
Loaded	0529	0035	0662	1858	0312	1328	1453	0968	1808	0743	0300
e	93	78	70	42	58	33	2	84	76	55	40
Act. f	930	780	700	420	580	330	20	840	760	550	400
Comp. f	1100	880	880	417	625	320	0	881	881	626	662
% Diff.	15.5	11.3	13.6	0.7	7.2	3.1		4.6	13.7	12.1	39.7

P = 40 lbs.

Gage	1	2	3	4	5	6	7	8	9	10	11
Zero	0622	0113	0732	1900	0370	1361	1453	1052	1884	0798	0260
Loaded	0498	0009	0640	1840	0292	1317	1452	1022	1860	0779	0273
e	124	104	92	60	78	44	1	30	24	19	13
Act. f	1240	1040	920	600	780	440	10	300	240	190	130
Comp. f	1470	1175	1175	555	831	426	0	293	293	209	220
% Diff.	15.6	11.5	21.7	8.1	6.1	3.3		2.4	18.1	9.0	41.0

P = 50 lbs.

Gage	1	2	3	4	5	6	7	8	9	10	11
Zero	0624	2115	0731	1900	0364	1355	1451	1052	1884	0798	0260
Loaded	0461	1984	0620	1829	0273	1301	1449	0906	1763	0709	0329
e	163	131	111	71	91	54	2	146	121	89	69
Act. f	1630	1310	1110	710	910	540	20	1460	1210	890	690
Comp. f	1838	1470	1470	695	1040	533	0	1470	1470	1442	1102
% Diff.	11.3	10.9	24.5	2.2	12.5	1.3		0.7	17.6	14.6	37.5

C. Conclusions

In general, the difference between the computed and actual values of stress becomes less as the load is increased. This indicates that for higher stresses, errors introduced by slight inaccuracies in construction have reduced effect. The difference between values of stress indicated by gages 2 and 3 shows that the edge of the flange participates less in resisting the load than the center of the flange. This was probably due to a slight buckling of the flange at its outer edge. Gages 4 and 6, which were located on the web midway between the neutral axis and the flange, gave consistently good results. This was due, it was thought, to their location away from the point where the web and flange were joined. Gages 5 and 10, located on the web near the flange, gave good results, but a little less accurately than gages 4 and 6. The difference between stresses at gages 8 and 9 was caused by the knife edge of the loading yoke not bearing evenly across the top flange. This caused one side of the flange to assume more load than the other. No reason can be given for the large discrepancy between the computed and actual stresses given by gage 11, unless it was due to a defective gage.

An overall comparison of computed and actual stresses indicated that the model was acting satisfactorily. The stress distribution closely approximated that given by the flexural theory.

V. Constructing and Testing a Rigid Frame

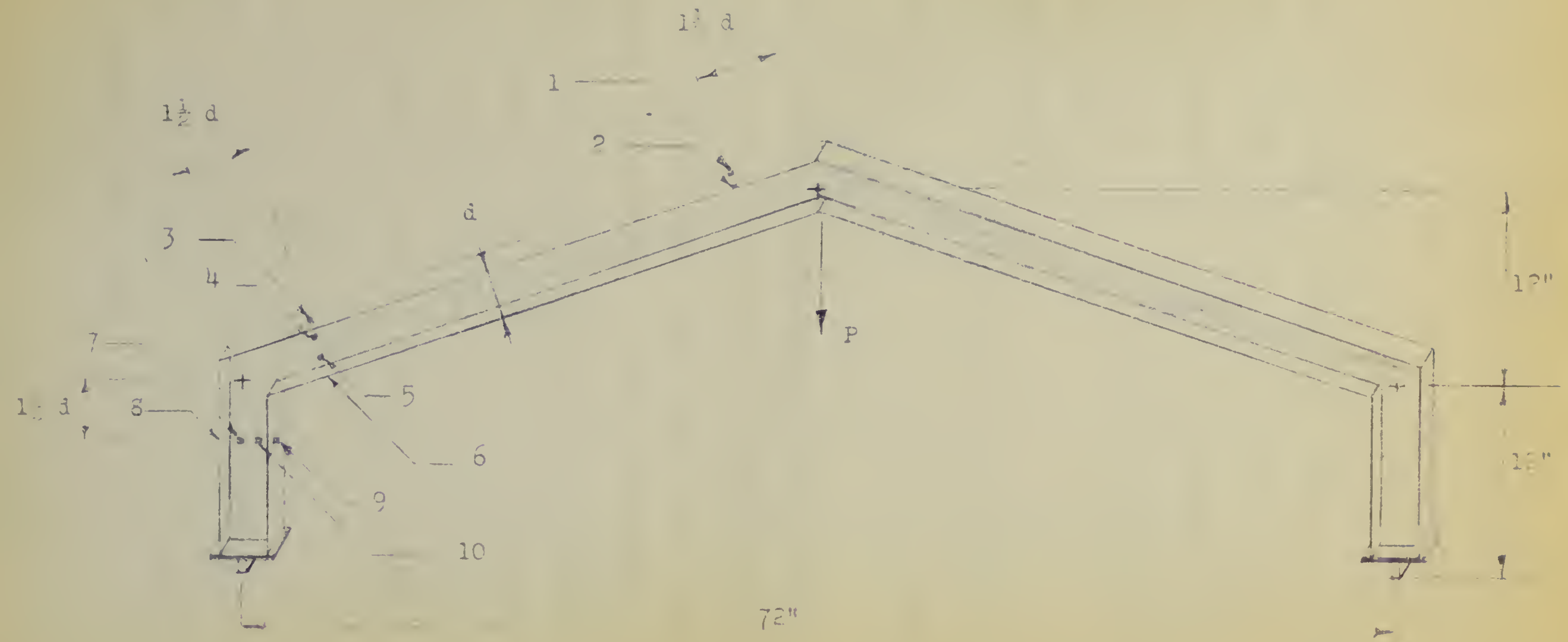
The construction and testing of a rigid frame was considered as the culmination of all the work done on this thesis. A rigid frame is one that is constructed to resist moment at the joints. The method of building a joint to resist moment may be either by riveting or welding. It is in this section that we discuss how we constructed and tested a welded rigid frame.

A. Purpose

The task of constructing a rigid frame was undertaken for two main reasons. The first, and most important to us, was to investigate the soundness of our techniques and methods in building models other than plain straight beams. Our last tests of beams were very successful, however, the beams were all of the same design. Thus, in order to be certain that the techniques and methods were sound, we built the rigid frame as shown in Figure 20. It would have been possible to construct a differently shaped model to test, but it was for the reason mentioned below that made us decide in favor of a rigid frame. As evidenced by the tests run on rigid frames, as mentioned in the introduction, there was still much to be learned, particularly about the stresses at the knees. Therefore, by building a rigid frame, we hoped not only to prove that our techniques were sould, but also to advance, perhaps, the understanding of stresses at knees in rigid frames.

B. Design

The design of the frame was not completely an



Rigid Frame Showing Location of Strain Gages

Figure 20

arbitrary one. We attempted to build a frame that, although not an exact copy of a large structure, was similar in most ways to one that might possibly be built. The important feature that influenced our design was the limit we placed on the amount of horizontal shear that we would allow. Although our sample tests indicated that we could go to about 12 lbs./inch, we tried to stay down lower than 8 lbs./inch to be sure that no harm would be done to the welds. Therefore, we designed the frame to give us a maximum deflection with the span being used, along with the lowest possible horizontal shear for any given load.

C. Construction

The rigid frame was constructed using the alladin solder method. It was held and supported as indicated in the discussion under jigging #3 modified.

The base detail of the legs is indicated in Figure 21. Since there are several ways of testing the frame, it was necessary to develop a base detail that would accommodate any desired method. Therefore, a piece of aluminum plate about 1/4 inch thick was welded to the base of each leg. Two holes were drilled through each plate so that different types of base attachments could be used. The particular attachment we used was a simulated pin on each leg. This was accomplished by bolting a piece of steel bar, rounded on the bottom, to the plate. When the rigid frame was mounted on the horizontal loading frame, the steel bar was inserted into a slotted plate mounted on the loading frame. This slot supported the bar at the bottom and along the sides.

Rigid Frame Base Details

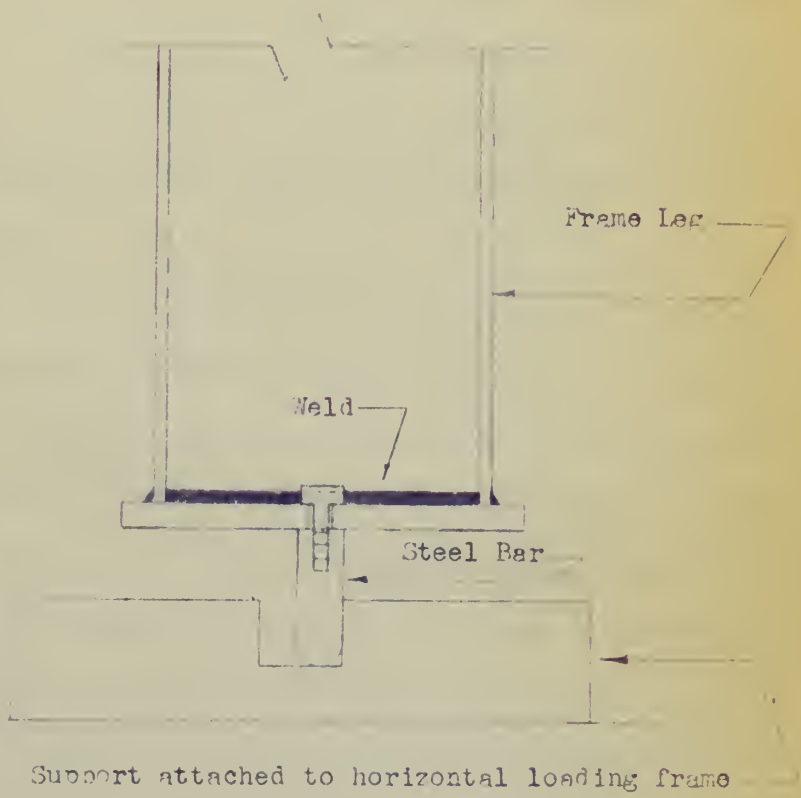
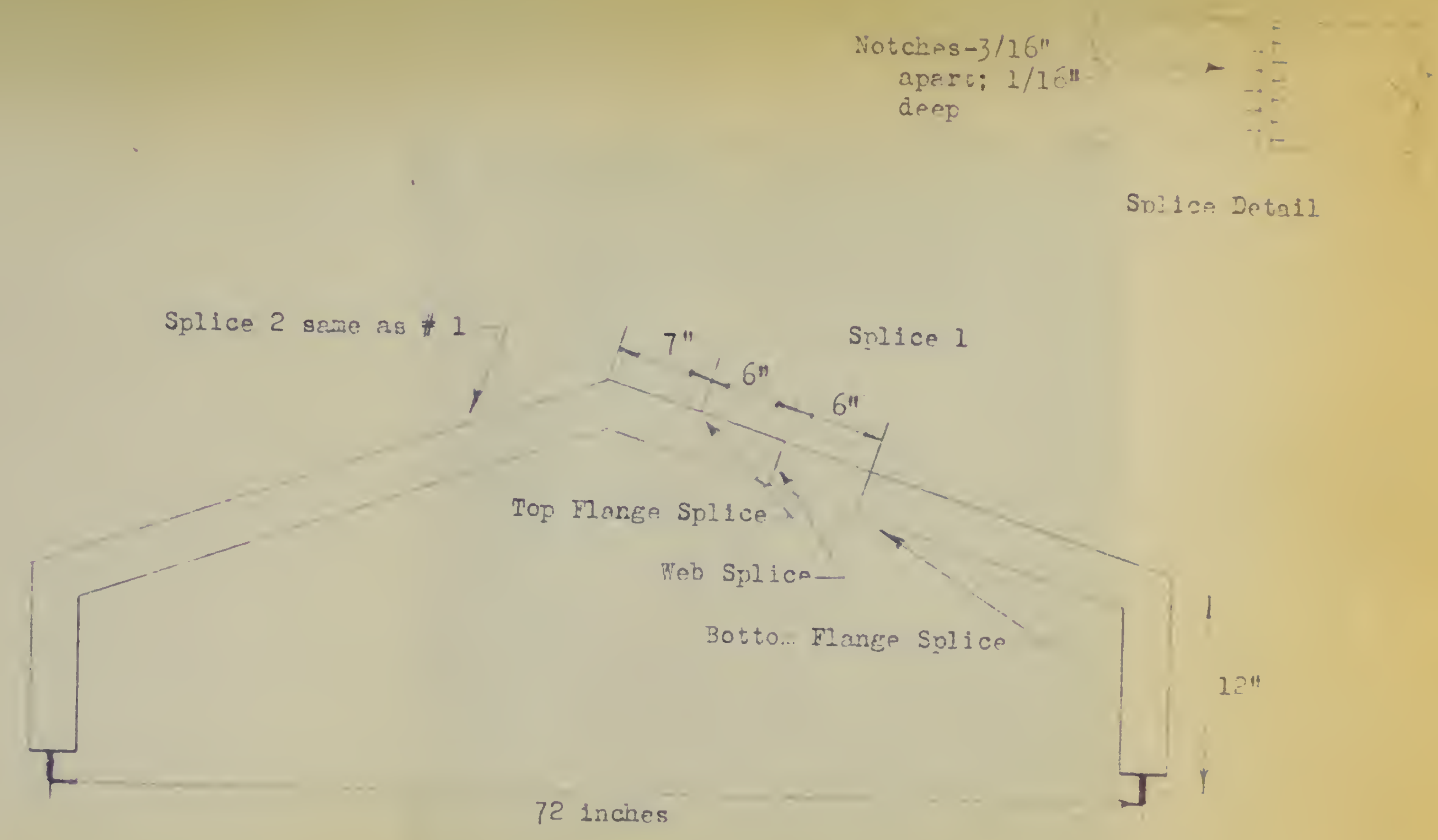


Figure 21

Since the length of the frame was 6 ft., it was impractical to cut the flanges and web in one piece. Therefore, it was necessary to devise a method for splicing. It was felt that the best way to insure the maximum strength was to stagger the splices. The location of these splices are shown in Figure 22. In making a splice, the ends of the material should be prepared as shown in Figure 22. This is a recognized method for butt joints as recommended by the Aluminum Company of America. The splices were made using alladin solder, care being used not to apply too much heat, such that the pieces being joined would warp at the splice.

D. Mounting

The frame was mounted on the horizontal loading frame in the same way that beam #11 was mounted. (See Figures 23, 24 and 25.) The four support points used were under the two knees, and one on each side of the load point. Lateral support was provided by two pound weights placed on the frame above the support points. It should be noted here that great care must be taken to insure that the beam is supported correctly at the bases. It is important to have both the bottom of the steel bar and the side of the steel bar bearing along the whole length of the support, or the readings taken will be inaccurate.



Rigid Frame showing location of Splices and Splice Detail.

Figure 22

Rigid Frame on Horizontal

Loading Device

Figure 23

Rigid Frame Peak Detail

Figure 24

E. Computations

1. Solution for Deflection of Rigid Frame by the Conjugate Structure Method for a Pinned Base.

See Figure 26

(a) $D_A = Mxx = (20)(341\ P)(2) = 13640\ P$

(b) $d_H = Mxx = (72)(8)(2) + (2)(455)(18) + (2)(228)(20) = 26632$

$H_A = \frac{13640\ P}{26632} = .513\ P$

(c) $(60.9\ P)(6.25) + (65.75)(60.9\ P) + (37\ P)(72) - (51.7\ P)$

$(30.25) - (51.7\ P)\ (41.75) - 72\ \theta_E = 0$

$\frac{3333\ P}{72} = \theta_E = 46.25\ P$

$\frac{EID_B}{2} = (46.25\ P)(12) - (37.0\ P)(4) + (60.9\ P)(2.08) -$

$(51.7\ P)(8.16) = 111.8\ P$

$D_D = D_B = \frac{(2)(111.8)}{(10^7)(.4)} = .0000559\ P$

$EID_C = (46.25\ P)(36) + (51.7\ P)(5.75) - (60.9\ P)(29.75) -$

$(37\ P)(36) = 1182\ P$

$D_C = \frac{1182\ P}{(10^7)(.4)} = .000296\ P$

Diagram for solution of Conjugate Structure

Figure 26

2. Check Solution for Deflections of Rigid Frame by Integration Using the Method of Virtual Work

$$EID_c = \int Mm\,dx$$

$$EID_c = \int_0^{12} (.513\ Px)(.513\ x)\ dx$$

$$+ \int_0^{37.93} \left[(.513\ P)(12 + x \sin a) - \frac{P}{2}(x \cos a)\right]\left[(.513)(12 + x \sin a) - .5\,(x \cos a)\right]$$

$$= .264\ P \int_0^{12} x^2 dx + \int_0^{37.93} (38.1\ P - 3.85\ P\,x + .0974\ Px^2)\ dx$$

$$= 152\ P + 1441\ P - 2760\ P + 1765\ P$$

$$= 598\ P$$

$$D_c = 2\left(\frac{598\ P}{EI}\right) = 2\frac{(598\ P)}{(10^7)(.4)} = .000299\ P$$

3. Corrections to Deflections Resulting from Movement of Base.

It was noted that the base deflected a slight amount when the structure was loaded; therefore, it was necessary to correct previously computed deflections for this movement. This was accomplished by interpolating between the deflections resulting from a pinned base and a base on rollers to obtain the correct deflections.

a. Solution for horizontal deflection at E, with E on rollers. (See Figure 27.)

$$D_E = \int \frac{Mm\ dx}{EI}$$

$$\frac{EI\ D_E}{2} = \int_0^{37.93} (P/2)(.949)(x)(12 + .316x)\ dx = 6820\ P$$

$$D_E = \frac{(2)(6820)(P)}{(.4)(10^7)} = .00341\ P$$

b. Solution for vertical deflection at C with E on rollers. (See Figure 27.)

$$D_C = \int \frac{Mm\ dx}{EI}$$

$$\frac{EI\ D_C}{2} = \int_0^{36} .25\ P\ x^2 dx = 3888\ P$$

$$D_C = \frac{(2)(3888\ P)}{(.4)(10^7)} = .001944\ P$$

c. Sample correction for any load P.

	D_C	D_E
Base pinned	.000296 P	0
Actual Conditions	Z	R
Base on rollers	.001944 P	.00341 P

Diagram for Solution of Deflections by Virtual Work

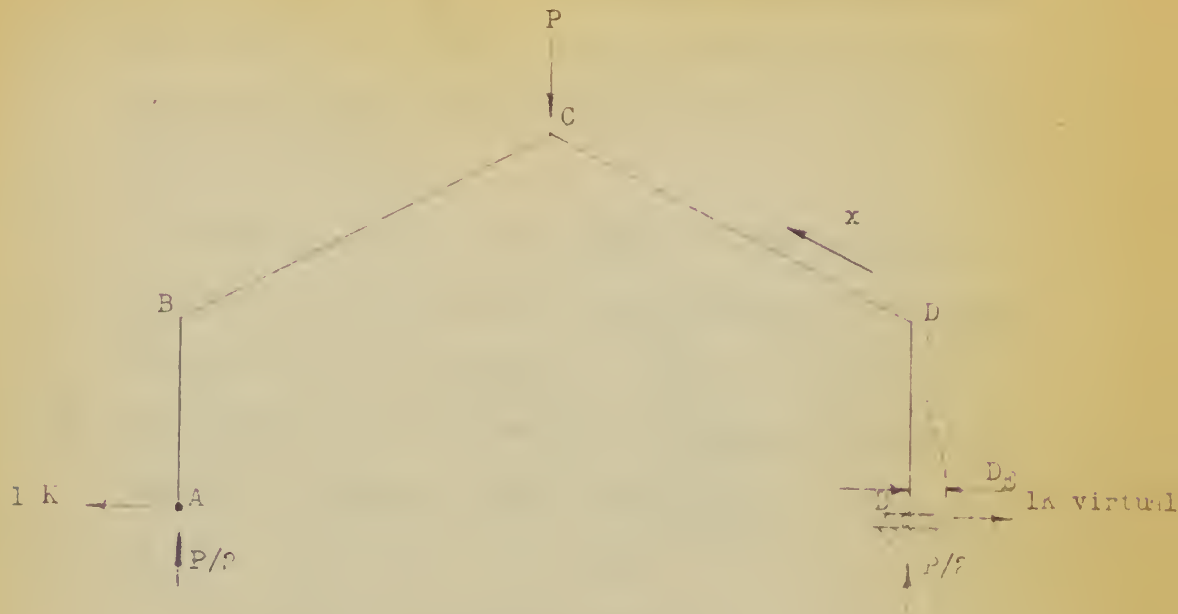


Figure 27

R is the sum of the outward deflections at the bases, as determined by mechanical dials. Z is the corrected deflection at C, arrived at by interpolation.

The corrected deflection at the knee is arrived at by applying the movement of the base directly to the computed value at the knee.

4. Computations for stresses at various sections along the frame. (See Figure 20.)

On the leg, 1.5 d from knee:

$$M = (.513\ P)(8.30) = 4.27\ P$$

$$f = \frac{Mc}{I} = \frac{(4.27\ P)(c)}{.40} = 10.66\ Pc$$

On the girder, 1.5 d from knee

$$M = .513\ P\left[(3.75)\left(\frac{12}{37.93}\right) + 12\right] - \left(\frac{P}{2}\right)(3.75)\left(\frac{36}{37.93}\right) = 4.99\ P$$

$$f = \frac{Mc}{I} = \frac{(4.99\ P)(c)}{.40} = 12.5\ Pc$$

On the girder 1.5 d from C:

$$M = (.513\ P)\left[(34.55)\left(\frac{12}{37.93}\right) + 12\right] - (P/2)(34.55)\left(\frac{36}{37.93}\right) = 4.60\ P$$

$$f = \frac{Mc}{I} = \frac{(4.60\ P)(c)}{.40} = 11.5\ Pc$$

5. Correction to stresses resulting from movement of base.

Due to the movement of the base it was necessary to apply a correction to the stresses computed in section 4

above. The manner in which the stresses were corrected is shown below.

	H_E	D_E
Base Pinned	.513 P	0
Actual Conditions	Y	Q
Base on Rollers	0	.00341 P

Q is the average of the outward deflection at the two bases. Y is the corrected value of horizontal reaction (H_E) due to movement of the bases. The corrected stresses are obtained by multiplying the computed values, as obtained in section 4 above, by $\frac{Y}{.513\ P}$.

above. The manner in which the stresses were corrected is shown below.

	H_A	H_B
Base Pinned	.213 p	0
Actual Conditions	X	q
Base on Rollers	0	.00341 p

q is the average of the outward deflection at the two bases. X is the corrected value of horizontal reaction (H_B) due to movement of the bases. The corrected stresses were obtained by multiplying the computed values, as obtained in section 4 above, by $\frac{X}{.213\ p}$.

F. Load Tests and Results

1. Deflections

a. Deflections at C

Load	Dial Reading Zero	Loaded	Act. Def.	Corr. Def. (Z)	% Diff.
10	.1085	.11225	.00375	.00339	10.6
20	.1095	.1166	.0071	.00688	3.2
30	.1095	.1212	.0117	.01036	12.9
40	.1090	.1250	.0160	.01443	9.8
50	.1090	.1290	.0200	.01796	11.3

b. Deflection at B or D

Load	Dial Reading Zero	Loaded	Act. Def.	Corr. Def.	% Diff.
10	.04085	.04185	.0010	.000609	64.0
20	.0415	.0434	.0019	.00192	1.0
30	.0549	.0579	.0030	.00288	4.2
40	.0483	.0528	.0045	.00464	3.0
50	.0537	.0478	.0059	.0060	1.7

c. Sum of the Deflections of the two bases

Load	Deflection
10	.0009
20	.0020
30	.0031
40	.0054
50	.0066

2. Stresses

P = 10 lbs.

Gage	1	2	3	4	5	6	7	8	9	10
Zero	0220	1878	1202	0770	0220	1699	2000	1340	1069	1981
Loaded	0206	1865	1217	0778	0216	1686	2003	1352	1060	1977
e	14	13	15	8	4	13	3	12	9	4
Act. f	140	130	150	80	40	130	30	120	90	40
Corr. f	140	140	151.5	67.7	67.7	151.5	51.2	130	130	59
% Diff.	0	7.1	1.0	18.1	40.7	14.1	41.6	7.7	32.5	32.2

P = 20 lbs.

Gage	1	2	3	4	5	6	7	8	9	10
Zero	0220	1878	1202	0770	0220	1699	2000	1340	1069	1981
Loaded	0193	1850	1230	0783	0209	1673	2008	1362	1051	1971
e	27	28	28	13	11	26	8	22	18	10
Act. f	270	280	280	130	110	260	80	220	180	100
Corr. f	280	280	304	136	136	304	102	260	260	118
% Diff.	3.5	0	7.8	4.4	19.1	14.5	21.6	18.2	30.8	15.2

P = 30 lbs.

Gage	1	2	3	4	5	6	7	8	9	10
Zero	0220	1878	1198	0770	0220	1698	1998	1330	1072	1981
Loaded	0178	1836	1241	0788	0200	1660	2011	1373	1041	1965
e	42	42	43	18	20	38	13	43	31	16
Act. f	420	420	430	180	200	380	130	430	310	160
Corr. f	419	419	457	204	204	457	155	389	389	178
% Diff.	.2	.2	5.9	11.7	1.9	16.9	16.1	10.5	20.3	10.1

P = 40 lbs.

Gage	1	2	3	4	5	6	7	8	9	10
Zero	0219	1874	1198	0768	0220	1698	1998	1330	1072	1981
Loaded	0161	1821	1251	0791	0193	1649	2015	1381	1033	1960
e	58	53	53	23	27	49	17	51	39	21
Act. f	580	530	530	230	270	490	170	510	390	210
Corr. f	557	557	604	270	270	604	205	517	517	236
% Diff.	4.1	4.1	12.2	14.8	0	18.8	17.0	1.3	24.6	11.0

P = 50 lbs.

Gage	1	2	3	4	5	6	7	8	9	10
Zero	0219	1874	1198	0768	0220	1698	1998	1330	1072	1981
Loaded	0149	1806	1263	0796	0186	1634	2018	1393	1023	1953
e	70	68	65	28	34	64	20	63	49	28
Act. f	700	680	650	280	340	640	200	630	490	280
Corr. f	696	696	756	337	337	756	256	645	645	295
% Diff.	.6	2.3	14.0	16.9	.9	15.3	21.8	2.3	24.9	18.6

3. Conclusions

In the process of testing our beams and the rigid frame on the horizontal loading device, we came across a method of loading that eliminates the possibility of the beam twisting due to the eccentricity of the load.

It was necessary to have some method for centering the load since any twisting causes errors in the values of the stresses. The way this was done for the rigid frame is indicated below.

Gages #1 and #2 were mounted, one on each side of the loaded flange near the load point. The loading yoke was then adjusted so that the stresses indicated by these gages were as near equal as possible. When these stresses are equal, the yoke is applying the load correctly to the frame. By using this method, the percentage error for all strain gages was less.

Although the differences between the observed and calculated stresses and deflections for the rigid frame were greater than for beam number 11, they were still considered satisfactory. There were many more sources of error in the construction of a rigid frame. Possibilities for inaccuracies were introduced in the fabrication of other than a straight model, in splicing, and in the construction of the base detail. The base detail, in particular, introduced complications. It should be noted that corrections to both the deflections and stresses had to be made to compensate for horizontal movement of the base, which was originally designed for no movement.

In general, the authors felt that the results indicate the overall soundness of the techniques and methods used.

VI. Discussion

In writing this thesis, we have attempted to break it down into sections so that each division was a subject in itself. This method allowed us to gather the results from each test and to present them along with the material from which they were deduced. Therefore, it will not be necessary for us to mention the results we have already listed. There are, however, several items of a general nature that are of interest as an overall result of each method attempted.

The welding of aluminum using eutecrod was very difficult. It took weeks of practice for us to become proficient enough to weld the aluminum without fear of completely melting the parent material. Also, the heating of the aluminum to a high temperature annealed it so that a large furnace for heat treatment would be required to temper it. We, therefore, conclude that eutecrod welding is impractical for building models in the laboratory.

From the tests we have run, we feel that the construction of accurate models by soldering is practical. It is definitely possible to construct models and to obtain reasonable results with close accuracy. The major fault with soldering is that low loads must be applied in order to stay within the required limits of horizontal shear. Although the models constructed were near perfect, the allowable stress was never developed, and it was, therefore, impossible to ascertain the effects of high stresses.

The results from the tests run on the beams constructed with steel and silver solder were not satisfactory. The beams obtained from the furnace method seemed absolutely perfect. We have no explanation for the poor results obtained, other than perhaps that the joint was not perfectly soldered although it appeared to be so. In view of the high loads the horizontal loading frame is capable of handling, we feel that the investigation of steel should be continued. It is definitely the feeling of the authors that a small amount of work with the steel method would produce very satisfying results.

VII. Conclusions

A. Aluminum soldering, using alladin rod to form the joint between model components, which are assembled in accordance with jigging method number 3 modified, is suitable for model construction.

B. Aluminum welding as a method of joining model components is not feasible because of the amount of time required to become proficient in welding, and because of the uncontrollable warping and distortion attendant with it.

C. Furnace brazing aluminum, using eutecrod as the filler material, is not possible.

D. With further work and development, a method of silver soldering steel to fabricate models suitable for high stresses could be evolved.

15630
Thesis
J64 Johnson
The development of a laboratory technique for model construction.