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Assessment of Feasibility of Proposed Bolted Connections for Tubular Structures

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APPROVED BY MEMBERS OF THE THESIS COMMITTEE:

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The search for new and additional sources of energy--from sun, wind, waves, and ocean currents--is necessitating the development of structures in the open environment of the oceans as well as on land. The advantages of round or tubular members for use in such structures are shown; and to avoid the uncertainties of welded joints, two bolted connections are proposed and their feasibility explored.

A model was designed and made to resolve the problems

presented by size, fabrication, and code requirements, and considerations that influence analysis have been pointed out. A typical computation is included to illustrate the application of current design methods to the proposed bolted connections.

Based on these investigations, the two bolted connections are considered feasible for tubular structures both in protected areas and under severe weather conditions.

ASSESSMENT OF FEASIBILITY OF PROPOSED BOLTED CONNECTIONS FOR TUBULAR STRUCTURES

by

JOHN HENRY TAUSCH

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CHAPTER I

INTRODUCTION

All indications are that the need for energy is unabated and rising. The quest for new and additional sources of energy is underway throughout the world. Deposits of minerals, gas, and oil on land--once considered inexhaustible--are being depleted at an alarming rate.

Ocean exploration has shown that large deposits of minerals and fuels are located beneath the seas. Today much is being done to develop ways and means of obtaining access to these deposits. Exploration, drilling, and mining for these resources proceed from platforms fixed or floating at the proper locations in our oceans. Vessels for deep sea mining are in the development stages, and a few are already on location.

Proposals are being made to locate platforms in the open environment of the oceans which will have mounted on them wind generators, solar concentrators, and equipment to harness the energy available from the waves.

The vessels and platforms currently in use require a multitude of special support structures that are designed and built to meet individual needs. The platforms themselves employ structural members of both conventional and tubular section. Almost all are rigid or semirigid frames with welded or bolted joints.

This paper will consider structures suggested for the support of equipment employed for the generation of energy from the sun, wind, waves, and other sources. It is proposed:

(1) To review members of round or tubular section used in these structures.

(2) To explore the feasibility of tubular connections of bolted design.

CHAPTER II

TUBULAR STRUCTURAL MEMBERS

Standard structural sections employed in frame construction include the H- and I-sections, angle combinations, and the tube or pipe. The industry can currently offer tubes of both round and rectangular configuration, which offer similar section characteristics.

Square tubing is produced by at least three manufacturers in the United States, and foreign tubing is stocked by some warehouses. The Welded Steel Tube Institute (1) lists cold formed square tubes in ranges from 2" x 2" to 16" x 16", with thicknesses from 1/4 inch to 1/2 inch depending upon the tube size. In the past twenty years lack of availability has made itself felt in sizes from 6 inches up. Orders in the larger sizes had to be of sufficient tonnage and required six months for delivery. This can be a very real limitation in a given design effort, where time is limited.

Round tube and pipe is manufactured by every industrialized country around the globe. Nominal sizes from the small to about 24 inches in diameter are readily available from the larger warehouses in principal cities of this country. Nippon Kokan (2,3) and Bethlehem Steel

(4) are two suppliers.

In the author's experience in shipbuilding and other heavy construction, it was demonstrated that structural members fabricated of round cross-section are desirable, if not mandatory, for the following reasons:

(1) They offer less resistance to flow of wind and water as compared to the square or angular section.

(2) Maintenance (repair and painting) is easier and less costly. Concealed areas are eliminated, making inspection more reliable.

(3) De-icing (hot conductor method) is almost automatic.

(4) The round tube or pipe is designed to be a conductor of fluid under pressure. This requirement calls for proper attention in the selection of materials and methods of manufacture. Service requirements act in the interest of quality control and reliability.

(5) The round tube and pipe is universally available.

The mast, the tripod, the quadrupod, and similar structures on modern vessels are now mostly constructed of round tubular members. They are fabricated and welded on shore under controlled conditions--that is, supervision and inspection are properly carried out.

The advantages in the use of round tubular members on ships apply equally to fixed and waterborne platforms for various other services at sea and also for land operations.

Structures that will at times be immersed in seawater may involve materials other than medium- and high-strength steels. In ship design extruded aluminum is regularly used for tripod masts and frames that must be light and anticorrosive. Research is being conducted both in this country and abroad in the development of equipment and means for obtaining energy from the waves. Stainless steel arms and frames made of tube are making their appearance in equipment now being proposed.

Factors such as economy, design, fabrication, service, and maintenance are part of the overall considerations. Therefore, round tube in nominal sizes, standard, extra strong, and to schedule number, is employed in these investigations.

CHAPTER III

BOLTED CONNECTIONS FOR ROUND TUBULAR MEMBERS

The bolted connection for round tube structures is recommended for the following reasons:

(1) Bolt fasteners are economical and reliable.

(2) They can be obtained in several grades of strength to meet various design requirements.

(3) They are stocked in the several grades in most communities throughout continental United States and also in the larger cities of the world.

(4) Bolting is faster in erection. McCormac (5, p. 232) points to time savings realized if bolted connections are used instead of welded connections. Conn (6) says, "It takes over 12 months to train a certified welder but only 15 minutes to train a man to tighten a nut correctly."

(5) Welding and fabrication in the field always lead to alignment problems. In producing some of the tailormade joints in the field, and also in the shop, the necessary fitting and adjustment is time-consuming and can be wasteful of materials, and for these reasons is costly.

(6) Misalignment can lead to uncertain load distribution and stress concentration.

(7) Bolted connections lend themselves better to maintenance. Bolts can be replaced. Larger bolts can be installed if required.

(8) Field welding can lead to poorly made joints if accessibility is limited. Also, welding and inspection on a structure that is not stable or is subject to high winds can be costly and welding standards can be overlooked.

(9) Welding cracks are eliminated. These cracks, produced by improper preheating or lack of preheating, may at first not be evident but can become troublesome later in the life of the structure. Cracks are stress raisers and therefore can lead to structural failure.

(10) Bolted structures can be analyzed for stress and also for vibration with more certainty by methods now available.

These points are borne out in several technical publications (6,7,8).

TWO PROPOSED BOLTED CONNECTIONS

Two bolted connections for tubular structures for both marine and land installations are here being presented. In developing the fabrication and design features of these connections, ease of manufacture, economy, and availability are important factors.

At the outset it should be stated that the designs to be developed should meet the requirements of sound structural principles and also be in agreement with the basic and applicable requirements of the American Institute of Steel Construction (AISC) and American Welding Society (AWS). However, certain limitations are usually recognized which are related to manufacturing, economics, service requirements, etc. McGuire (9, p. 787) states:

> Most connections are highly indeterminate, with the distribution of stress depending upon the deformations of the fasteners and the detail material. Local restraints may prevent the deformation necessary for desirable stress redistribution. For these reasons a purely theoretical approach to connection problems is always difficult and often nearly impossible.

It has already been pointed out that the structures to be served here will find application in the support of machinery and equipment that will be required for the generation of energy from the sun, wind, and waves or ocean currents. The proposed bolted connections would apply to structures generally, such as towers, frames, trusses, etc.

To provide a fixed base from which to proceed with the detail discussion, it is necessary to define structural members in regard to size, materials, and reliability. The usual practice of referring to pipe standards long in use is adhered to, that is, classification as standard, extra strong, and double extra strong pipe or tube. Sizes which fall into the schedule classification are also included. This allows selections to be made based on nominal dimensions with outside diameter and thickness specified. In regard to materials and physical properties, a wide selection is possible.

The range of sizes here under consideration will start with 5 inches and terminate with 24 inches, and will include intermediate sizes in this range. The usual methods followed in structural work regarding detail, fabrication, materials, etc., are here also adhered to.

THE DESIGN AND THE MODEL

The general design of the bolted connection is shown in Figure 1. As this study progressed it became clear that an actual model would be required in order to resolve the problems presented by size, fabrication, and code requirements.

The pipe of smallest diameter in the range established was chosen for both the initial design and the model for the reason that it has the greatest curvature and any mismatch between the outside radius of the structural member and the inside radius of the T-bracket flange would be most pronounced.

Space and clearance considerations were also factors in selecting the model size.

The maximum curvature or smallest tube size was

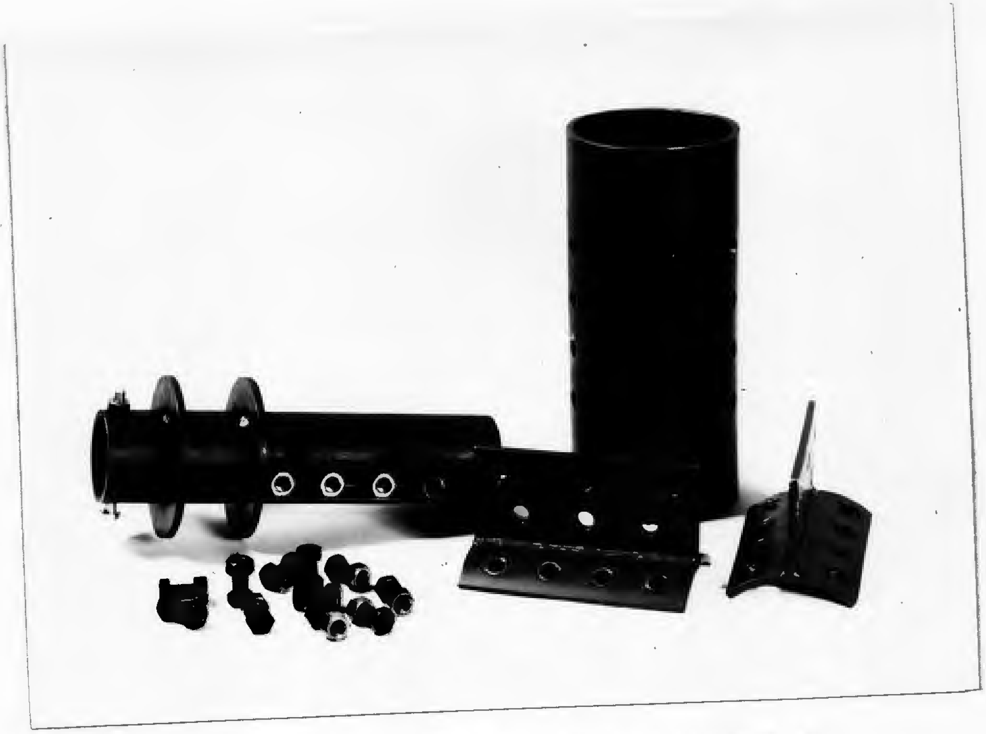


Figure 2. The model unassembled.

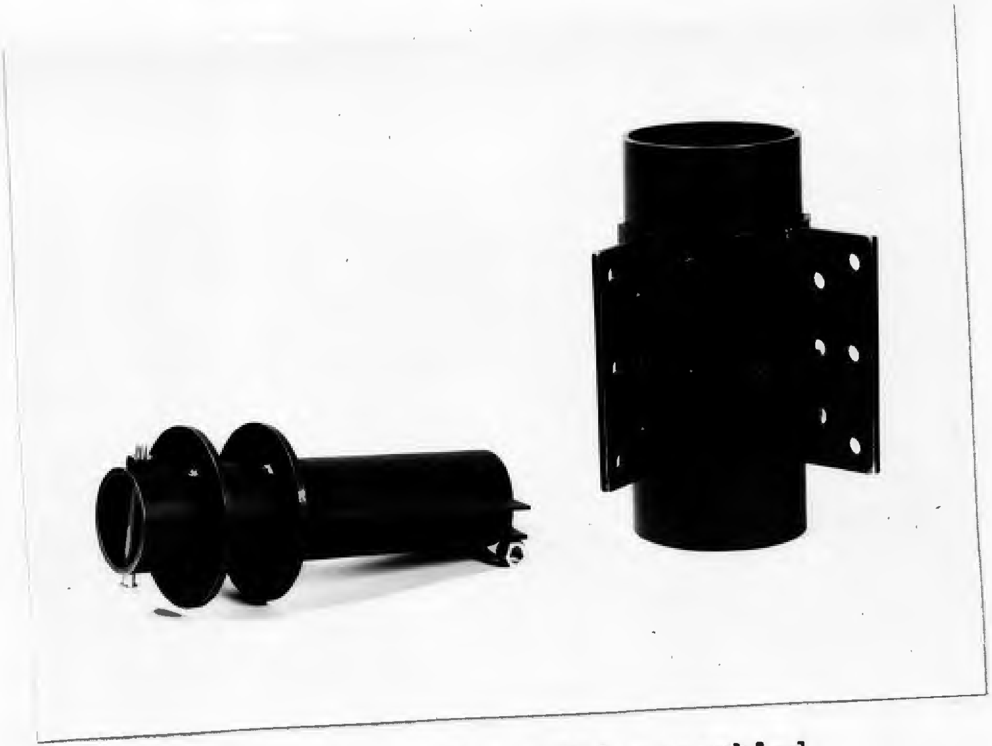


Figure 3. The model assembled.

T-bracket to the outside radius of the tube, in the example illustrated in Figure 1 and for the model the lower limit or 5 inch tube was chosen as the size with the smallest diameter and the maximum curvature.

The material used in making the model or prototype is structural type tubing to American Society for Testing Materials (ASTM) specifications, A501, $F_y = 36$ ksi, as given in the AISC Manual (10, p. 1-101), and the flanges of the T-brackets are fabricated of tubing of the same material and size.

The steps in the fabrication of the T-brackets can be followed by reference to Figure 1. The bracket is shown to accommodate two rows of four bolts. A section of tube is cut to the length of the required flanges. The selected length, in this case 7 inches, is divided parallel to the axis of the tube into four equal sections. These quadrants are marked to show up on the section face at each end of the pipe. These divisions are carried down the outside of the tube section, dividing the outer surface of the tube into four equal curved areas. These vertical lines can then be fine-burned. However, in making the model it was found that the cuts could be made just as well on an available band saw.

It should be noted here that the curved flange was produced in a small shop with regular equipment and labor, including the author's. The entire operation of making the saw cuts took about fifteen minutes. The author performed the layout work himself for the reason that no material could be spared. The maximum diameters were located on the end face of the tube with a machinist's divider, a center punch, and other simple means. For a check, the maximum diameters were brought to the other end of the pipe section by means of the parallel division lines mentioned above. These lines located the four maximum diameters to less than 1/32 of an inch.

The same procedure would hold for manufacturing the flange of the T-bracket if the primary tube is fabricated of rolled can sections instead of regular or special pipe. Plate of required thickness and width of flange is rolled into a ring similar in shape to the can. The inside radius is adjusted to exactly match the outside radius of the fabricated pipe. The open tube section is then cut into quadrants required for the T-brackets.

Detail calculation may show that thicker flanges are required in a given design. These could then be fabricated from sections of thicker tubing. Also, they could be rolled and formed from thicker plate of width equal to the length of the brackets needed. The rolled rings are marked parallel to the principal axis of the ring, then fine-burned or cut by band-sawing into the required section sizes.

The gusset is joined to the curved flanges by means of a full penetration weld. The flat gussets are of structural grade steel, and the joint for the weld was prepared about as specified for welded joints by the AISC Manual (10, p. 4-137, TC-U9a, Double-J Groove).

All drilling was to be done after welding. The curved faces on each end of the flanges were halved and clearly marked by center punching. These marks were to be used for the location of the gussets, indicated also in Figure 1. In the case at hand, the gusset and flange clamped easily together by means of two large C-clamps after the proper alignment with the curved flange was obtained (punch marks at half sections of the curved surfaces). All welding was then performed by a qualified welder, using E 70 T electrodes.

After the gussets were tacked lightly and checked for verticality (with slight corrections made on the spot), a second set of tacks went into place, with no need for correction of verticality. The weld was then made. Also, each end of the welds was sealed to prevent any ingress of moisture.

McGuire (9, p. 863) mentions the possible flange distortion that could be produced at a T-connection. While this did not occur, any uplift would have bettered the adjustment of the inside radius of the flange to the outside radius of the tube.

In placing the T-bracket flange on the outside of the tubular section, a gap of a little less than 1/16 inch could be measured. Such a gap is considered unacceptable, although the pull of the attachment bolts would reduce this gap to a certain extent. The following procedure gave a satisfactory match by reducing the gap to zero at one-half flange width and to less than 1/32 inch at one-quarter flange width. The T-connection was placed in a vise with the concave surface of the flange facing upwards. An oxy-acetylene torch was played along the center of the concave flange; heat was applied up to the plastic range indicated by a bright white color; the T-bracket was then removed from the vise and placed on a piece of tube of the same diameter as the one to be matched. The center of the T-bracket, now in or close to the plastic range, was struck several hammer blows and the adjustment was made. When cold, measurement revealed that the 1/16 inch gap at half point was eliminated, and at quarter points the clearance was close to 1/64 inch. In a later discussion of Fatigue and Stress Corrosion reference will be made to this gap, if it occurs, and to a method of preventing ingress of moisture to the body of the bolt.

In the model shown in Figure 3, the bolts are torqued as required by the AISC specifications on structural joints using ASTM A325 or A490 bolts (10). With these loads applied, the slight gap at quarter points vanished entirely.

With the flange in position and attached, the next step is to locate the bolt holes on the convex side of the T-bracket from dimensions available from the detail plan. Parallel lines are scribed, spaced, and prick-punched on the flange at each side of the gusset. Although drilling may appear to be involved and roundabout, it really is not.

The T-bracket is placed on the table of an ordinary drill press sidewise against a fixed stop; the side of the flange to be drilled is blocked by a piece of steel to the height required to produce the necessary radial direction, then fixed. No special jig is needed, but would probably be used in a production setup. Also, the arrangement allows motion sidewise, to slide the T-bracket under the drill as required. The holes can now be drilled.

Again, it may appear involved to produce the flat washer surfaces that match those of similar dimensions under the bolt head or on the sides of mating nuts. This is done with the same setup as used for drilling the holes. This bearing surface is produced by a counterbore or circular cutter, into the center of which the drill for the drilling of the bolt holes is mounted. After a bolt hole is drilled, the counterbore produces or mills the surface for the washer faces of either the bolts or the nuts. If this equipment is not available, the same operations can be accomplished in several steps with conventional tools.

Earlier in discussing the matter of locating lines and points of reference on the tube member, the T-bracket locations were also fixed. These fixed locations are now used in conjunction with the finished T-bracket, to be used as a template, from which to take the locations and drill the holes in the tubular members.

The entire fabrication procedures described above for the T-brackets will apply to both methods of attachment detailed in Figure 1 as the First Method and the Second Method.

First Method of Attachment (Figure 1)

Instead of employing through bolts and nuts for attachment of the T-brackets to the primary tubular members of a given structure, it is proposed that the bolts be threaded directly into the structural tube; that is, nuts are omitted and replaced by the tube as the second part of the fastener. The question arises, How reliable is such a connection when compared with the usual through bolt arrangement?

To thread the tube, the same setup is used as for drilling the holes for a through bolt design, the difference being that the tap drill replaces the drill required to produce the clearance holes for the through bolts. After these holes are drilled, the drill is replaced by the tap for the required bolt size and threads specified, the threaded holes being produced on the same machine tool with a proper change in cutting speed.

Strength of Threaded Insert and Regular Nut Compared. The A325 bolt and nut are used as a base for comparison with the threaded insert shown in Figure 1. The AISC Manual (10, p. 5-195) specifies the initial fastener tension as 12,000 lbs., to be produced by a predetermined torque, or the turn-of-nut method. This method was used in the assembly of the model, Figure 2 and Figure 3.

When a threaded insert takes the place of a through-bolt design, the tube wall should have strength properties equal to or better than the nut for the bolt size under consideration. By deduction, any insert must provide sufficient thread depth, that is, depth equal to or better than that provided by the standard nut thickness. A general rule for the thickness of a nut is that it should be at least equal to the nominal diameter of the bolt employed. (Under certain circumstances, nuts of lesser height than standard can be effectively used, as in many special applications.) In the case here considered, where a 1/2 inch nominal bolt size is used, the rule would specify that the tube thickness be at least 1/2 inch. The 0.258 inch in the design in Figure 1 (First Method) is insufficient. However, the tube used in Figure 1 was of standard size and with F_y = 36 ksi material. If extra strong tube or pipe, or a doubler, is provided in the construction and perhaps a higher quality material, then the proposed design should after analysis be entirely satisfactory.

Later, in the discussion of the adapter design, the threaded insert will again be touched upon and shown to have considerable merit since ample thread depth can be provided.

Second Method of Attachment (Figure 1)

The bolting arrangement shown in Figure 1 as the Second Method employs through bolts and is to conform to the detail specifications for bolted joints as required by the AISC. Here the threads and associated nuts are enclosed entirely by the tube, away from the detrimental influences of the elements. These standard fasteners can be installed in several ways. Two means of installation are described here; others will suggest themselves to the reader.

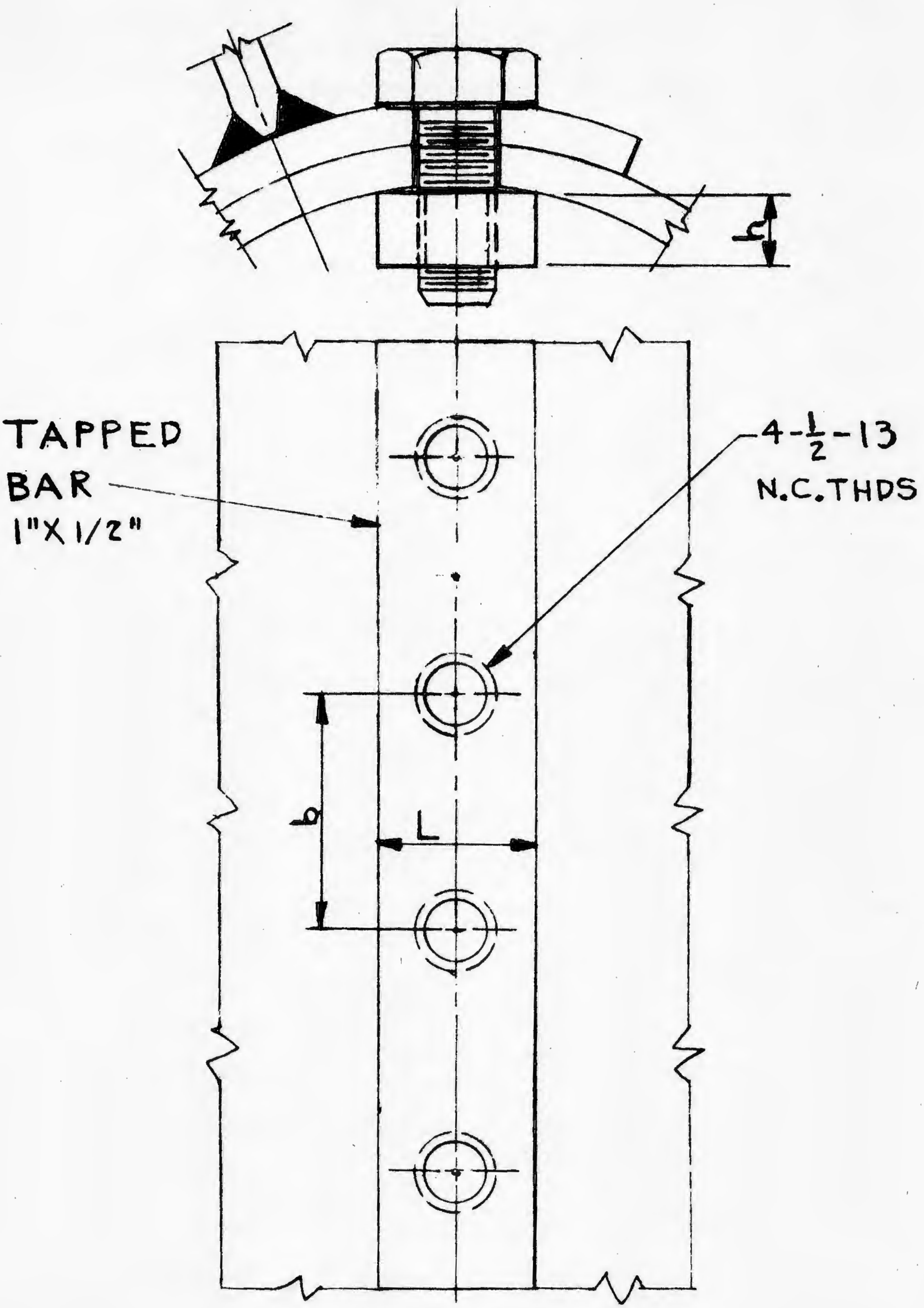
The detail sketch of an installation tool is shown in Figure 4, with the nuts located in a small channel piece ready for installation in the structure, with nut spacing taken from drawings provided. To place a group of nuts behind mating holes in the primary member of the structure to be assembled, the tool is lowered down the tube or, if the tube is on its side, slid in sidewise. After the holes in the tube are aligned with the nut centers, the bolts are inserted from the outside and torqued as required in the detail specifications mentioned above. After installation of the nuts, the tool is removed.

The steps just enumerated were followed in the assembly of the model fabricated from the detail drawing Figure 1. The two photographs show the connection and its parts, Figure 2 Unassembled and Figure 3 Assembled. Care was taken in the production of both the steel model and the installation tool that average shop practice prevailed. It can also be said that no great precision was required, at least, no more than that which would be practiced by the average fabricator.

Instead of a channel piece with nuts inserted, a tapped bar can be strapped to the installation tool. Such a tapped bar is shown in Figure 5, installed in the structure. The spacing of the tapped holes is determined from the dimensions shown on the structural plan.

The threaded bar can also be placed on and strapped lightly to a wooden reach rod by means of electrician's tape. The installation tool with bar or bars is slid into place and the threaded holes are picked up from the outside by insertion of the mating bolts. The bolts are taken up and torque applied as required by the specifications and similar design requirements.

This bolting design is considered to conform in all respects to the specifications in the AISC Manual (10).



<u>Figure 5</u>. The tapped bar.

TUBULAR BOLTED CONNECTION WITH ADAPTER PIECE

The detail design and the assembly of components of this connection are shown in Figure 6. The adapter or saddle shown provides the change from round to flat in order that structural members of various sections can be used. Again, the size range 5 to 24 inches primary tube diameter will be adhered to.

Since the parts that make up the complete connection are standard structural items, no model has been constructed to full size, as was done for Figure 1. However, a smaller model using 2 inch standard pipe size was constructed by the author in order to assemble the information necessary to discuss the design shown in Figure 6.

The material suggested for any given design would be cast steel, although the adapter can be rolled of steel bar stock, provided that the order is of sufficient size or tonnage to make it profitable to the mill. The re-rolling process proposed is to take bar stock of sufficient size, heat and re-roll by means of contour rolls to give the radius desired to match the structural tubes to be employed in the structure. To the author, this procedure has limited application at the present time, therefore the cast steel adapter is discussed here in detail.

Once a tube size or tube sizes are selected and the other details of a structure are determined, it is a simple matter to provide the principal dimensions of the adapter to be used in the assembly. A pattern must be made. For the cross-section see Figure 6, which is for the 6 inch size shown, although these comments apply to the entire range of the tubes considered.

The author finds that the cost of such a pattern is insignificant. It will be noticed that no loose or secondary pieces are required for the pattern. In fact, these simple patterns can be made by any small pattern shop or by the fabricator himself. The needed castings can be made by small job foundries that produce steel castings. The parting line for cope and drag will be at the flat of the pattern. The piece is cast with the curvature down. The castings made from the author's pattern came out sound and were flat and true. The curvature (to shrinkage scale) matched the pipe selected very closely. The steel used was to ASTM specifications but not specially selected for the service intended.

As in Figure 1, the design here considered, Figure 6, shows for attachment both the through bolt, the Second Method, and the tube and adapter threaded, the First Method. The fastener indicated as the Second Method will be installed as was suggested in the installation procedure for the T-bracket design. Where threading into the wall of the tube was not considered satisfactory in the T-bracket design, it is considered entirely satisfactory when both the steel adapter and the walls of the tube are threaded.

In Figure 6 the welding of the adapter to the tube is entirely satisfactory, first, from a strength point of view; and secondly, because any moisture that might find its way into the contact area between the adapter and the outside of the tube is ruled out since the weld is continuous at the sides and top and bottom.

The designs considered here concern themselves with the bolting, assembly, fabrication, and economic considerations of the actual connections. In the discussion of the design proposed in Figure 1 it was mentioned that the T-bracket would provide the desirable effect of strengthening, and as a result of this giving additional rigidity to, the joint. The adapter design proposed here (see Figure 6) also provides additional rigidity to the connection, which can be varied to the requirements of a given structure. This desirable feature will not be made a part of this investigation for the reason that the designs proposed here will, among others that will be developed in the future, need to be evaluated in regard to stress and load transfer, which will require further research.

Several typical connections are shown in the sketches following. In Figure 7 several tubular members come together at a nodal point in the structure. It should be mentioned that the open construction provides for easier

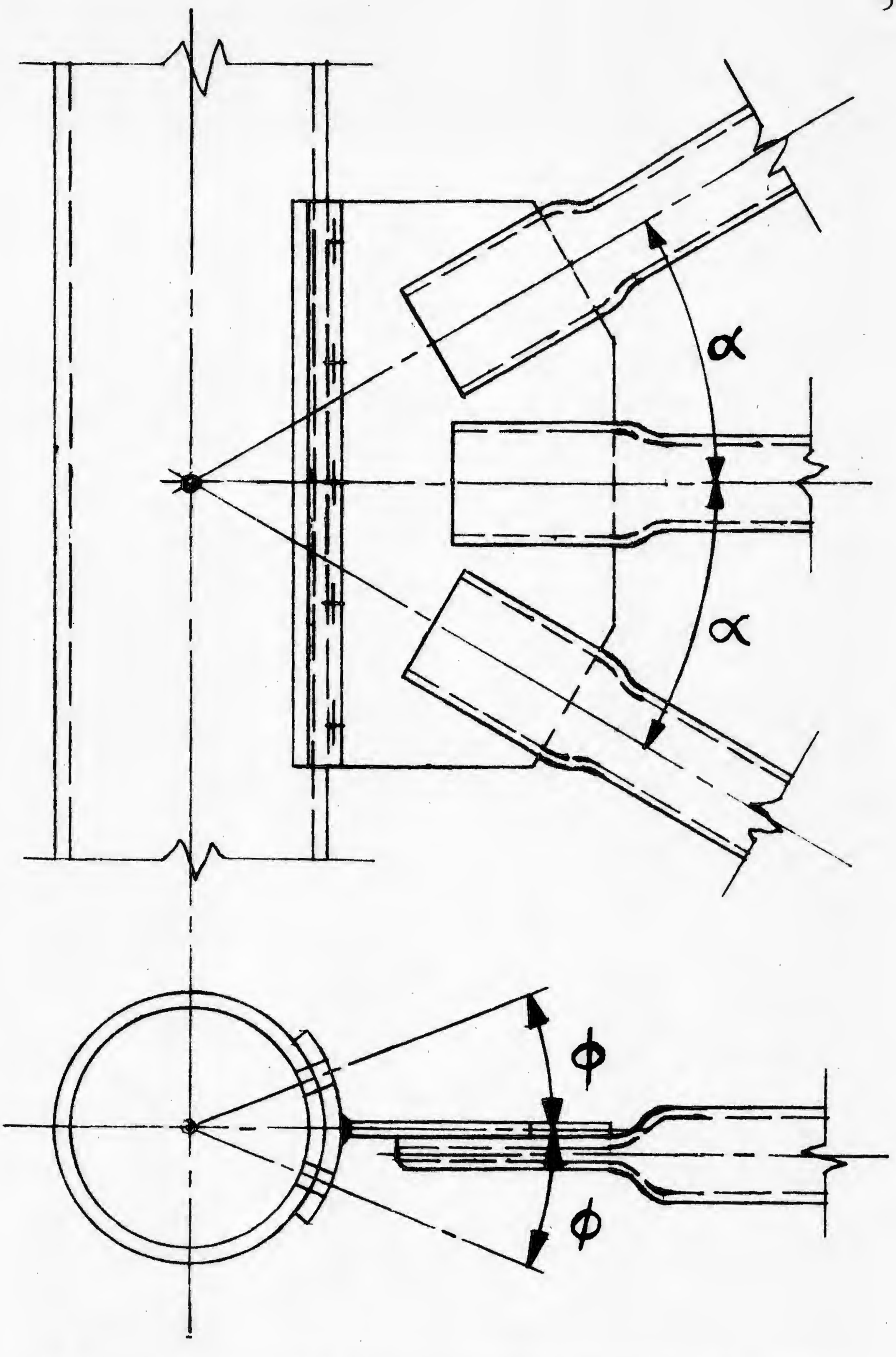


Figure 7. Gusset plate connection with T-bracket.

maintenance for the reason that all parts are more accessible. Any bolting can be reached with standard tools. The three members coming into the joint and shown also as tubes are either bolted to the gusset or welded to the mating member as the design requires.

Two methods of attachment for the three tubular members coming into the joint are indicated. The one shown in Figure 7 and presented in detail in Figure 8 is produced by heating the tube end in a portable induction heater. The heated tube is deformed by a press, either without or by means of a latch die, to its final shape.

In the design of a structural member with this type of flat end connection, it should be mentioned that a certain amount of eccentricity is unavoidable. This eccentricity is indicated by the letter "e" in the detail of the connection in Figure 8. This type of pressed end connection should therefore be employed only for members under axial load, that is, as secondary members in a structure.

In the case where a member is both loaded in the axial direction and has moment applied to it, eccentricity should be absent. The design shown in Figure 9, the slotted tube, which is symmetrical and without eccentricity, is suitable for use as a primary member in a given structure.

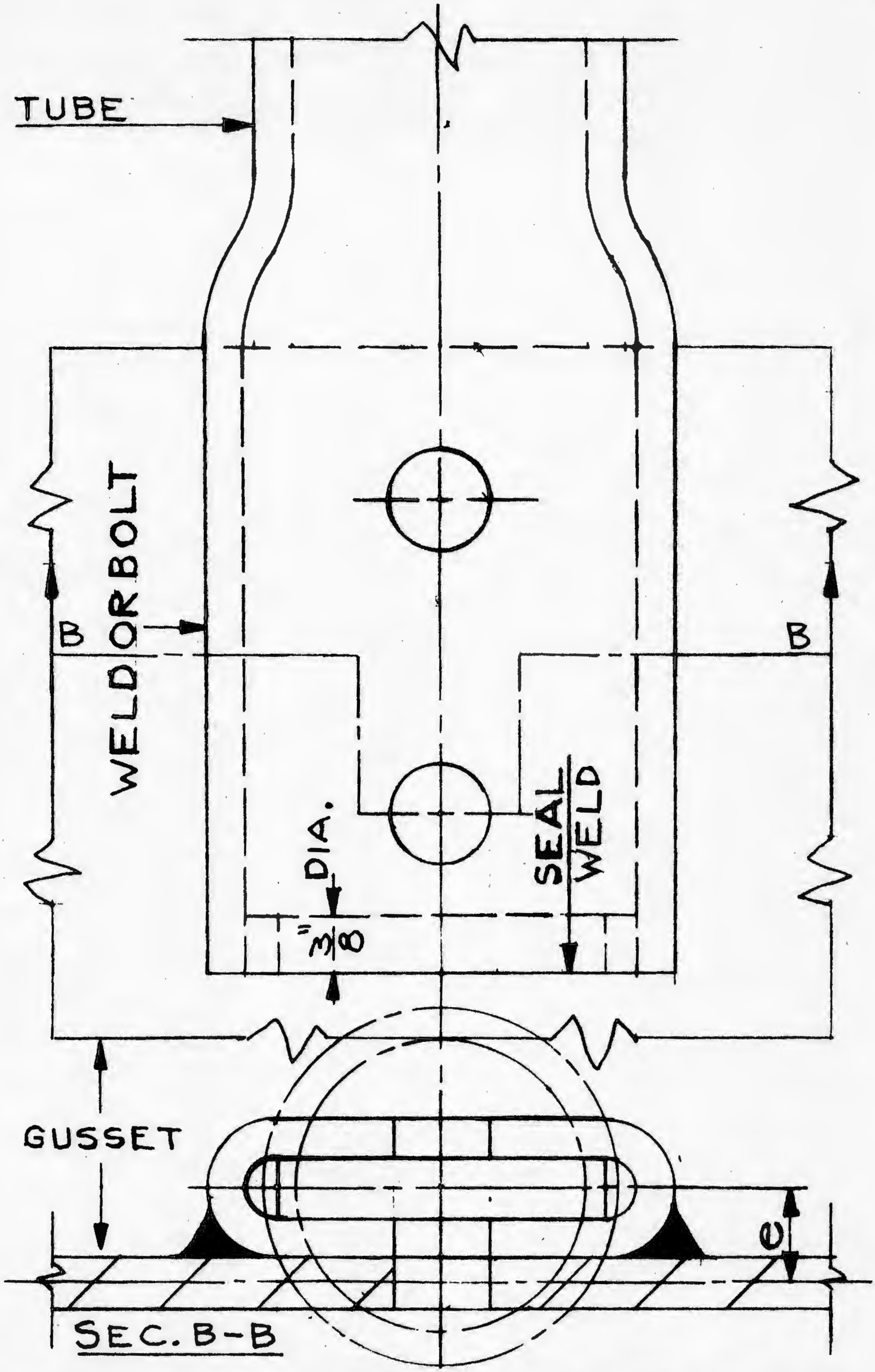


Figure 8. Tubular strut flat pressed end connection.

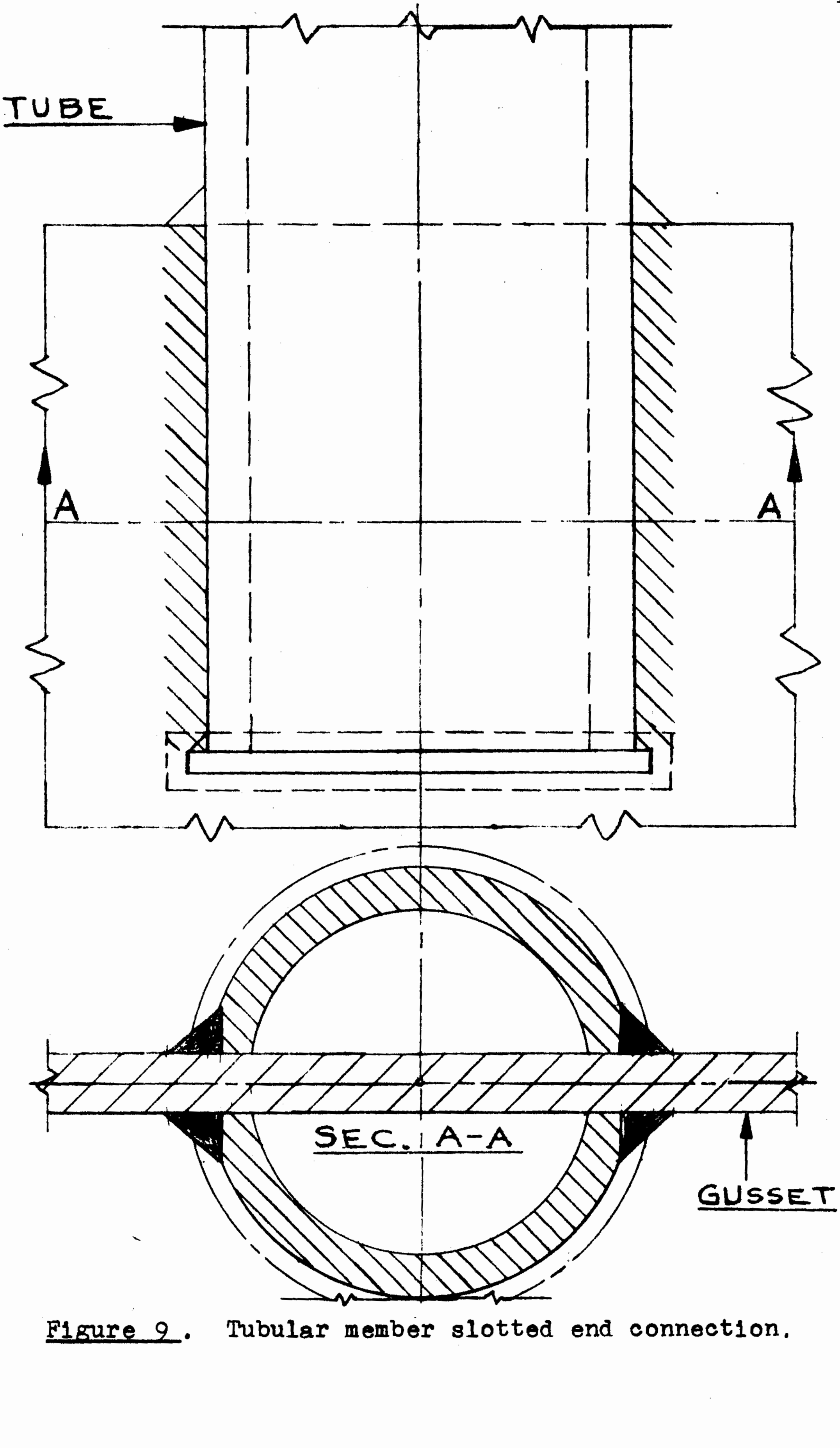


Figure 9 . Tubular member slotted end connection.

To show a light framed connection employing the T-bracket, Figure 10 is added. The individual proportions are only to indicate the relationship of the various components. Sizes shown are average in order that a better picture of the assembly may be produced.

To illustrate the applicability of standard methods of analysis to the T-bracket design, a typical calculation is given in the Appendix.

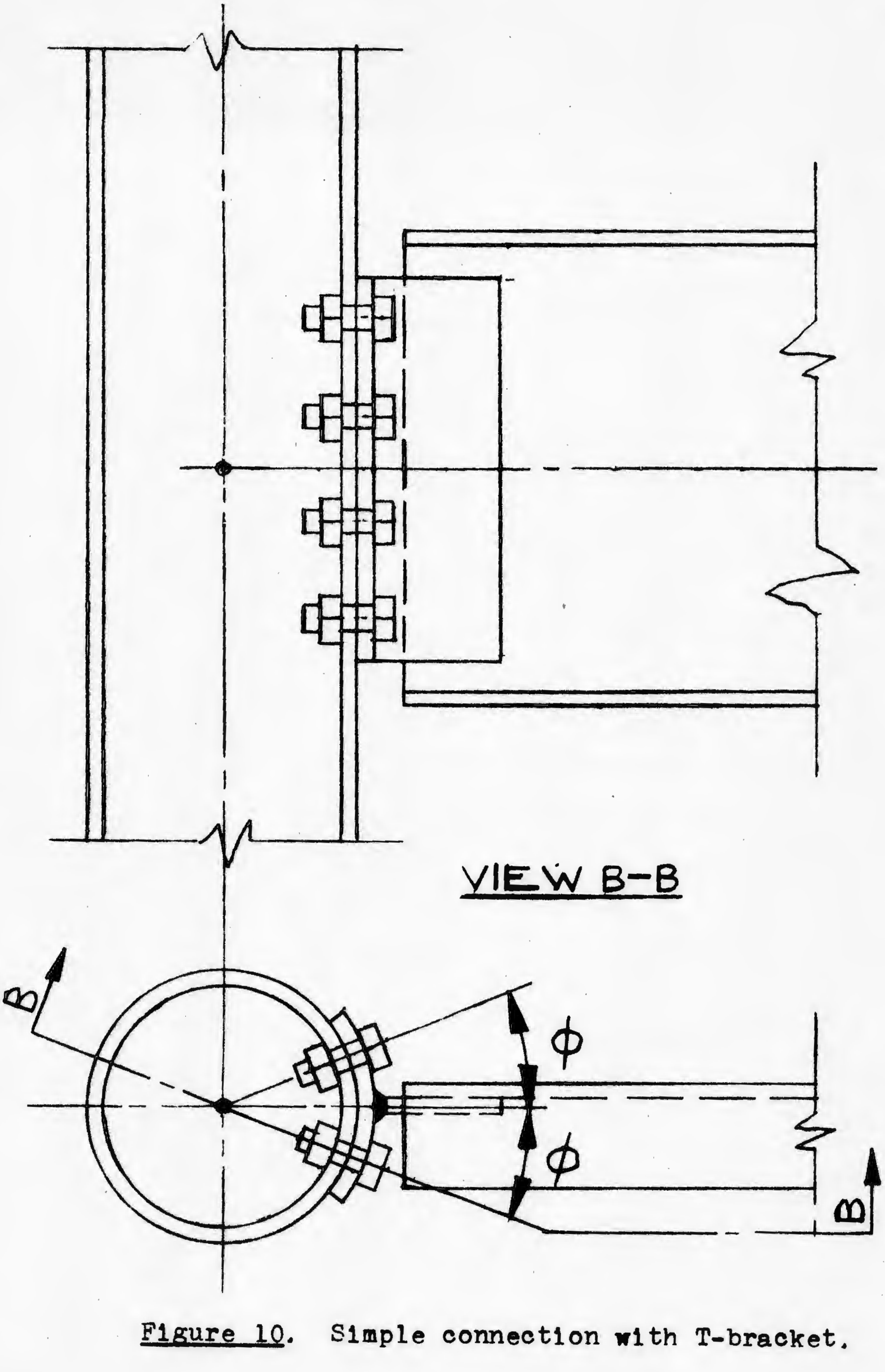


Figure 10. Simple connection with T-bracket.

CHAPTER IV

FATIGUE AND STRESS CORROSION

Literature past and present cites many cases of failure that can be attributed to stress corrosion, the notch effect, fretting corrosion, etc., and various combinations thereof (11,12,13,14). Under consideration here is the service life of a structure and the fatigue characteristics of the component members. The sea environment and weather conditions such as wave impact and cyclic loading, which can influence the fatigue properties of the materials employed, need proper attention.

"The first rule of design in fatigue situations is to keep stress raisers to a practicable minimum," says McGuire (9, p. 1071). This fundamental rule is at times overlooked in the design of machinery and equipment that goes to sea, such as cranes, cargo handling equipment, deck machinery, stabilizers, etc. Research points to the areas that are causative, and gives certain criteria considered to be important in these situations. A useful guideline proposed for the design of structures intended for unattended failure-free service is to reduce or eliminate the side effects produced by corrosion, questionable welds, fretting, and lack of proper quality control. Ample support for this is furnished in the paper entitled "Subcritical Crack Growth and Ship Structural Design" (8).

The two proposed designs, Figure 1 and Figure 6, show several features that tend to minimize the factors that have caused failure or malfunctioning of both machinery and structures.

First, the stress raisers, in this case the bolt threads, are placed out of reach of the elements; that is, the assembled bolt and nut are concealed on the inside of the tubular members. On the outside, sealing action is provided by placing a thin copper-nickel washer under the bolt head at the washer face.

Second, minor irregularities and any mismatch between the surfaces of the outside radius of the tube and the inside radius of the T-bracket flange can be made moistureproof. These surfaces are painted at assembly with a liquid sealing compound, of which several are on the market. The material familiar to the author has a urethane base, is seawater resistant, and gives satisfactory service up to about 450° F. A useful manual describing the application and general characteristics of this sealing compound is provided in reference (15). The sealing of flat unmachined surfaces is considered satisfactory in marine practice; curved surfaces should be treated in the same manner.

A third method for moistureproofing a threaded bolt is to use a nut with a nylon insert at the top side of the nut. This device, which is intended to provide the nut with locking means, will also serve as a very effective barrier against moisture. Experience has shown that bolted connections made up with this type of nut (with insert) which were opened up after years of service gave no indication that water had found its way past the insert into the threaded connection by way of the bolt.

The T-bracket is shown as a weldment. If the weld is accomplished under controlled conditions, that is, with satisfactory preparation of the joint and proper joint materials (electrodes), by qualified welders, and with weldment stresses selected to be below the endurance strength for the joint employed, then a satisfactory service life can be expected (8). In regard to these weldments, field welding is eliminated. The welds can be fabricated in agreement with the requirements of AISC or AWS codes.

The bolted connections here presented can be analyzed by current structural procedures and are in agreement with general specifications as provided by the structural codes and the AISC.

CHAPTER V

SUPPORT STRUCTURE FOR EQUIPMENT

What types of equipment will require support structures in the accelerating search for new energy sources? Advances in technology involve new methods and new solutions to old problems.

The modern drilling platform at sea is familiar to all. It contains supporting structures for equipment such as mooring systems, outriggers for platform positioning, radar units, blowout preventer stacks, etc. The list of new developments is constantly expanding, based on the increased demand for oil and gas from additional sources not so readily available. Current exploration is being pushed far north and into much deeper water. As a consequence, new procedures and equipment must be developed.

The same applies to vessels engaged in ocean mining operations; to floating platforms proposed for nuclear power plants; and to oil storage and refining installations. Articles in the publication Marine Technology support the view that the future will demand advanced methods of construction (16,17,18).

The type of structure will, as always, depend upon the service it is intended for. The adequacy of the structure is a primary requirement, especially for heavy equipment on a nonstable platform subjected to motion stresses and to wind and extreme weather conditions. Several possible structural forms are suggested in Figure 11. Current methods of structural analysis, both approximate and exact, are provided in references (5,19,20).

If the energy source sought is wind power, air flow will be a primary consideration. Here a tubular structure without cross-bracing (such as Vierendeel) might offer the least wind resistance. Groups of wind mills are being planned for certain areas, and one built under contract for ERDA is now in operation in Ohio.

In locations where severe weather, such as ice and snow, prevails the round hollow section would provide a protective channel for power lines and heating elements.

Results from dynamic analysis are considered of greater reliability if structures are symmetrical and present simple constructional forms.

The prefabricated bolted connection described in this paper would apply to all of these structures.

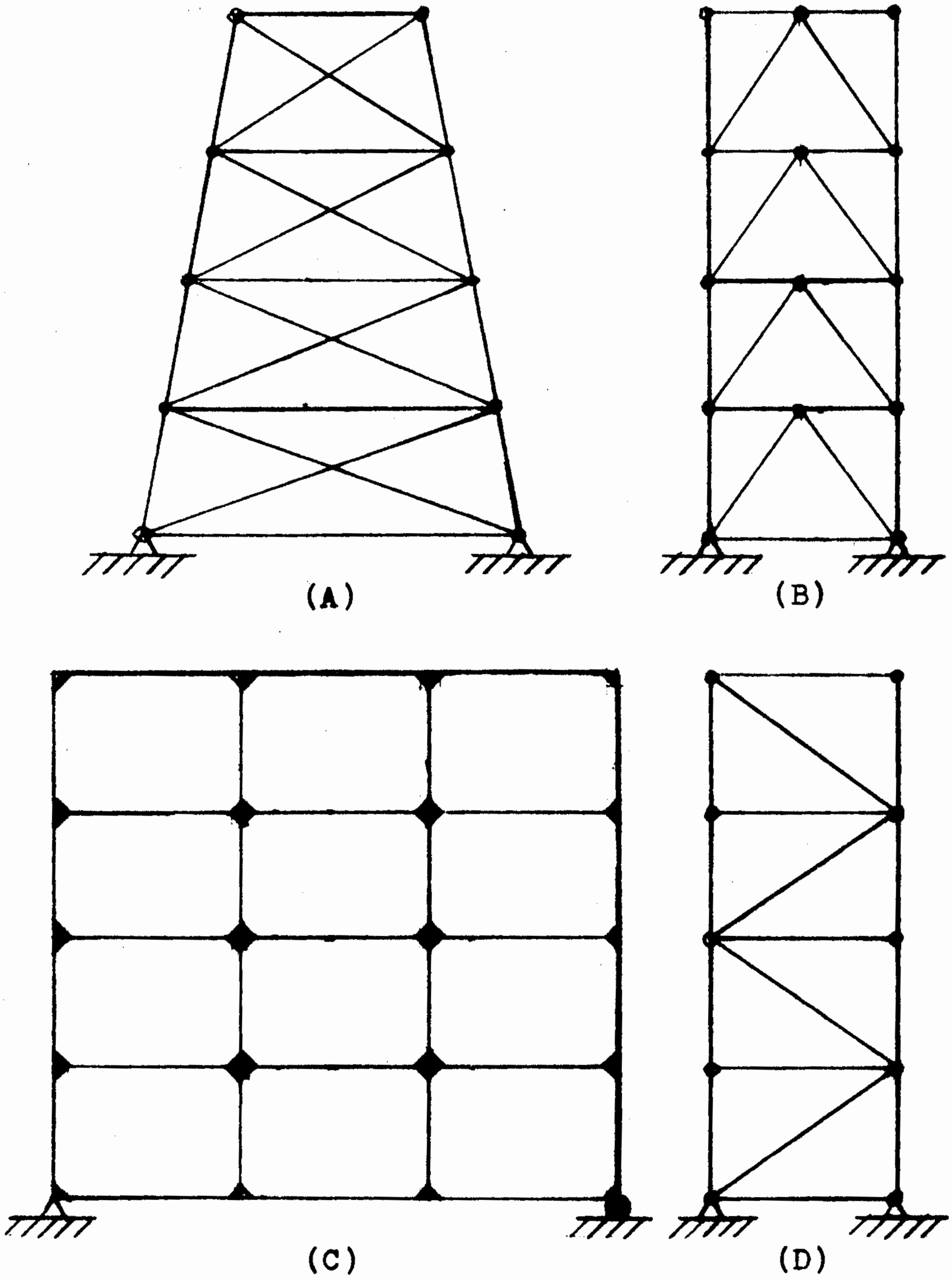


Figure 11. Types of trusses and frames used for the support of wind power equipment and solar concentration units. (A) "X" bracing. (B) "K" bracing. (C) Vierendeel truss. (D) Warren truss.

CHAPTER VI

CONCLUSIONS

Structures intended for the support of machinery and equipment needed for the collection and transformation of energy available from the sun, wind, and waves have been considered. It was shown that round tubular sections employed in these structures, whether for land or sea installations, would offer a number of advantages.

Detail design considerations that influence analysis have been pointed out, such as wave and air motion and the corrosive action of the sea.

The design has taken into consideration such features as ease and economy of fabrication, using the tools and labor available to the average fabricator; satisfactory performance; and ease of maintenance of both the structure itself and the machinery it supports.

Two bolted connections have been proposed and shown to be suitable for tubular construction.

A full-size model was fabricated and assembled in conformity with standard specifications (AISC).

A typical computation is included in the Appendix to illustrate the application of current design methods to the connections proposed.

The designs proposed have been proportioned so that adequate strength can be provided in a given application to meet the requirements of rigidity for the structural members coming into the connections.

These mutual requirements are and will be the subject of a great deal of research and development now and in the future.

Based on the investigations and information presented above, the two bolted connections are considered feasible for the structures under consideration.

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APPENDIX

CALCULATION OF SHEAR AND TENSION FORCES APPLIED TO TUBULAR CONNECTIONS

These computations are intended to demonstrate that the proposed connections can be analyzed according to structural principles and also will conform to the current requirements of regulatory bodies such as the AISC.

Figure 12 shows a tension member connected to a vertical tubular leg of a structural frame. The rotation diagram (Figure 13) shows the relationship of the load on the tension member to the bolted connection. Due to symmetry, only half the flange will be considered. In connections that bolt to flat surfaces, for instance the vertical flange of an H-column, the X component would produce tension in the bolts and the Y component would be resisted by the bolt shear. For the tubular connection under consideration, the X component is resisted by the bolts in the plane A-B. This load produces tension in the bolts and is shown as R in the load rotation diagram, Figure 13.

To illustrate: R is obtained from the angle of rotation Phi (ϕ), the angular amount the flange bolts are rotated from the plane of the tension member. This angle is indicated in both Figure 12 and Figure 13.

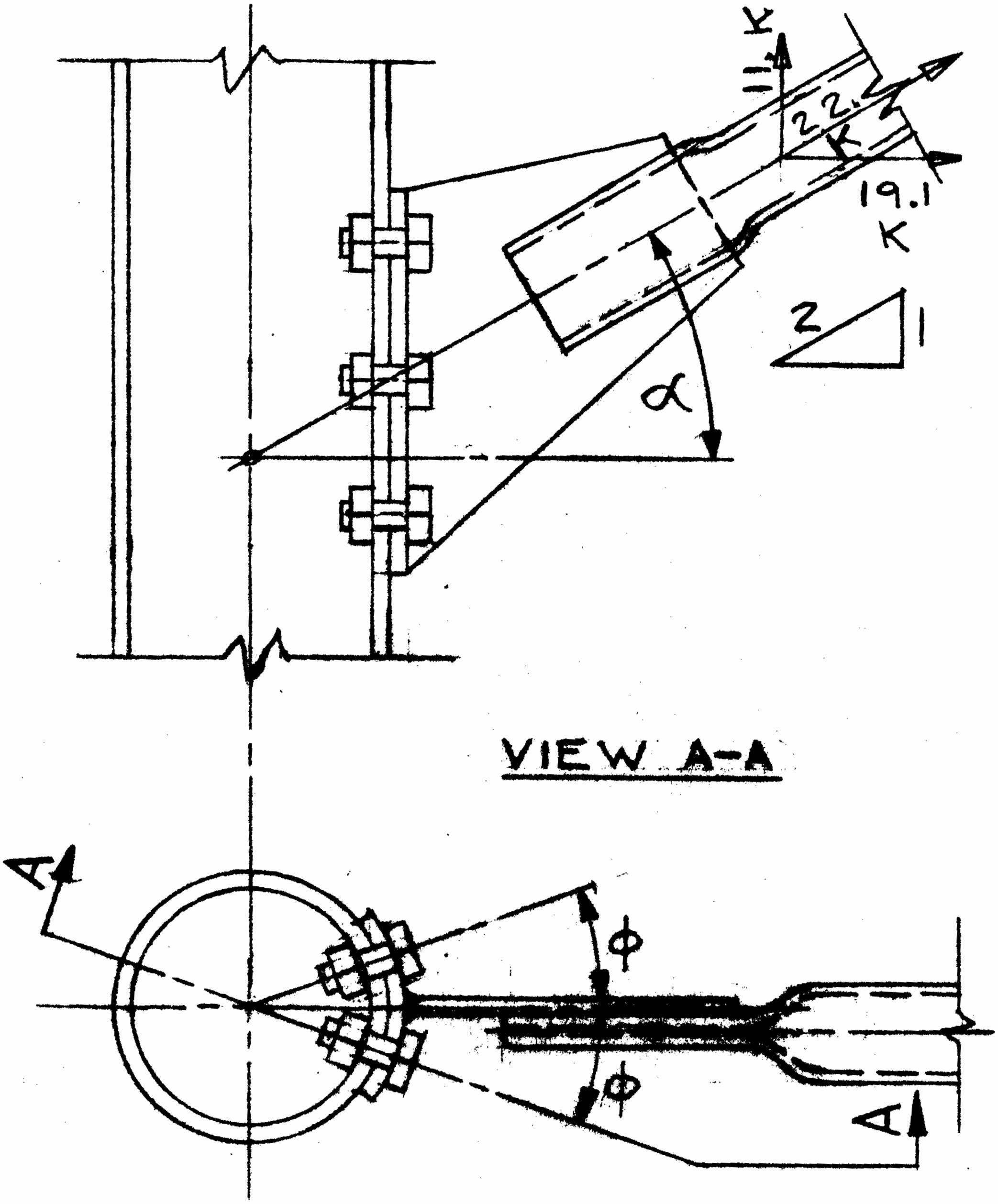

Figure 12. Tension member with T-bracket.

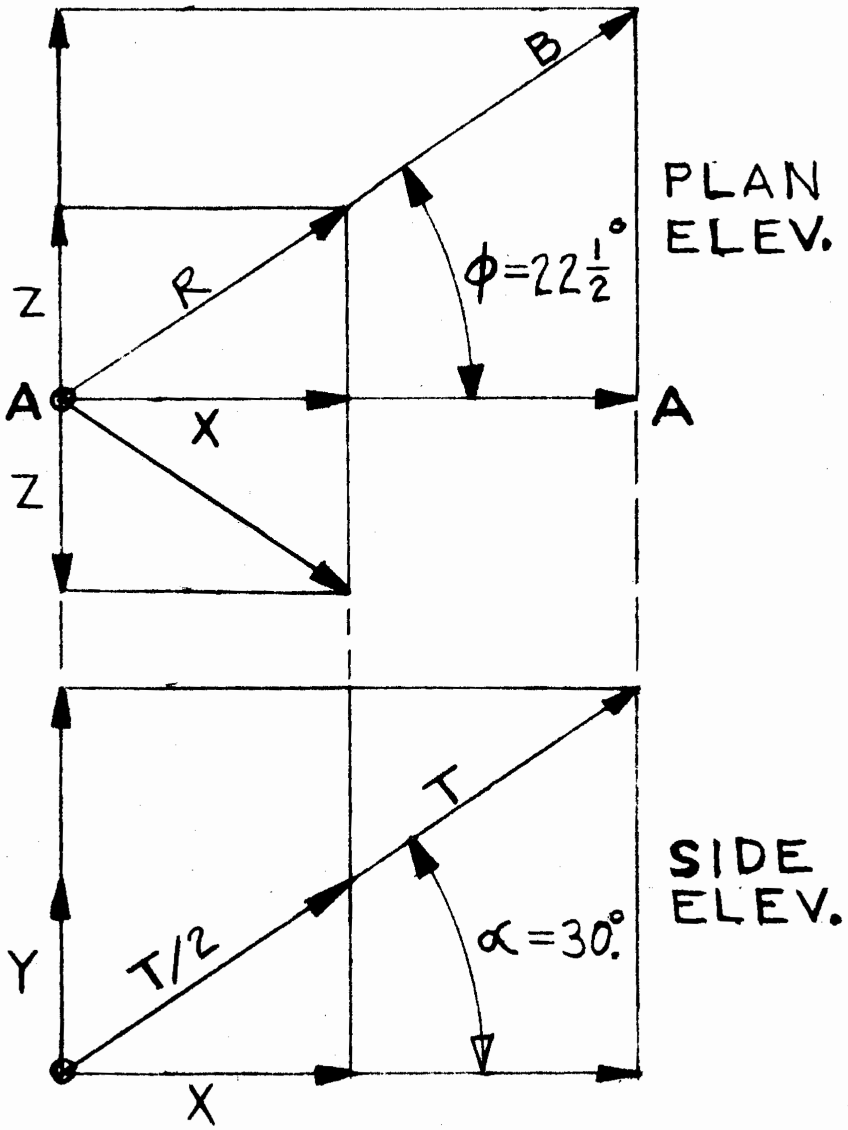

Figure 13. Load rotation diagram. Loads due to thrust and moment in plane A-A are rotated into plane A-B as indicated above.

In both figures the applied tension is specified as 22 kips and

T = Member tension, kips

X = Normal tension, kips

Y = Shear component, kips

Z = Bracket balanced component, kips

R = In-plane bolt tension, kips

Half flange load = $T/2 = 22.0/2 = 11.0$ kips

$X = T/2 \cos\alpha = 11.0 \times 0.86660 = 9.53$ kips

$Y = T/2 \sin\alpha = 11.0 \times 0.500 = 5.50$ kips

$$R = \frac{X}{\cos\phi} = \frac{9.53}{0.9239} = 10.30 \text{ kips}$$

In the calculation to follow the tubular connection will be investigated both as a bearing-type connection and also as a friction-type connection. Light frame construction is assumed. The tension member and the T-bracket are connected to the tubular column with six 1/2 inch A325 high-strength bolts. AISC specifications will govern. Can the design provided resist the applied load under the above code?

<u>The T-Bracket as a Bearing-Type Connection</u>

The shearing stress is given as f_v, and A_b is the nominal bolt area of the fastener.

$$f_v = \frac{Y}{(3)\ (A_b)} = \frac{5.50}{(3)\ (0.1964)} = \frac{5.50}{0.588} = 9.35 \text{ ksi}$$

$$< 22 \text{ ksi}$$

The AISC Manual (10) on p. 5-193, Table 2, gives as the allowable working stress for a bearing-type connection, threads excluded, 22,000 psi. On p. 5-23 of the Manual, Section 1.6.3 Shear and Tension, the following statement is made:

> Rivets and bolts subject to combined shear and tension shall be so proportioned that the tension stress, in kips per square inch, produced by forces applied to the connected parts, shall not exceed the following:
>
> For A325 and A449 bolts
> in bearing-type joints $F_t = 50.0 - 1.6f_v \leqslant 40.0$

$$\text{Allowable, } F_t = 50.0 - 1.6(9.35) = 50.0 - 14.94 = 35.05 \text{ ksi} < 40 \text{ ksi}$$

Table 2, p. 5-193, of the Manual gives as the allowable applied tension for ASTM A325 bolts 40,000 psi maximum.

$$\text{Actual, } f_t = \frac{R}{(3)\ (A_b)} = \frac{10.30}{(3)\ (0.1964)} = \frac{10.30}{0.588} = 17.60 \text{ ksi} \leqslant 35.05 \text{ ksi}$$

This is considered satisfactory.

The T-Bracket as a Friction-Type Connection

The computed tensile stress is given as f_t.

$$f_t = \frac{R}{(3)\ (A_b)} = \frac{10.30}{(3)\ (0.1964)} = \frac{10.30}{0.588} = 17.60 \text{ ksi} < 40 \text{ ksi}$$

In regard to the friction-type joint the AISC Manual has the following statement on p. 5-24:

> For bolts used in friction-type joints, the shear stress allowed in Sect. 1.5.2 shall be reduced so that:

For A325 and A449 bolts $F_v \leqslant 15.0\ (1.0 - f_t A_b/T_b)$ where f_t is the average tensile stress due to a direct load applied to all of the bolts in a connection and T_b is the specified pretension load of the bolt.

In the calculation here presented:

f_t = 17.60 ksi

T_b = 12,000 lbs. = 12.0 kips

A_b = 0.1964 in.^{2}

$$\text{Allowable, } F_v = 15.(1.0 - \frac{17.6 \times 0.1964}{12.0})$$

$$= 15.(1.0 - 0.287)$$

$$F_v = 15. \times 0.713 = 10.70 \text{ ksi}$$

$$\text{Actual, } f_v = \frac{5.50}{0.588} = 9.36 \text{ ksi}$$

$$< 10.70 \text{ ksi}$$

The design is therefore considered satisfactory as a friction-type connection.

Other examples could be presented, but the above figures will show the application of structural codes and methods of computation.

VITA

John H. Tausch received the degree of Bachelor of Science in Mechanical Engineering from Northeastern University in 1940. His early experience was as a machine and tool designer in the rubber, crane, and machine tool fields; but the major part of his work has been in the shipbuilding and construction industries. As a mechanical engineer he has designed equipment for the process industry, dredges, cranes, and the powering of industrial equipment. His marine engineering experience includes the design and development of propelling machinery, ship structure, steering equipment, hydraulic drives, cargo handling equipment, etc. He is a registered engineer in Massachusetts, Maine, and Oregon; and a member of the Society of Naval Architects and Marine Engineers (SNAME), National Society of Professional Engineers (NSPE), and Professional Engineers of Oregon (PEO).