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THE USE OF RECTANGULAR STEEL BOX MEMBERS IN THE U.S. BUILDING CONSTRUCTION INDUSTRY

Philip B. Plottel
Graduate Research Assistant

Dr. Michael D. Engelhardt
Assistant Professor of Civil Engineering

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HUCK MANUFACTURING COMPANY

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ABSTRACT

This report summarizes the findings of a study on the use of hollow rectangular steel members in the U.S. building construction industry. Hollow rectangular structural steel sections have been used in structures since the advent of steel construction at the end of the nineteenth century. The first sections were built up by rivetting together plates and angles to form a box. Current practice is to weld together four or more plates, or to weld plates onto a rolled wide flange (W) section in order to form the built up box section. After World War II, rectangular sections started being manufactured from a single plate by a cold forming process. These cold formed sections are commonly known in the United States as structural tubes. At present both welded built up box sections and cold formed structural tubes are used in U.S. practice.

Built up box sections can be made to almost any dimension. Size and availability are limited by cost, the number of fabricators with the expertise to make these sections, and transportation and erection limitations. Built up boxes used in buildings are usually several feet on a side, with plate thicknesses on the order of 1 to 5 inches, and are typically of all welded construction.

Structural tubes manufactured in the United States generally conform to the ASTM 500 Grade B specification and are produced in standard sizes. Compared to W sections, structural tubes are only manufactured in a relatively limited number of light sizes. Most tubes produced have a weight of 100 pounds per linear foot or less, a maximum perimeter of 64 inches, and a maximum wall thickness of 5/8 of an inch. Eight

domestic manufacturers account for 80 to 85% of the tubes used in U.S. building construction.

Hollow rectangular sections, both built up boxes and structural tubes, offer several advantages in building construction. These members are structurally efficient for compression, bi-axial bending, torsion, and long unbraced uniaxial bending. Of these conditions, compression is by far the most common. Box sections also generally occupy less space than W sections. Tubing is often small enough to be placed within a wall or partition, thus eliminating the need for protrusions. The hollow interior of boxes can be used to hide utilities, or can be filled with concrete for greater strength. Finally, when left exposed, tubing has a clean, sleek and pleasing appearance.

The material, fabrication and erection costs of boxes are generally higher than for rolled sections. On a tonnage basis, rolled sections cost anywhere from 50% to 75% less than boxes in the U.S.. In addition, connections to box sections, especially structural tubes, are more difficult and costly than connections to W sections.

Hollow rectangular sections at present comprise less then 10% of the total structural steel used in buildings. The primary applications of built up boxes are columns, often only at the corners, in mid to high rise buildings. Structural tubing is primarily used as columns in one story retail, commercial, and institutional structures, and as supports for one story canopy structures. Structural tubing is also sometimes used as columns in two story buildings, braces and as ornamentation.

Connections are a key element that affects both the safety and cost of a structure. Connections to boxes generally require some welding, and sometimes require bolts, if only for erection. Connections to built up boxes are often similar to connections to W sections, with the exception of internal stiffeners. Many engineers lack familiarity with structural tubes connections, and consider them difficult and costly. However, many proven connections do exist and qualitative examples are presented in this report.

The availability of heavier jumbo steel wide flange sections, high strength steels, and the increasing use of high strength concrete may cause a decrease in use of the built up box member. However it is anticipated that manufactured tubes will continue to be used in one story buildings, and in exposed architectural applications. Promotion, publicity and the development of design literature will contribute to a gradual increase in structural tubing used in the U.S. building construction industry.

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1. INTRODUCTION

The objective of this study is to provide an overview on the use of hollow rectangular steel members in the U.S. building construction industry.

Two different types of hollow rectangular steel members are commonly used in the United States. The first type used since the beginning of steel construction is the built up box section, custom made from plates or other structural members to form a hollow shape. The other type of hollow section, manufactured tubing, is more recent. Manufactured tubing is produced in standard sizes, and is generally cold formed from one plate.

This report will cover some of the history, the methods of fabrication and manufacture, the advantages and the disadvantages, and current and future applications of both built up boxes and manufactured tubing used in buildings. In addition, many typical connection details will be illustrated. The report covers only hollow box shapes used in building construction. Bridges, offshore structures, or other non-building uses of hollow shapes are not within the scope of this study.

Information was gathered using the resources of the faculty and libraries of the University of Texas at Austin as well as manufacturer's information. The literature search was supplemented by telephone interviews with engineers and contractors throughout the United States, as well as, office and plant visits to engineers and fabricators in New York, NY; Cambridge, MA; Washington D.C.; Houston, TX; Austin, TX; San Francisco, CA; and Seattle, WA.

2. TYPE AND AVAILABILITY OF BOX MEMBERS

2.1 BUILT UP BOX SECTIONS

In 1855, Henry Bessemer invented a new, profitable method for producing steel in large quantities. The Brooklyn Bridge, completed in 1883, was the first important use of Bessemer steel in the United States. "Composed entirely of steel, the Bridge floor represented a major industrial and technological innovation. No structure of such size had ever been built of steel, and the contractors had to design new machinery in order to manufacture the girders." (Nevins p. 62) Having proved its versatility, steel has become the metal of choice in building construction.

The first steel box sections were fabricated from plates, angles and channels and riveted together to obtain a square or rectangular shape. Hool and Kinne's 1923 text on steel construction (Figure 1) shows many different configurations of compression members including several box sections. With the advent of welding in building construction in the 1950's, the rivets and bolts used in built up members were replaced by welds. Presently, all new built up box sections (excepting some replacements of historic structures) are welded. Welding allows for a truly closed section and less material preparation. Examples of built up boxes commonly used in current practice are shown in Figure 2.

Built up boxes may be difficult to fabricate due to tight tolerances, welding, and internal stiffeners. As an example, the order of construction for a four plated box may be as follows: first, connect the internal stiffeners to one of the plates. The stiffeners act as a guide to keep the box in line and to prevent warping. Next, the two side plates are welded to the bottom plate and to the stiffeners. The top plate is then welded. The stiffeners may be attached to the top plate by welding if the box is large enough to allow a worker inside (in which case cutouts are located in each stiffener), or by electroslag welding from the outside of the box. In some applications, the final stiffener weld may be omitted. Fillet welds are used in connecting the elements if they are feasible. Otherwise partial or full penetration welds are used. Some fabricators will use a thicker plate and a partial penetration weld instead of the more costly and complicated full penetration weld when putting together a section. Welding is discussed in greater detail in section 5 of this report.

Built up box sections are custom made. The limitations on availability are the ability and expertise of fabricators to make these sections, and the capacity of cranes to erect them. In building applications, box dimensions may be several feet on a side, with plate thicknesses on the order of 1 to 5 inches (Photograph 1).

2.2 MANUFACTURED STRUCTURAL TUBING

The first steel tubular elements formed from a single plate were made in the nineteenth century. These circular tubes were produced by "rounding a strip and joining it together by forming and welding (fire welding)."(Wardenier p. 2) The process was used to form pipes, and it was improved by substituting fire welding with a continuous welded process and the electric resistance welding process. From the continuous welded process, rectangular tubing evolved.

The current process (Electric Resistance Welding) for most manufactured tubing starts with a plate which is cold formed into a cylinder, seam welded to create a closed section and then cold rolled into a rectangular shape (Figure 3). The manufacturing method was developed in Europe after World War II as a cost effective way to replace the hot wide flange rolling mills destroyed in the war. (Palmer as quoted in Structural Tube: Old/new ...). Rectangular hollow structural steel was first manufactured by Stewarts and Lloyds in England in 1952 (Wardenier p. 4). The first use and manufacture of hollow structural steel in the U.S. was in the early 1960's. In the United States, a milestone was reached in 1980 when "the American Institute of Steel Construction, the American Iron & Steel Institute and the Welded Steel Tube Institute agreed on common industry standards concerning the engineering properties and design parameters of hollow structural sections." (Stark).

Valmont Industries manufactures larger sizes of tubing using the submerged arc welding (SAW) process. This process cold forms two plates into "C" shaped sections. These two sections are then welded together using complete penetration welds to form a tube (Figure 3).

Most manufactured tubing produced and used in building construction in the United States conforms to ASTM A500 Grade B <u>Cold-Formed Welded and Seamless Carbon Steel Structural Tubing in Rounds and Shapes</u>, with a specified minimum yield strength of 46 ksi. These tubes are produced from ASTM A36 plate with a yield strength of 36 ksi. The increased yield strength is due to cold working during the manufacturing process. Tubing can also be produced from weathering and higher strength steel grades.

The usual designation of tubing is TS a x b x c where TS is the mark for structural tubing, a and b are the outside dimension of the tube faces and c is the wall thickness of a tube (Figure 3). The corner radius is limited to three times the thickness of the tube.

A list of structural tube manufacturers belonging to the American Institute for Hollow Structural Sections, which combined, account for 80 to 85% of tube usage in U.S. building construction is shown in Figure 4. Structural tubes are also called Hollow Structural Sections (HSS). The sections these producers manufacture are shown in Figure 5.

3. ADVANTAGES AND DISADVANTAGES OF BOX SECTIONS

3.1 ADVANTAGES

3.1.1 Structural

Box shapes are structurally efficient for certain applications. For column applications, where the member is subjected to axial compression without bending, box sections can sometimes offer substantial weight reductions compared to the more commonly used W section. The symmetry of the box shape allows for equal buckling resistance in both directions and limits the need for bracing.

Manufactured tubing is particularly efficient when used for lightly loaded columns, such as in single story buildings. Example 1(a) illustrates two alternative column designs, a W section versus a tube, for a typical single story retail structure. For this example, the tube uses 45% less steel than a W section to carry the same load. As the design load for the column increases, as for a building with several stories, the weight savings provided by the tube become less substantial as illustrated by examples 1(b) and 1(c). Tubing's ability to carry light compression loads efficiently also makes it very useful for diagonal bracing members for resisting wind or earthquake loads.

For heavily loaded columns in mid to high rise buildings, the available tube sizes are generally too small to provide the required axial compression strength. If a box shaped column is desired, a built up section is required. Example 1(d) compares a W section to a built up box for a heavily loaded column in a mid rise (30-40 stories) building. For this example, the box offers a 7 % savings in material as compared to the W section.

Box shaped members may also offer weight savings in other structural applications. These include beams with long unbraced lengths (Example 2), members subject to torsion (Example 3) and members subject to bi-axial bending (Example 4). It should be noted, however, that these three structural applications are not common in buildings. That is, for typical structural steel framing in U. S. practice, beams are braced by concrete floor slabs, few framing members are subject to significant torsional loads, and few members are generally subject to bi-axial bending.

Finally, a box's closed shape makes it an obvious candidate to be used as formwork and reinforcement for a composite section with concrete.

3.1.2 Architectural

Structural tubing has a clean, sleek, pleasing appearance. The tube's flat surface facilitates connections with window mullions, skylights and other architectural elements (Photograph 2). Tubes are compact. As columns, they often require less projected area than a wide flange column, and have less exposed surface area, reducing painting costs (Example 1 (a)). Additionally, a box's closed section allows it to be fitted with internal piping, thus hiding the drainage system or other utilities. In a large complex, tubes allow for more useable floor space than a conventional wide flange column system.

Structural tubing used as columns and as bracing members can often be hidden inside walls, consequently eliminating bumps in the walls (Photograph 3). Monetary savings realized by eliminating bumps result due to easier framing, less surface area to paint, and quicker finishing of interiors. Longer term savings include easier cleaning of corridors and less surface areas to repaint and clean.

3.1.3 Fire Resistance

At high temperatures, steel loses strength and steel members may fail. The amount of protection to shield structural steel from the heat of a fire is based on occupancy, type of construction, and other factors detailed in local building codes. In the U.S., fire resistance is typically achieved by either coating the steel with a fire resistant material or sheathing the steel with fire rated boards (Figure 6). A sprinkler system sometimes may substitute for either method. Boxes may be protected against a fire's heat by unconventional methods which include a circulating water system and the use of concrete to achieve composite action.

A circulating water system keeps the column cool in the advent of a fire. As the temperature of the steel rises, the water (antifreeze in cold climates) in the box heats. This hot water in then cooled and recirculated through the structure. This system has been used in only a handful of structures in the United States; however, more European buildings incorporate this design. Filling tubes with concrete also may impart fire resistance to a column. As the outer steel loses strength, the concrete takes a larger portion of the applied loading. The concrete also acts as a heat sink, slowing the rate of temperature rise in the steel.

3.2 DISADVANTAGES

3.2.1 Structural

Hollow sections are generally inefficient for certain applications such as braced beams (Example 5) and columns with uniaxial bending. Most beams in building applications are braced by a concrete floor. Consequently, tubes are not typically used as beams. Most columns with uniaxial bending are subject to significant bending due to wind or seismic forces. If the wind or seismic forces are small, box shapes may be efficient for use as a column with uniaxial bending.

3.2.2 Cost

Built up boxes are custom made; hence require more fabrication than rolled sections. Since the mill cost per pound of rolled wide flange section and plate are comparable, the finished cost of a box shape is significantly higher than the cost of a rolled wide flange section of the same weight. A built up section must typically use 30% less steel than the equivalent rolled section to be economical in a building, according to one partner in an engineering firm.

More expensive fabrication costs also account for the higher price of structural tubes versus rolled sections. The current (1991) published mill price of the most common sizes of square and rectangular structural tubing varies between 30 and 35 cents per pound; comparatively, the current mill price for hot rolled steel sections varies between 17 and 24 cents per pound.

In some applications box sections use less material than an open shape. However, for any box section to be competitive, the increased cost per pound of the box must be offset by either a material or labor savings achieved by using the box. The significantly higher cost of a built up box or manufactured tube often negate much of the material savings offered by these members.

3.2.3 Connections

A box's closed shape generally makes connections more difficult and costly than with a wide flange section. Furthermore, few standard details exist for connection to or from boxes. Most engineers interviewed for this project mentioned connections as a major problem in the use of built up boxes and manufactured tubing. A more detailed discussion on connections is provided in Section 5.

3.2.4 Familiarity

Tubes and built up boxes are not frequently used in building construction. As a result, engineers have limited experience and knowledge about these sections. This problem is especially acute where manufactured tubes are concerned. These sections are relatively new for a construction product (about 30 years in the U.S.), and structural engineering is slow to use "new" technology.

3.2.5 Interior Corrosion

Care must be used to insure that hollow sections do not corrode. The insides of a closed section are difficult to inspect. Corrosion can be due to the accumulation of water or the presence of a harsh environment such as a chemical plant or salt water. Water is especially a big problem in the use of hollow sections during construction when it is present at the site. Vertical members, therefore, should either be fitted with a cap plate or have weep holes at the bottom.

Also, during site storage, the interior of hollow sections should be protected from water to prevent rusty water runoff. For boxes in a highly corrosive environment, the section should be sealed, the air pumped out and replaced with an inert gas.

3.2.6 Architectural

Because a manufactured tube has rounded corners, the designer will not get a square edge. An architect may use channels welded toe to toe to get a box with a square edge if desired.

3.2.7 Manufacture Limitations

a) Manufactured Tubing

Compared to wide flange sections, only a few tube sections are manufactured. Of readily available sections: the heaviest standard structural tube weighs about a 100 pounds per linear foot; comparatively, the heaviest wide flange section rolled weighs 850 pounds per foot. The fact that tubes are produced in relatively light sections and in a limited number of standard sizes inherently limits their applications.

b) Built up Box Sections

Built up box sections are difficult to fabricate. The thick plates often used in large built up box sections require special care and procedures in welding. Generally, only the largest fabricators are equipped and experienced to produce large box sections. Some engineers are hesitant to use built up box sections because of potential welding difficulties.

4. CURRENT APPLICATIONS

4.1 INTRODUCTION

"I" shaped members have been, currently still are, and most likely will continue to be the primary structural shape used in the U. S. building construction industry. However, tubes and boxes are used in some limited applications, as will be discussed in this section.

4.2 STATISTICS

Accurate statistics concerning the use of tube and box sections are not available; however, some "ballpark" estimates are available. According to the American Institute of Hollow Structural Sections (AIHSS), manufactured structural tubing accounts for about 3% to 8% --probably closer to 3%-- of the structural steel used in buildings in the United States. Based on observation and interviews, built up boxes appear to account for less then 3%. Thus at present, tubes and boxes represent a small fraction of steel used in the U.S. building construction industry.

4.3 APPLICATIONS OF MANUFACTURED TUBING

4.3.1 Most Common Applications

One story retail structures such as K-Mart, Target, (Photograph 4) shopping malls and strip shopping centers use tubes extensively as columns (Photograph 5). Tubes are structurally efficient for these loadings and column heights. The connections, typically to bar joist or W section roof systems, are relatively simple (Photograph 6). The exposed tube is pleasing in appearance and occupies less floor area than a wide flange. Pipe sections are sometimes used instead of rectangular tubes.

Columns supporting gas station canopies are often tubes. The tubes provide resistance against wind in any direction, and are more compact than wide flanges. An added advantage is the use of the tubes to conceal drains from the canopies.

Tubes are often used for their sleek, pleasing appearance as entrances to buildings, atriums and canopy supports. Many architects create sculptural entrances to shopping malls and office complexes out of tubes to achieve a distinctive atmosphere. Tubes are frequently used as supports for covered walkways between buildings.

4.3.2 Other Applications

One and two story office and institutional buildings (churches, schools) are increasingly using tubes as columns. The tubes fit into the stud or masonry walls, eliminating bumps in the corridors and rooms. This arrangement is not yet commonplace, but its use is increasing.

Steel braced frames often use tubes as diagonal bracing members (Photograph 2). The use of tubes as braces appears to be particularly prevalent in California.

Steel tubing is often used in curtain walls with large plate glass windows. The tubes can either be exposed and serve as the mullion, or they may be used inside an aluminum mullion as reinforcement.

It was also found that tubes are occasionally filled with concrete for greater strength. This procedure is not commonly used in the U.S. because of the high cost in coordinating two different construction trades.

4.3.3 Examples of Structures which have used Structural Tubing:

Wilson Inns and Wilson World Hotels located primarily in the Southeast uses 8" x 4" x 5/16" rectangular tubes as columns for the five story hotel. "'We [Wilson Inns] choose tubes because with them we can maintain a relatively small dimension, which meant we could keep the column within a wall stud'"(McCaskill as quoted in Innovative Design Speeds Construction). Tubular bracing was also kept within partitions.

6" x 6" tubes are used in the Tennenbaum Residence in Vail CO. Here the tubes minimize the structural system and hide the roof drainage pipes. Moment connection between the columns and wide flange beams are achieved by using "'clip angles with welded plates on the top and bottom ...'" (Neujahr as quoted in Minimal Structure ...) . The steel was left exposed leading the architect Mr Edward R. Niles FAIA to comment:

> When people care about workmanship, there's nothing the matter with leaving steel exposed. Steel can be inherently beautiful . . . Leaving the steel exposed allows you to trail through the methodology and construction of the home. It creates an understanding of how things are made. (Minimal Structure Maximizes View).

Wheeler Hall at the University of California, Berkeley is an eighty five year old building which has recently undergone a seismic retrofit. 7" x 7" structural tubing was slotted and welded to new steel gusset plates and attached to the existing columns. The architects and engineers' comment on this decision was "Tubular steel sections were found to be the most efficient steel sections as they used the least space in the wall, which enclosed ducts, piping and electrical conduit." (Messinger et al.).

Tubular steel is very efficient for a self supporting "rack structure." A rack structure is a warehouse designed to be completely computer controlled. An example of one was recently built in Brampton, Ontario, Canada.

> The racks are constructed from rectangular steel tubes. 'Tubular steel is very efficient for this type of building.' Esper said. 'The weight of a 4" x 4" tube is much less than the equivalent wide flange. Also, square tube is good in compression and doesn't have a weak axis. The reason you use wide flanges in most buildings is that it's easier to fabricate the connections. In this building, most of the components are welded together, so tubes are much more efficient.'(Totally Tubular...)

Tubes used in trusses and space frames "are dramatically exposed to view. Highly compatible with masonry, glass and other construction materials, hollow structural sections offer architects clean linear design elements that can be readily integrated into contemporary architecture, as in exemplified by the Hyatt Regency Hotel in San Antonio, Texas." (Stark)

Another dramatic use of exposed tubular steel trusses is the Gerald R. Ford Amphitheater in Vail, Colorado. The trusses support acoustic roof panels and "lend a feeling of spaciousness the citizens of Vail desired." The main members of the structure are 8" x 8" x 1/4" and 6" x 6" x 1/4" which are shop and field welded. (Weingardt).

The new Minneapolis Convention Center in Minneapolis, Minnesota also uses structural tubing. The all welded space frame was constructed from both manufactured tubing (TS 8x8, TS 8x4 or TS 4x4), built up boxes, and solid plates. These built up sections were used when loads exceeded the capacity of the manufactured tubes (Kloiber). Alternatively to carry heavy loads or to span long unbraced lengths, the chords may be made from two tubes instead of one.

Tubes may also be used as beams in "food processing plants where health codes require the elimination of ledges that could cause food contamination" (High Design, Low Cost).

Some companies have patented roof systems incorporating structural tubing. One such company is Unistrut Space Frames System, Inc. The tubes used in these applications are typically small and have light gage thicknesses.

A large proportion of tubing in the United States is used for non-building applications such as truck bodies, farm machinery, exercise equipment, and sign structures.

4.4 APPLICATIONS OF BUILT UP BOXES

4.4.1 Common Applications

Built up boxes are often used as corner columns in mid rise to high rise buildings to resist bi-axial bending. Many engineers avoid the use of corner columns by cantilevering the corners (see Figure 7). Boxes are also used for very heavily loaded columns in tall buildings where the heaviest rolled shape is not adequate. However, some engineers will use a built up "I" section from three plates instead of using a closed shape.

4.4.2 Examples of Buildings which Have Used Box Columns:

The Pacific Design Center, "an inverted pyramid" shaped building in West Hollywood, California, uses 8 large box columns to support and withstand "the combinations of extra large bays, the unusual building shape, and seismic conditions."(Putting the Pieces Together) This building has office bays of 40' to 44' instead of the usual 30', and it is an addition to an existing, architecturally praised building.

Other notable buildings built with box shape columns include the World Trade Center in New York City which is the second tallest building in the world, and the U.S. Steel building in Pittsburgh Pennsylvania which also includes an internal circulating water fireproofing system.

One of the most promising new applications is the use of a built up steel box section (round or rectangular) as reinforcement for high strength concrete to form a composite column in high rise buildings. Some notable examples of this type of construction are the rectangular boxed composite columns in the Bank of China building in Honk Kong and the circular composite columns in the Two Union Square building in Seattle, Washington (Godfrey).

5. CONNECTIONS

5.1 GENERAL

Connections are a key element that affect both the safety and cost of a structure. "The cost is in the connections! . . . the selection of the connection details involves many choices and these choices can play a major role in the costs of the structure" (Post 1990). Whereas the closed section of a tube has advantages in member strength, it is generally a disadvantage at the connections. The inaccessibility of the inside of the tube and the flexibility of the tube face may cause difficulty. By comparison, a wide flange generally has no accessibility problems and where flexibility is an issue, a stiffener can easily be added. Connections are the single most common concern expressed by engineers and fabricators about tubes. They consider tube connections difficult and costly.

A variety of connection details for built up boxes and tubes were identified in discussions with engineers. In addition, connection details for tubes were illustrated in several useful sources: the Stelco Manual, the Cidect Manual, American Welding Society (AWS) D.1.1 (for all welded connections only) and the AISC Steel Manual. Many of the details illustrated in these design guides are qualitative only. That is, little or no guidance on how to size various connection elements exists. Standard connections for W sections, on the other hand, have well established quantitative design procedures with numerous design aids. The lack of detailed design procedures and design aids for most tube connections discourage their use.

Connections involving tubes can be completely welded, welded and bolted, or completely bolted. The first two types are the most common in current practice. This section illustrates a number of different connection details identified as part of this study.

5.2 WELDING

Welding is often the fastening system of choice when joining tubes and built up boxes. It typically does not require access to the center of the hollow box shape or the drilling of holes. If tubes are used in an architecturally exposed application, welded connections maintain a clean simple appearance.

Welds for tubes can be either fillet, partial penetration groove, or complete penetration groove welds. Fillet welds are the easiest welds to make and to inspect, and they require the least amount of joint preparation. When increased strength is needed or no room is available for fillet welds, partial penetration groove welds are used. Partial penetration groove welds generally require joint preparation but are much easier to make and inspect than complete penetration groove welds. Very often a partial penetration groove weld can develop the full strength of the section. Complete penetration groove welds are used when the joint must develop the strength of the connected section or when fatigue is a concern.

Complete penetration groove welds pose special problems in tube connections. AWS D1.1 (Structural Welding Code -- Steel) requires the use of a back up strip for most prequalified complete penetration groove welds. Inaccessibility makes the use of back up strips difficult. AWS D1.1 does permit complete penetration groove welds in tubes without backup strips; however, a very high welder qualification rating is required. Some fabricators report that few welders are available with the required qualification. When an engineer specifies a complete penetration groove weld for a tube, a fabricator may need to search out and hire a special welder for the job, at a considerable cost premium.

5.3 BOLTING

Bolting to a hollow box shape can be very difficult: either access is needed to the inside of the section, or special preparation is required. Access may be obtained by using a very large cross section and putting an ironworker inside the section or by using a handhold (common when riveting was extensively used). Other options include the use of bolts that pass completely through the entire tube, the use of a threaded stud welded to the outside face of the tube, the use of a nut tack welded to the inside face of the tube, the use of a tapped hole in the wall of the tube, or the use of self-tapping threaded fasteners. The last two options are generally limited to lightly loaded connections.

A recent development in tube connections is the use of "flow drilled" holes (Sherman, July 1989). With this process, a special high speed rotating tool is used to make a hole in the side of the tube. However, rather than removing material like a conventional drill, the flow drill displaces the steel inside the tube in the form of a hollow cone. The tensile and shear strength of up to 1" diameter A325 bolts can be developed. No engineer or fabricator interviewed during this study had used or was aware of this new process.

5.4 ERECTION

If a tube structure is to be erected it must typically have at least one erection bolt connecting the members. Extra material must be tack welded to the steel in order to allow for erection, or preferably, a detail employing field bolts is used.

Due to its small size and closed form, ironworkers have difficulty in working on tubing. An ironworker can climb up a wide flange but is unable to do so for a tube column. Some ironworkers have expressed a dislike for working with tubes.

5.5 TYPICAL CONNECTIONS

5.5.1 Tube Column to Wide Flange Beams

A) Shear Connections

Shear connections transmit gravity loads from beams to columns. Shear connections are the most common of all connections used in building construction. They are typically the simplest connection to fabricate and erect. Some common details are listed below.

1) Slotted tube connection (see Figure 8). In this connection a plate is inserted through slits in the tube column and is welded around the opening. At end columns, the plate is fitted against the back of the column. For beams framing in two directions (Figure 8), the connection can only be made at the top of the tube. This connection is an AISC suggested detail and has been widely used; its use will probably decrease with the advent of shear tabs (see below).

2) Shear tab (see Figure 9 and Photograph 7). This type of connection is widely used in current building construction practice, both with W sections and tubes. This connection has the advantage of being clean and simple. The new AISC Manual of Steel Construction, ASD includes, for the first time, a design procedure for shear tabs for wide flange beams and columns. This type of connection is also often used with built up box columns. Only very limited research has been conducted on shear tab connections to tube columns. Some engineers have expressed the concern that the connection may distort the wall of the tube column. Nonetheless, the shear tab connection, illustrated in Figure 9, is currently one of the most commonly used connections with tube columns. It is frequently used with built up box columns.

3) Tee connection (see Figure 10). The tee can be either a rolled structural tee or a tee built from two plates. This connection provides more stiffness to the column wall than a shear plate.

4) Seated connection (see Figure 11). This connection is simple to fabricate and erect, but it may require field welding. Giddings shows a detail which uses welded studs attaching the angle to the column instead of a weld. This connection is sometimes used to connect a member which is subject to torsion. With larger angles this connection may carry some moment.

5) Double angle or "knife" connection (see Figure 12). With this type of connection, two angles are welded to the tube column, and the beam is then bolted to the angles. The connection becomes unsightly if the angles are larger then the width of the tube face; furthermore,

in this situation two direction framing is difficult. This type of connection is also often used with built up box columns.

B) Partial Moment Connections

Partial moment connections allow for transmission of wind or other lateral load and part of the moment due to gravity. Consequently, partial moment connections can sometimes be used instead of wind bracing in a structure. The following details have been identified.

1) Continuous wide flange beam with split tube (see Figure 13 and Photograph 8). The beam runs continuously while the column is interrupted. The web of the beam is stiffened with a split tube, channel, or plates used between the lower and upper columns. This connection is simple to fabricate and erect and offers a clean and elegant joint, but it should be used only when small moments are transferred to the column.

2) Strap angles or wrap around angles (see Figure 14). The column runs continuously with angles connecting the beam flanges to the column. The angles are welded to the beam, and then are coped where they connect to the column. The beam, however, is not directly welded to the column face. The flange width of the beams must be equal or less than the width of the face of the column. This type of connection is reported to produce "good joint behavior" (Stelco, p89).

3) Welded diaphragm connection (see Figure 15). The column runs continuous; the beam flanges are connected to the column and each other with the use of a plate encircling the column. The beam is bolted to the plate

and welded to the column. A shear tab connects the beam web and the column.

4) Welded diaphragm end connection (see Figure 16). The connection is similar to that shown above, but the plates are cut short and do not encircle the column. This type of connection was developed in Japan and is able to resist large moments; it is also field bolted. The connection can also be used with a connection on adjacent faces of the column (Ricker 1986 fig 14).

5) Welded beam stub connection (see Figure 17). An "I" shaped built up section is welded to the column. The flange of the section encircles the column, and a bolted splice connects the stub to the rest of the beam at the inflection point. This connection was also developed in Japan.

6) End plates (see Figure 18). This popular connection is one of the simplest to erect. Plates are welded to the column and to the beam end. The plates are then bolted together. This connection does have some problems; the protruding plates may complicate placement of decking and adjacent connections. This type of connection is used in the Welded Tube of America warehouse/mill. A variation of the connection is the welding of a beam stub with an end plate to the columns and then bolting the rest of the beam to the stub.

7) Top and bottom angles (similar to Figure 11). This type of connection is popular and is similar to the type 2 seated connection, but the clip angles are heftier and longer then in a simple connection. This connection should be used only with small moments.

C) Rigid connections

This type of "connection is almost impossible to achieve because of the relative lack of stiffness of the tube walls and the entire tube shafts as compared to the wide flange beam." (Ricker, 1985). However, the details illustrated in Figures 15 to 18 approach a fully rigid connection and would be treated as fully rigid by many engineers.

5.5.2 Tube Column to Open Web Joist

Many one story buildings currently being constructed use tube columns, with an open web joist system to support the roof. A typical connection detail is illustrated in Figure 19 and in Photograph 7.

This type of connection is used frequently in current practice. Joists are very commonly used in low rise buildings. In the figure, one of the joists has a lower chord extension while the other does not.

5.5.3 Welded End Details for Structural Tubing

Due to the rectangular cross section of a tube, connections can be difficult. Often when making a connection, the end of the tube is prepared. Typical welded end preparations are

1) Welded cap or base plate (Figure 20)
2) Slotted tube with or without end plate (Figure 21)
3) Rolled or built up tee (Figure 22)
4) Double shear tongues (Figure 23).

Example applications of these types of connections are illustrated in the following subsections.

5.5.4 Tube Beam to Column

This type of detail connects a tube, used as a beam, a truss, or a torsion element, to a wide flange or tube column.

1) Seated connection (see Figure 24). Angles are welded to the top and bottom of the beam and to the flange of the column.

2) Double angle with seat (see Figure 25). Angles are welded around three sides of the tube beam and to the column. The top of the beam is left free. A designer may add the top angle in order to provide a torsion connection. Occasionally, instead of the side angles, plates may be used.

3) Double tee, bolted (see Figure 26) and
4) Double angle with tee, bolted (see Figure 27). These two are similar connection details. In both these situations, a built up or rolled tee is welded to the beam. The tee is connected to either another tee or double angles attached to the column. The double angles allow for the use of bolts in double shear but may require extra material and shimming.

5) Double angle, bolted (see Figure 28) and
6) Double plate, bolted (see Figure 29). These two are similar connection details. The angles or plates are welded to the column and then bolted to the tube beam. The tube can be coped at the top to allow for bolting, or alternatively, a long bolt going through both sides of the tube can be used. The plates allow for the connection of a beam flange width with a column of similar dimension.

7) Slit tube with gusset plate (see Figure 30). This connection detail is similar to the tee connection. The difference is, instead of a tee welded to the tube, a slit is cut into the tube, and a plate is slid into it and welded. The end of the tube is left open. Whether to leave the end of a tube open is a matter of discussion among engineers. The detail is frequently used in braced frames where tubes are used as bracing members.

8) Slit tube with gusset plate used in an eccentric braced connection (see Figure 31). This connection detail is similar to the one above except the gusset plate is reinforced with stiffeners. The connection is a recent application of tubes, and it is expected to see increased use in buildings in seismic zones.

9) Welded end plate bolted to a column (see Figure 32). An end plate is welded to the end of the beam and then bolted to the column. If the column is a tube, a plate will be welded to the tube column, as in the end plates of the moment connection section. If the column is a wide flange, the plate can be bolted directly to the column. This connection can transmit moment.

10) Field welded (see Figure 33). In this connection a temporary or permanent erection seat is used. Once the beam is seated, the beam is field welded to the column. This connection is an AISC suggested detail. Difficulty may arise with connecting the erection seat to the tube without an opening into the tube. This connection may transmit moment.

5.5.5 Tubular Truss to Column

The following details have been identified:

1) Stelco 9.1(a) (see Figure 34) and
2) Stelco 9.1(b) (see Figure 35) and
3) Stelco 9.1(c) (see Figure 36) and
4) Stelco 9.1(d) (see Figure 37) and
5) Stelco 9.1(e) (see Figure 38). These five are similar details with slightly different truss geometries. The connections are all similar to those discussed above.

5.5.6 Tube to Tube

These connections are often used in trusses and in joints where two or more tubes meet (Photograph 9). AWS D1.1 gives some detailed design guidelines for welded connections. Most joints have an "L", "T", or "K" shaped connection (see Figure 39). When two tubes meet, the connection may either be matched or stepped (see Figure 40). A matched connection is where the tubes have the same width; a stepped connection is when one tube is wider than the other.

When three or more tubes meet, the connection can either be overlapped or gapped (see Figure 40). An overlapped connection is where the tube branches meet and need to be truncated, while a gapped connection is where the branches connect individually into the main member.

The designer must be careful not to specify an overly conservative connection. Theoretically the best connection, using a complete penetration groove weld, is difficult and expensive to make as discussed earlier. Often partial penetration groove welding will suffice, and if a fillet weld can be used, it is the most economical solution. Complete penetration groove welding is problematic due to the extensive joint preparation, the use of a back up plate, and the stringent welder requirements. Except in situations where fatigue is a concern, a partial penetration groove weld can generally develop the full strength of the section. The easiest connection to fabricate is a gapped, stepped fillet welded connection (Post 1990). However, aesthetics or strength may necessitate a more complicated detail.

Examples of connections from the Stelco manual:

1) Typical vierendeel truss joint (see Figure 41). The weld connecting the web to the chord must be proportioned not only for the axial loads encountered in a truss but also for moments which are particular to vierendeel trusses.

2) Typical double tube chord truss welded joint (see Figure 42). The gapped connection (Figure 42(b)) has a stiffener to reinforce the face of the chord member and distribute the loads from the diagonal.

3) Typical connection to a triangular truss (see Figure 43).

When joining tubes, field erection may require the use of a bolted connection. Often plates are welded to a member prior to field erection; then they are removed once the connecting members are attached. In welded trusses, the truss may be completely or partially assembled on the ground before being lifted into place, thus eliminating erection bolts.

In large trusses designed for heavy loads, or when assembly on the ground is impractical, a designer may want to use bolted connections. Several details can be used:

1) Conventionally bolted truss (see Figure 44). This connection uses a gusset plate welded to the chord and bolted to the diagonals. The diagonal tubes include a cut out in order to bolt.

2) Modified bolted truss (see Figure 45). This connection is similar to a conventionally bolted truss, except that a plate is welded to the diagonal tube, and that plate is bolted to the gusset plate. The advantage of this connection is that no cut out is required.

3) Bolted double tube chord connection (see Figure 46). The gusset plate is welded to the chord, and the tube diagonals are bolted to the plate. Access for bolting is from the open end of the tube.

<u>5.5.7 Built Up Boxes</u>

Connections to built up boxes are typically similar to connecting to a W section flange due to the large face of the member. The details often used for transmitting shear are double angles and shear tabs, and details for transmitting moment are flange plates and angles, or simply complete penetration groove welds (Figure 47 and Photograph 10). However, when moments are transferred, built up boxes may require internal stiffeners at the connection, and as mentioned previously, the connection of stiffeners to built up boxes can be difficult.

5.6 SPLICES

5.6.1 Splices of Tubes

1) Bolted

Stelco proposes an aesthetic bolted splice with side plates (Figure 48). Simple bolted splices can be achieved by welding end plates to the tube, and then bolting the plates together (Figure 49). A potential splice using a blind bolt is shown in Figure 50.

2) Welded

Tubes can be spliced by butt welding. This may require the use of a back up plate and extensive preparation. Alternately a plate may be used as a member to weld to. The tubes to be connected are fillet welded to the plate on opposite sides (Figure 51).

5.6.2 Splices of Built Up Boxes

Splices of built up box section vary depending on the amount of moment to be transferred. For small moments, plates can be fillet welded to both halves (Figure 52); larger moments require the use of a partial penetration groove welds. Complete penetration groove welds require the use of a back-up bar, which increases the cost and difficulty of the splice. For boxes where interior access is possible, splice plates are bolted inside and out to transfer the forces (Figure 53).

6. FUTURE DIRECTIONS

Future applications of square and rectangular tubes and boxes in the U.S. building construction industry cannot be predicted with certainty. However, based on discussions with engineers and fabricators during the course of this study, some general trends have been identified.

It is anticipated that tubes will continue to be commonly used in one story buildings, particularly in retail and strip shopping centers. Increased use of tubes is anticipated in two to three story buildings, also in column applications. The use of tubes as bracing members in braced frames also appears to be increasing. It should be noted that tubes in low rise buildings will likely face stiff competition from low cost mini-mill produced wide flange shapes.

It is expected that the use of tubes will continue to grow in applications of exposed steel. In exposed applications such as canopies, pedestrian bridges, atriums, etc., the appearance of a tube is generally preferred to that of other shapes. This application is somewhat contingent on the public's taste and architectural fashion.

Large built up box sections are used primarily as columns in tall buildings. This application may decrease somewhat, due to competition from heavier jumbo wide flange shapes and also due to the increasing competition from high strength concrete. A number of engineers interviewed during the course of this project indicated that steel columns in tall buildings, regardless of the shape of the member, are often not cost competitive when compared to concrete. The use of hollow steel members, circular or rectangular, filled with concrete may become more common. In these applications, the steel acts primarily as formwork and as reinforcement for the concrete.

The establishment of the American Institute of Hollow Structural Sections (AIHSS) in 1989 by the tube industry is an important first step to increased tube use in the United States. Promotion, publicity and the development of design literature by AIHSS will certainly contribute to increased tube use. Research on tube connections and the development of design procedures and design aids for these connections is also needed. Currently, however, little effort appears to be happening towards this end in the United States.

Overall, a gradual increase in the use of square and rectangular tubes is anticipated in the U.S. building construction industry. A dramatic increase in tube use, however, is not likely. It is expected that tubes will continue to represent only a small percentage of the total structural steel in buildings in the U.S. in the foreseeable future.

7. EXAMPLES

Example: Column in Single Story Retail Building

KL=30 ft. $P_u=80^k$

<u>W</u> <u>Section:</u> (A36 or Gr. 50)

W8x40 (40 lb/ft)
enclosed area = 67 in^2
surface area per foot = 4 ft^2

<u>Tube:</u>

TS 7x7x1/4 (22 lb/ft)
enclosed area = 49 in^2
surface area per foot = 2.3 ft^2

Tube uses 45% less steel

Example 1(a)

Example: Column in 2 Story Office Building

KL=12 ft. P_u=114^k

W Section:

A36:W8x24 (24 lb/ft)
Gr. 50:W6x20 (20 lb/ft)

Tube:

TS 6x6x3/16 (14.5 lb/ft)

Tube uses 27% less steel

Example 1 (b)

Example: Column in 4 Story Office Building

KL=14 ft. $P_u=538^k$

W Section:

A36:W12x72 (72 lb/ft)
Gr. 50:W10x60 (60 lb/ft)

Tube:

TS 12x12x3/8 (58 lb/ft)

Tube uses 3% less steel

Example 1 (c)

Example: Column in Mid Rise Building

KL=14 ft. $P_u=5200^k$

W Section:

Gr. 50:W14x445 (445 lb/ft)

Built up Box:

Gr. 50: 32"x32"x1" (422 lb/ft)

Box uses 7% less steel

Example 1 (d)

Example: Unbraced Beam

L=30 ft. M_u=225$^{k\text{-}ft}$

<u>W</u> <u>Section:</u> (A36 or Gr. 50)

W16x67 (67 lb/ft)

<u>Tube:</u>

TS 14x10x5/16 (49 lb/ft)

Tube uses 27% less steel

Example 2

Example: Torsion

TS 16x16x5/16 (66 lb/ft)
vs.
W12x65 (65 lb/ft)

Torsional Stiffness:

Tube: $J=1220\ in^4$
W Section: $J=2.18\ in^4$

Tube is 560 times stiffer than W Section in torsion !

Torsional Shear Stress:

Applied torsional moment = $100^{in\text{-}k}$

Tube: $\tau=0.65$ ksi
W Section: $\tau=27.8$ ksi

Torsional shear stress is 43 times greater in W Section !

Example 3

Example: Corner Column in Mid Rise Building

KL = 15 ft.
$P_u = 5000^k$; $M_{ux} = 900^{k\text{-}ft}$; $M_{uy} = 900^{k\text{-}ft}$

W Section:

W 14 x 730 (Gr. 50)

Built up Box: (Gr. 50)

Box 20" x 20" x $2^1/_2$" (595 lf/ft)

Box uses 18% less steel

Example 4

Example: Beam Braced by a Concrete Slab

$M_u=225^{k\text{-}ft}$

W Section:

W 21 x 44 (A36)
W 18 x 35 (Gr. 50)

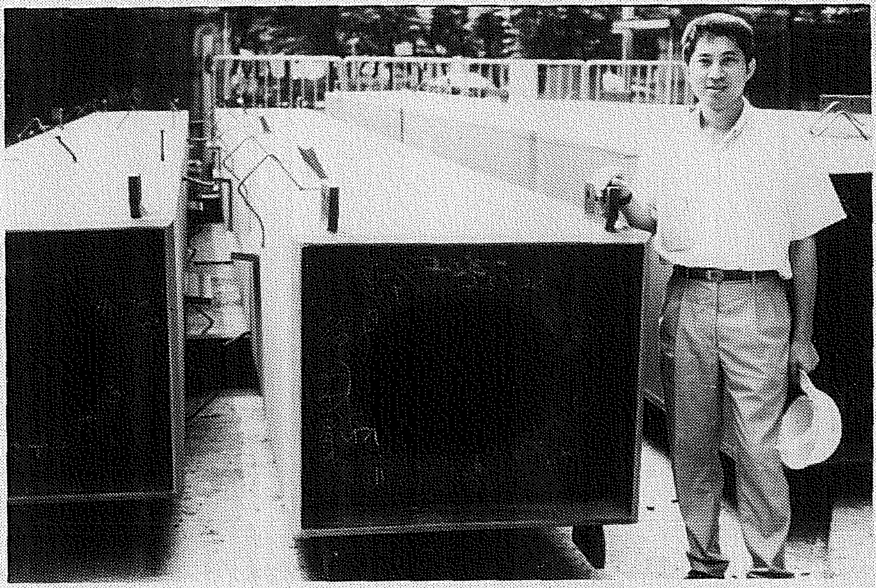
Tube:

TS 14x10x5/16 (49 lb/ft)

W Section uses 28% less steel

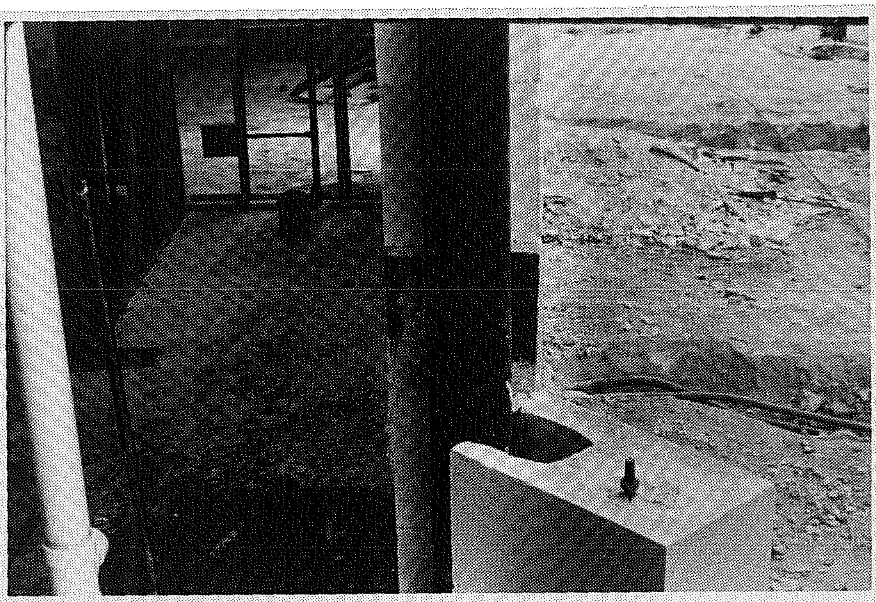
Example 5

8. PHOTOGRAPHS



Photograph 1: Built Up Box Section

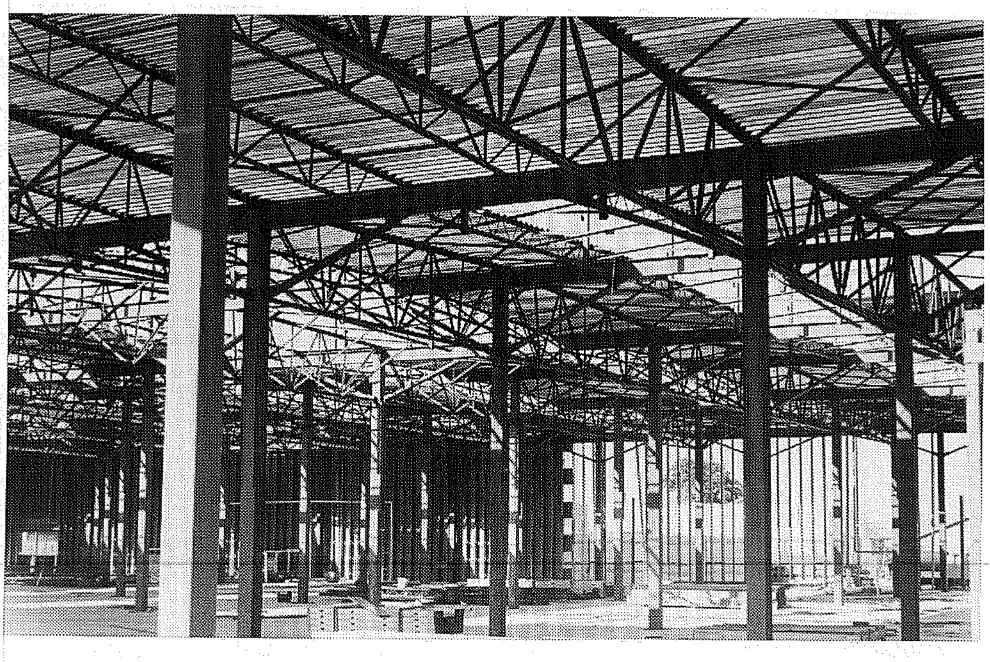
Photograph 2: Tube's Pleasing Appearance



Photograph 3: Tube Hidden Inside Wall

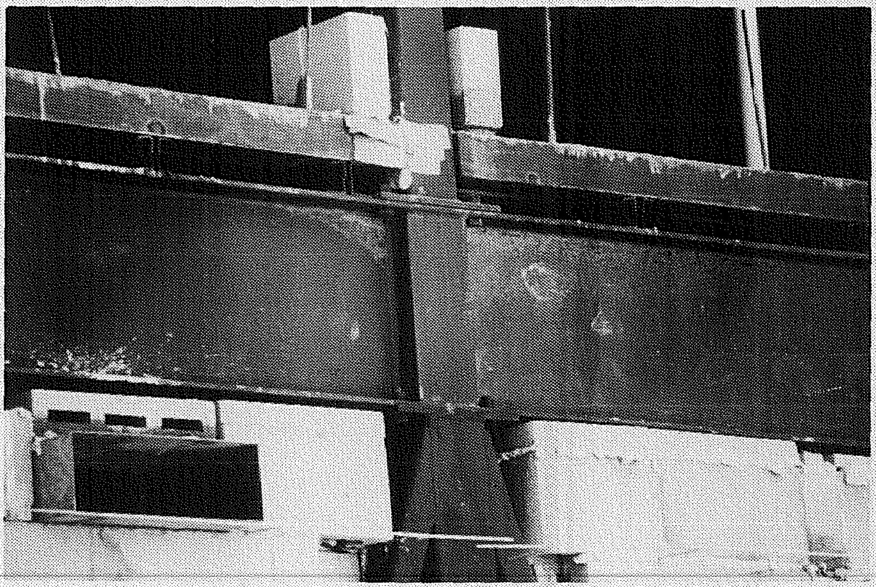
Photograph 4: Tubes in One Story Retail Building

Photograph 5: Tube Columns in a One Story Strip Mall

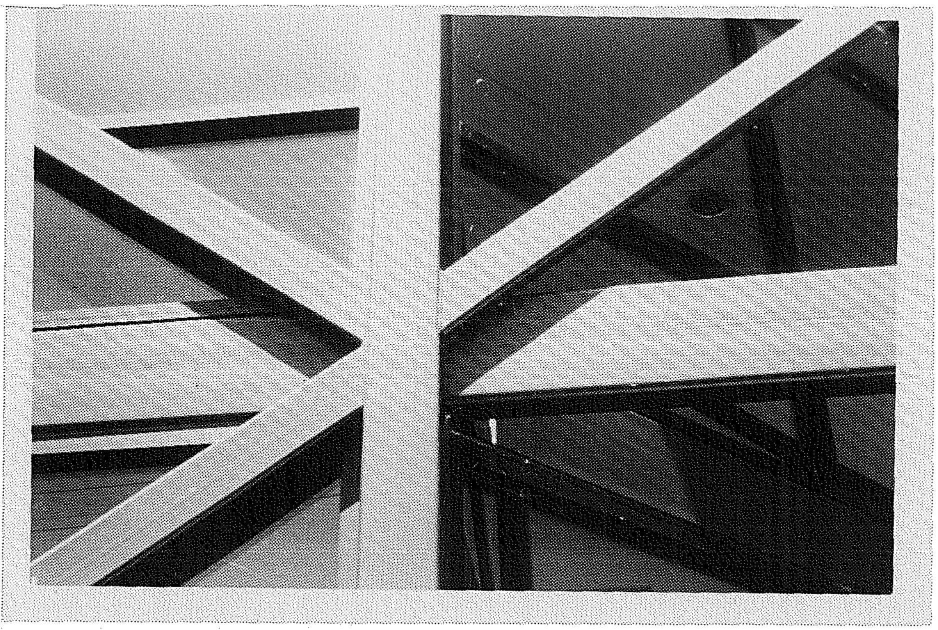


Photograph 6: Tube Column Connected to Bar Joist

Photograph 7: Tube Column Connection to Wide Flanges and Bar Joists



Photograph 8: Continuous Wide Flange with Split Tube Connection



Photograph 9: Welded Tube to Tube Connection

Photograph 10: Wide Flange to Built Up Box Column Connection

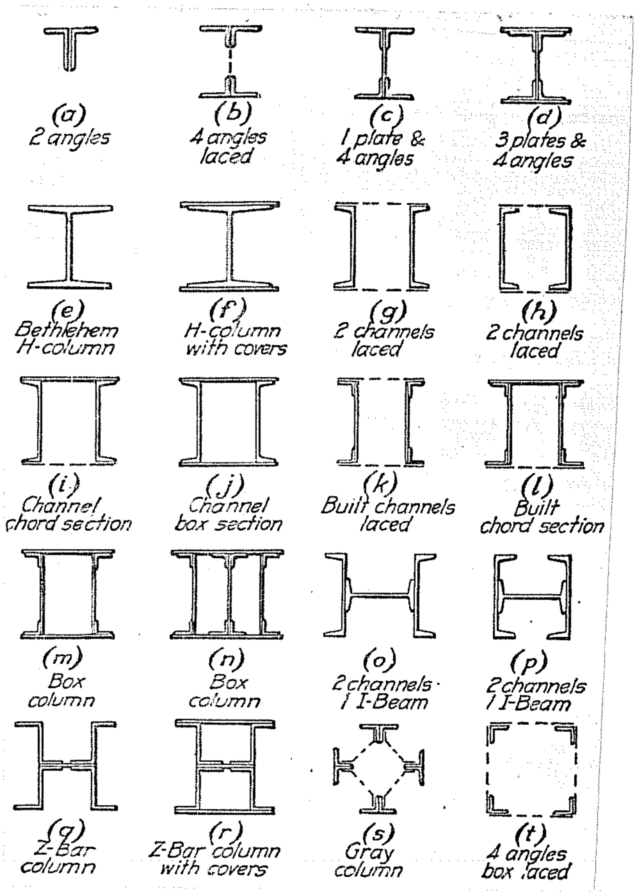
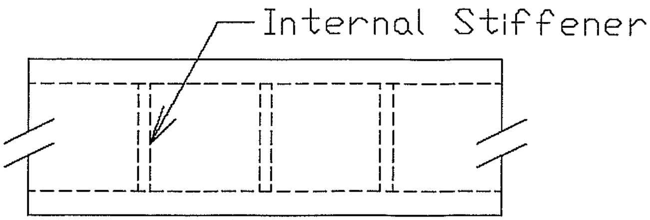


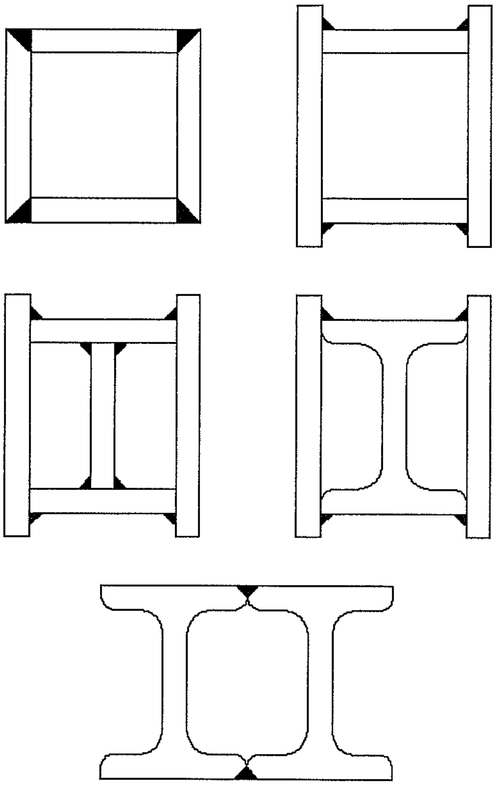
Figure 1

Typical Compression Members Used in 1923

from Hool and Kinne, p. 307.



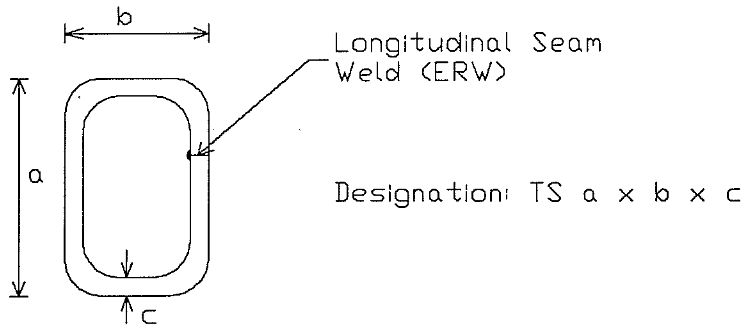
PLAN



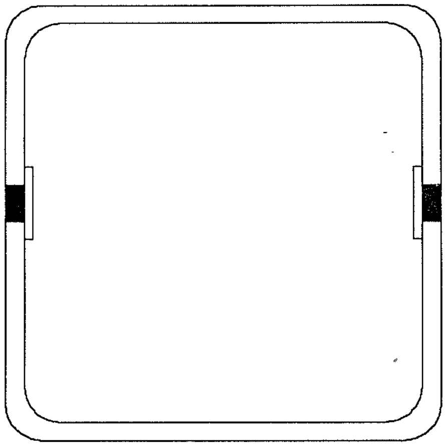
SECTIONS

Figure 2

Typical Built Up Boxes Used in Current Practice



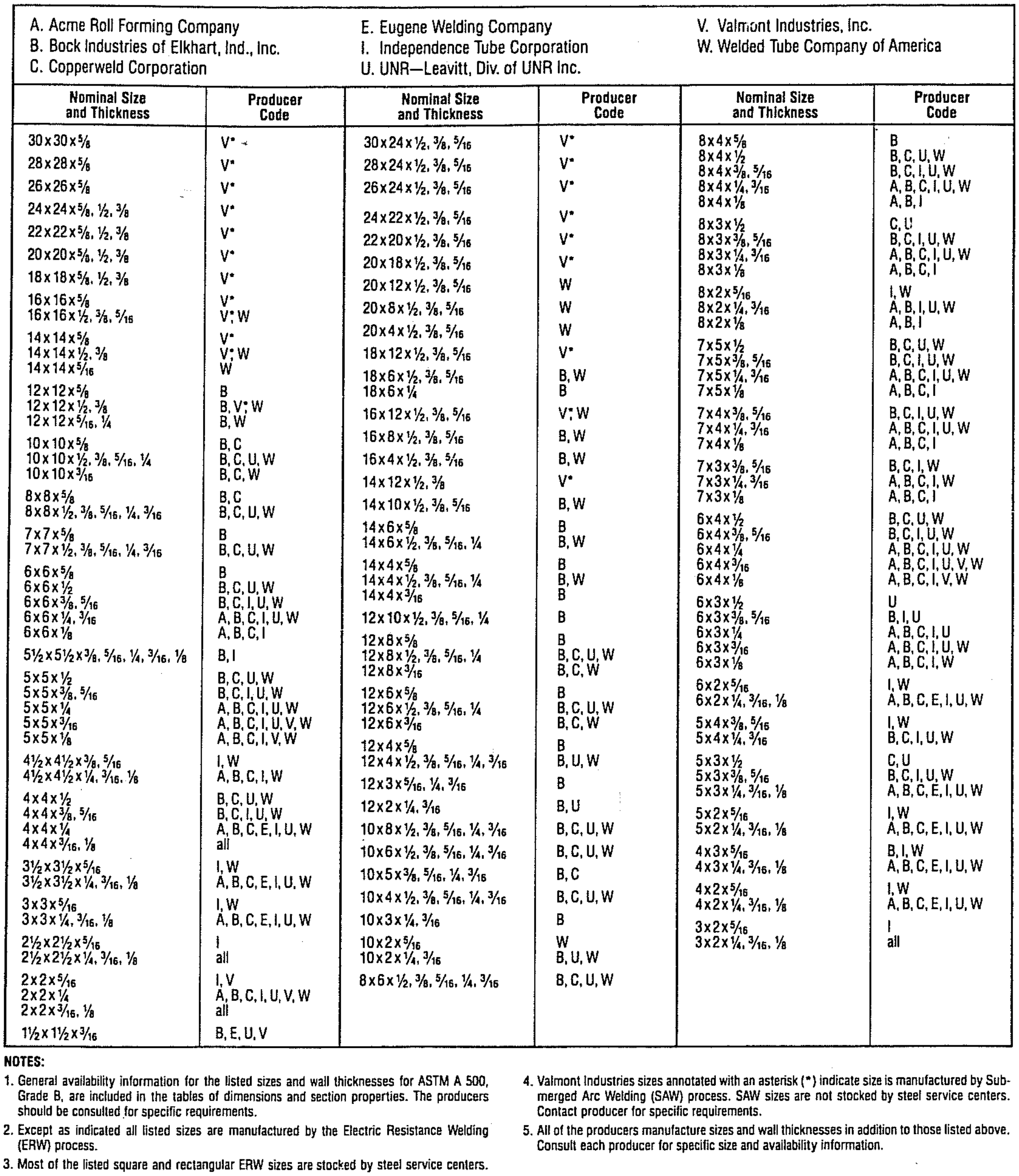
ERW Process Tubing



SAW Process Tubing

Figure 3

Types of Manufactured Tubing



A. Acme Roll Forming Company
B. Bock Industries of Elkhart, Ind., Inc.
C. Copperweld Corporation
E. Eugene Welding Company
I. Independence Tube Corporation
U. UNR—Leavitt, Div. of UNR Inc.
V. Valmont Industries, Inc.
W. Welded Tube Company of America

Nominal Size and Thickness	Producer Code
30x30x5/8	V*
28x28x5/8	V*
26x26x5/8	V*
24x24x5/8, 1/2, 3/8	V*
22x22x5/8, 1/2, 3/8	V*
20x20x5/8, 1/2, 3/8	V*
18x18x5/8, 1/2, 3/8	V*
16x16x5/8	V*
16x16x1/2, 3/8, 5/16	V*; W
14x14x5/8	V*
14x14x1/2, 3/8	V*; W
14x14x5/16	W
12x12x5/8	B
12x12x1/2, 3/8	B, V*; W
12x12x5/16, 1/4	B, W
10x10x5/8	B, C
10x10x1/2, 3/8, 5/16, 1/4	B, C, U, W
10x10x3/16	B, C, W
8x8x5/8	B, C
8x8x1/2, 3/8, 5/16, 1/4, 3/16	B, C, U, W
7x7x5/8	B
7x7x1/2, 3/8, 5/16, 1/4, 3/16	B, C, U, W
6x6x5/8	B
6x6x1/2	B, C, U, W
6x6x3/8, 5/16	B, C, I, U, W
6x6x1/4, 3/16	A, B, C, I, U, W
6x6x1/8	A, B, C, I
5 1/2x5 1/2x3/8, 5/16, 1/4, 3/16, 1/8	B, I
5x5x1/2	B, C, U, W
5x5x3/8, 5/16	B, C, I, U, W
5x5x1/4	A, B, C, I, U, W
5x5x3/16	A, B, C, I, U, V, W
5x5x1/8	A, B, C, I, V, W
4 1/2x4 1/2x3/8, 5/16	I, W
4 1/2x4 1/2x1/4, 3/16, 1/8	A, B, C, I, W
4x4x1/2	B, C, U, W
4x4x3/8, 5/16	B, C, I, U, W
4x4x1/4	A, B, C, E, I, U, W
4x4x3/16, 1/8	all
3 1/2x3 1/2x5/16	I, W
3 1/2x3 1/2x1/4, 3/16, 1/8	A, B, C, E, I, U, W
3x3x5/16	I, W
3x3x1/4, 3/16, 1/8	A, B, C, E, I, U, W
2 1/2x2 1/2x5/16	I
2 1/2x2 1/2x1/4, 3/16, 1/8	all
2x2x5/16	I, V
2x2x1/4	A, B, C, I, U, V, W
2x2x3/16, 1/8	all
1 1/2x1 1/2x3/16	B, E, U, V
30x24x1/2, 3/8, 5/16	V*
28x24x1/2, 3/8, 5/16	V*
26x24x1/2, 3/8, 5/16	V*
24x22x1/2, 3/8, 5/16	V*
22x20x1/2, 3/8, 5/16	V*
20x18x1/2, 3/8, 5/16	V*
20x12x1/2, 3/8, 5/16	W
20x8x1/2, 3/8, 5/16	W
20x4x1/2, 3/8, 5/16	W
18x12x1/2, 3/8, 5/16	V*
18x6x1/2, 3/8, 5/16	B, W
18x6x1/4	B
16x12x1/2, 3/8, 5/16	V*; W
16x8x1/2, 3/8, 5/16	B, W
16x4x1/2, 3/8, 5/16	B, W
14x12x1/2, 3/8	V*
14x10x1/2, 3/8, 5/16	B, W
14x6x5/8	B
14x6x1/2, 3/8, 5/16, 1/4	B, W
14x4x5/8	B
14x4x1/2, 3/8, 5/16, 1/4	B, W
14x4x3/16	B
12x10x1/2, 3/8, 5/16, 1/4	B
12x8x5/8	B
12x8x1/2, 3/8, 5/16, 1/4	B, C, U, W
12x8x3/16	B, C, W
12x6x5/8	B
12x6x1/2, 3/8, 5/16, 1/4	B, C, U, W
12x6x3/16	B, C, W
12x4x5/8	B
12x4x1/2, 3/8, 5/16, 1/4, 3/16	B, U, W
12x3x5/16, 1/4, 3/16	B
12x2x1/4, 3/16	B, U
10x8x1/2, 3/8, 5/16, 1/4, 3/16	B, C, U, W
10x6x1/2, 3/8, 5/16, 1/4, 3/16	B, C, U, W
10x5x3/8, 5/16, 1/4, 3/16	B, C
10x4x1/2, 3/8, 5/16, 1/4, 3/16	B, C, U, W
10x3x1/4, 3/16	B
10x2x5/16	W
10x2x1/4, 3/16	B, U, W
8x6x1/2, 3/8, 5/16, 1/4, 3/16	B, C, U, W
8x4x5/8	B
8x4x1/2	B, C, U, W
8x4x3/8, 5/16	B, C, I, U, W
8x4x1/4, 3/16	A, B, C, I, U, W
8x4x1/8	A, B, I
8x3x1/2	C, U
8x3x3/8, 5/16	B, C, I, U, W
8x3x1/4, 3/16	A, B, C, I, U, W
8x3x1/8	A, B, C, I
8x2x5/16	I, W
8x2x1/4, 3/16	A, B, I, U, W
8x2x1/8	A, B, I
7x5x1/2	B, C, U, W
7x5x3/8, 5/16	B, C, I, U, W
7x5x1/4, 3/16	A, B, C, I, U, W
7x5x1/8	A, B, C, I
7x4x3/8, 5/16	B, C, I, U, W
7x4x1/4, 3/16	A, B, C, I, U, W
7x4x1/8	A, B, C, I
7x3x3/8, 5/16	B, C, I, W
7x3x1/4, 3/16	A, B, C, I, W
7x3x1/8	A, B, C, I
6x4x1/2	B, C, U, W
6x4x3/8, 5/16	B, C, I, U, W
6x4x1/4	A, B, C, I, U, W
6x4x3/16	A, B, C, I, U, V, W
6x4x1/8	A, B, C, I, V, W
6x3x1/2	U
6x3x3/8, 5/16	B, I, U
6x3x1/4	A, B, C, I, U
6x3x3/16	A, B, C, I, U, W
6x3x1/8	A, B, C, I, W
6x2x5/16	I, W
6x2x1/4, 3/16, 1/8	A, B, C, E, I, U, W
5x4x3/8, 5/16	I, W
5x4x1/4, 3/16	B, C, I, U, W
5x3x1/2	C, U
5x3x3/8, 5/16	B, C, I, U, W
5x3x1/4, 3/16, 1/8	A, B, C, E, I, U, W
5x2x5/16	I, W
5x2x1/4, 3/16, 1/8	A, B, C, E, I, U, W
4x3x5/16	B, I, W
4x3x1/4, 3/16, 1/8	A, B, C, E, I, U, W
4x2x5/16	I, W
4x2x1/4, 3/16, 1/8	A, B, C, E, I, U, W
3x2x5/16	I
3x2x1/4, 3/16, 1/8	all

NOTES:

1. General availability information for the listed sizes and wall thicknesses for ASTM A 500, Grade B, are included in the tables of dimensions and section properties. The producers should be consulted for specific requirements.
2. Except as indicated all listed sizes are manufactured by the Electric Resistance Welding (ERW) process.
3. Most of the listed square and rectangular ERW sizes are stocked by steel service centers.
4. Valmont Industries sizes annotated with an asterisk (*) indicate size is manufactured by Submerged Arc Welding (SAW) process. SAW sizes are not stocked by steel service centers. Contact producer for specific requirements.
5. All of the producers manufacture sizes and wall thicknesses in addition to those listed above. Consult each producer for specific size and availability information.

Figure 5

Sizes of Available Structural Tubes

from AIHSS

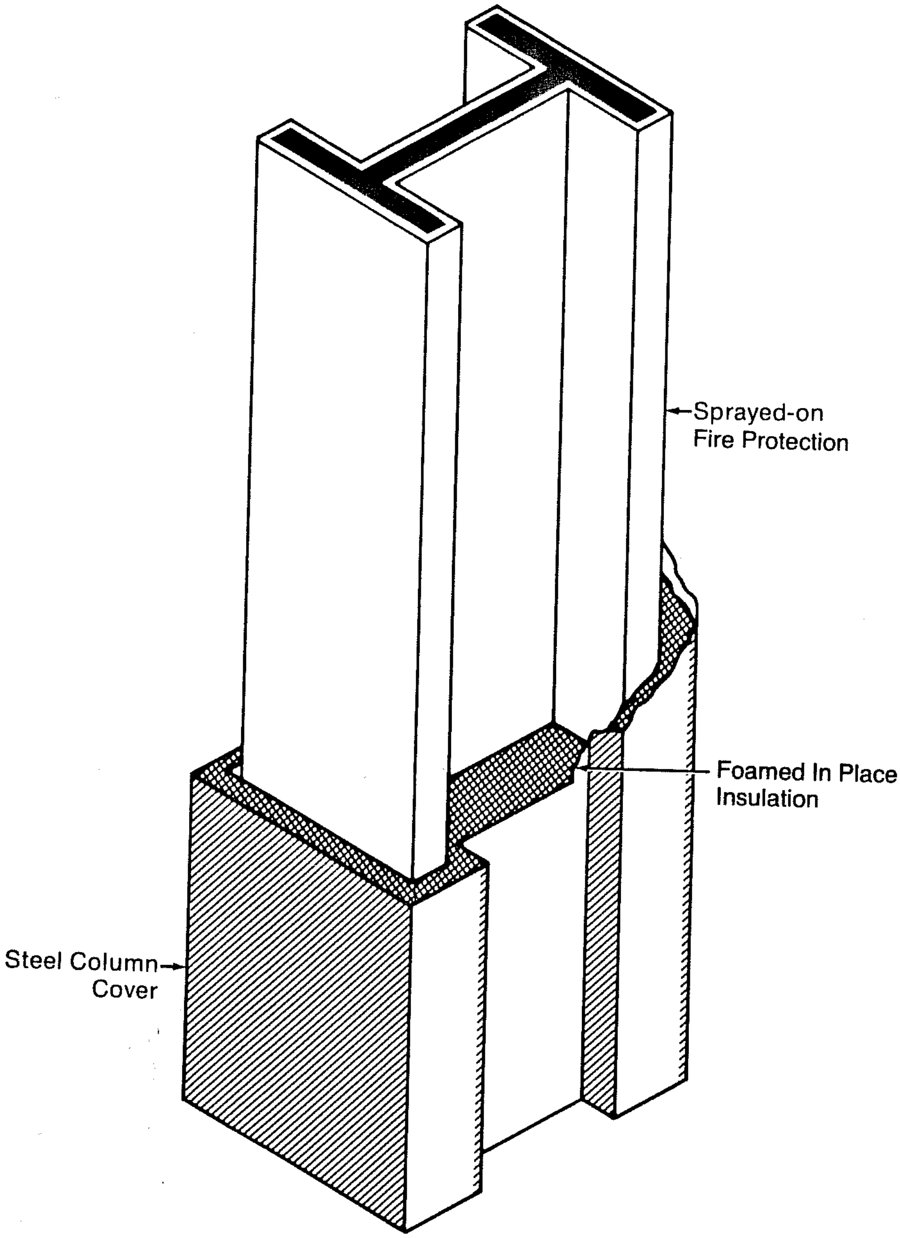
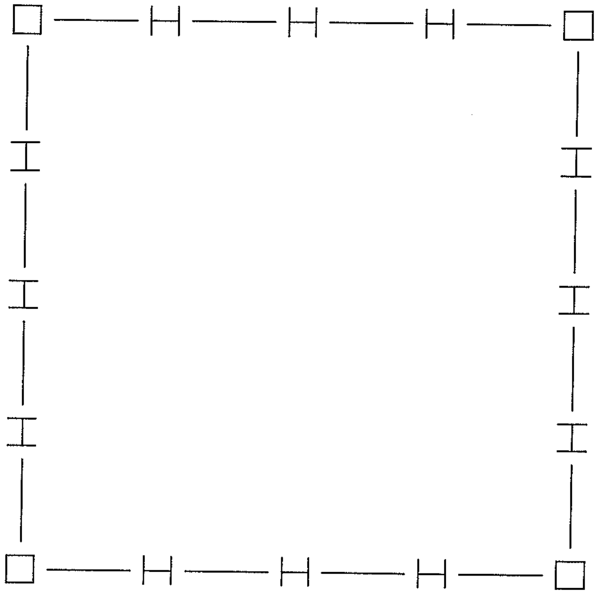


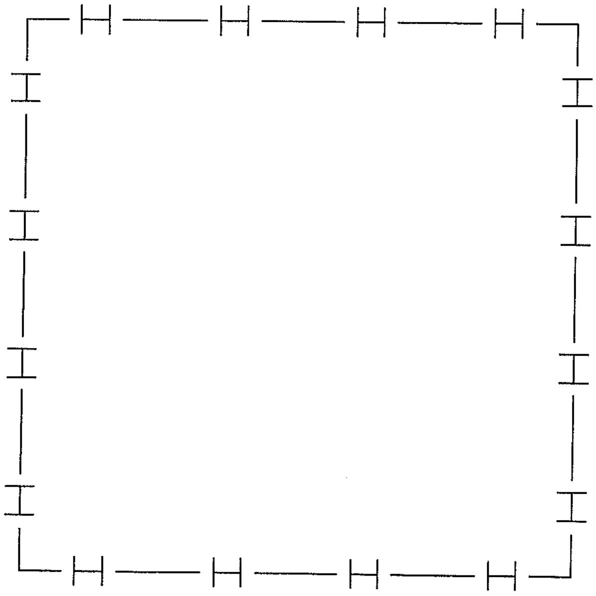
Figure 6

Methods of Conventional Fire Protection for Steel

from Boring P. 140



Boxes Used as Corner Columns



Cantilevered Corners, All H Shaped Columns

Figure 7

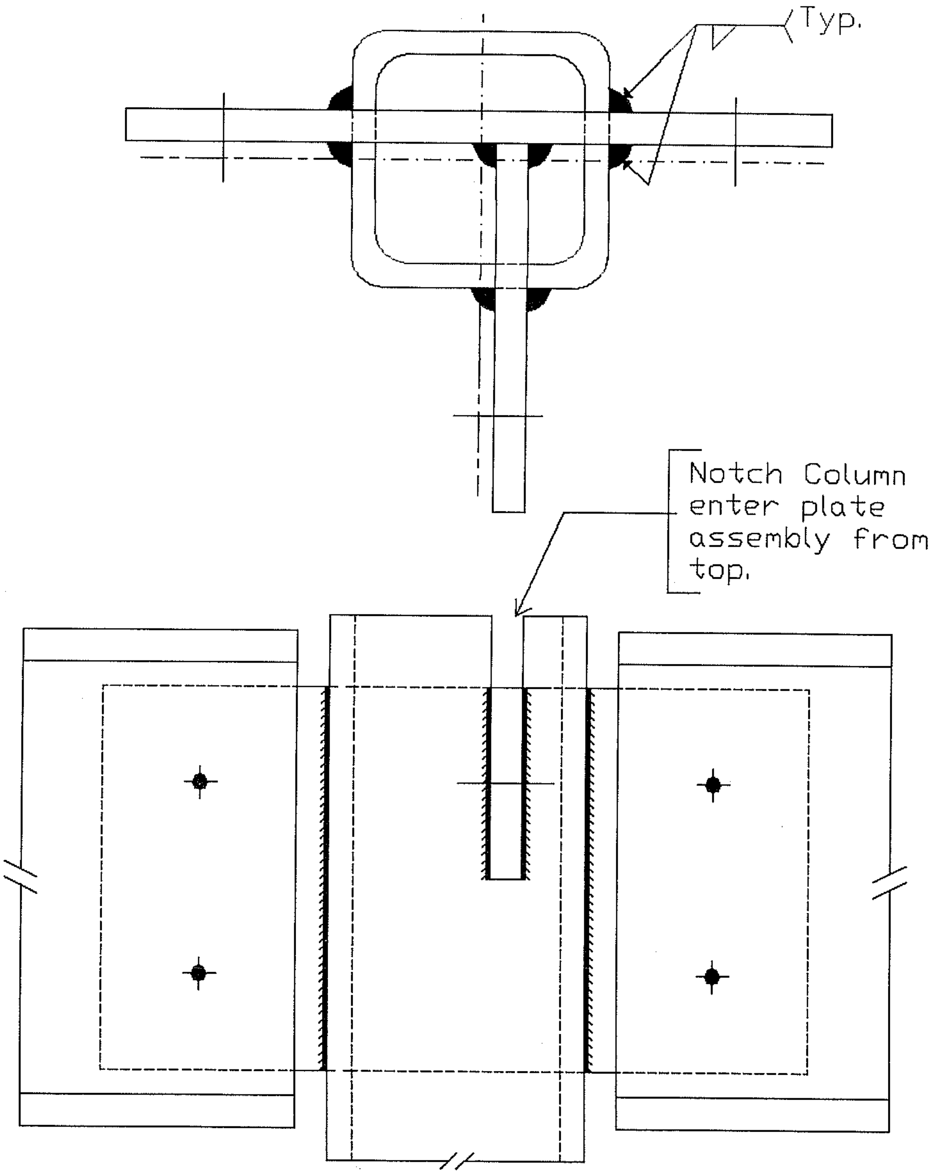


Figure 8

Slotted Tube Column Connection

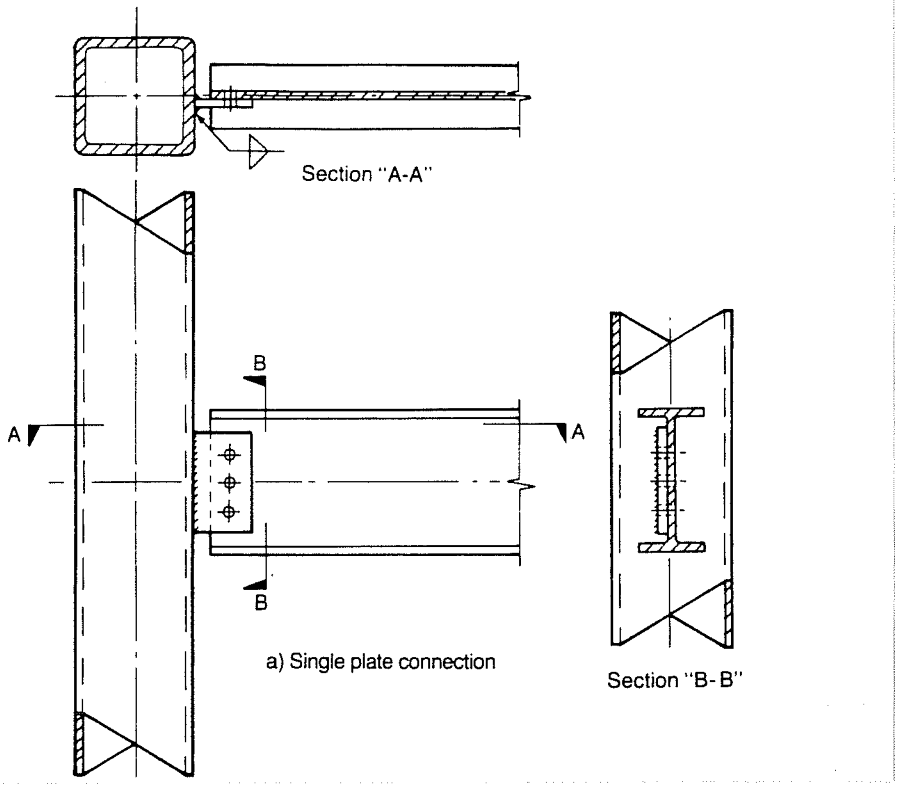


Figure 9

Shear Tab

from Stelco p. 88

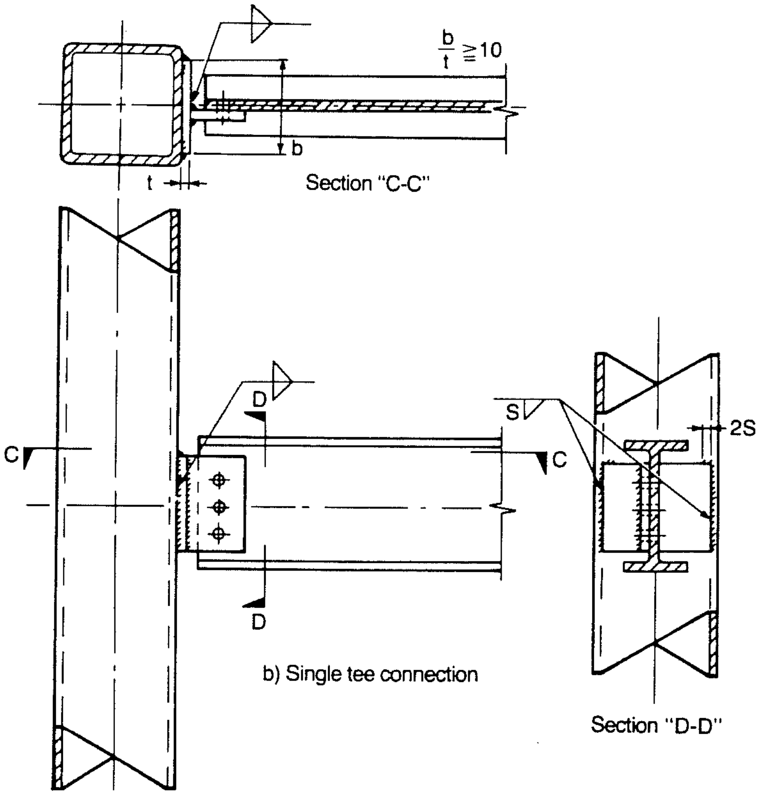


Figure 10

Column Tee Connection

from Stelco p. 88

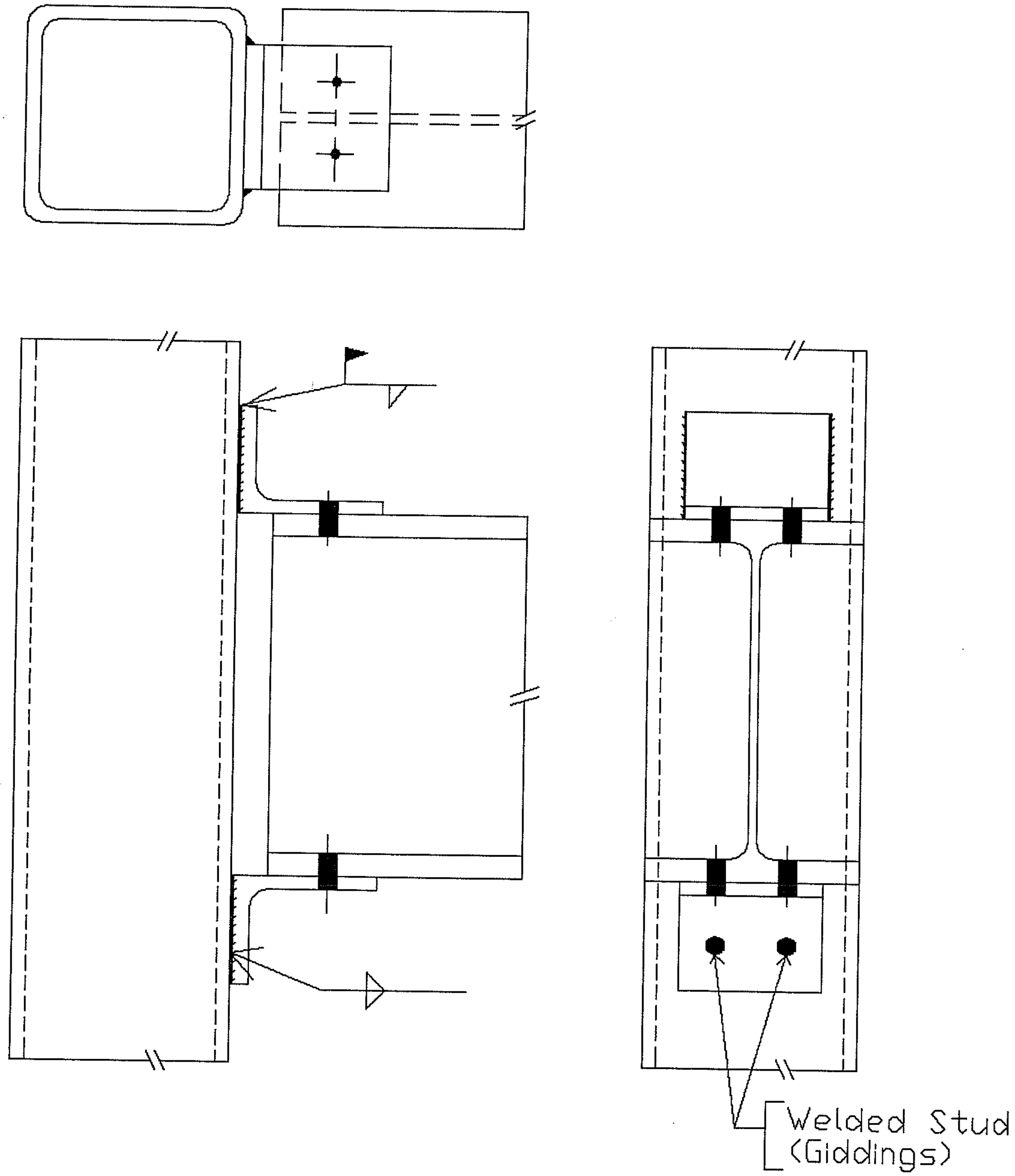


Figure 11

Seated Tube Column Connection

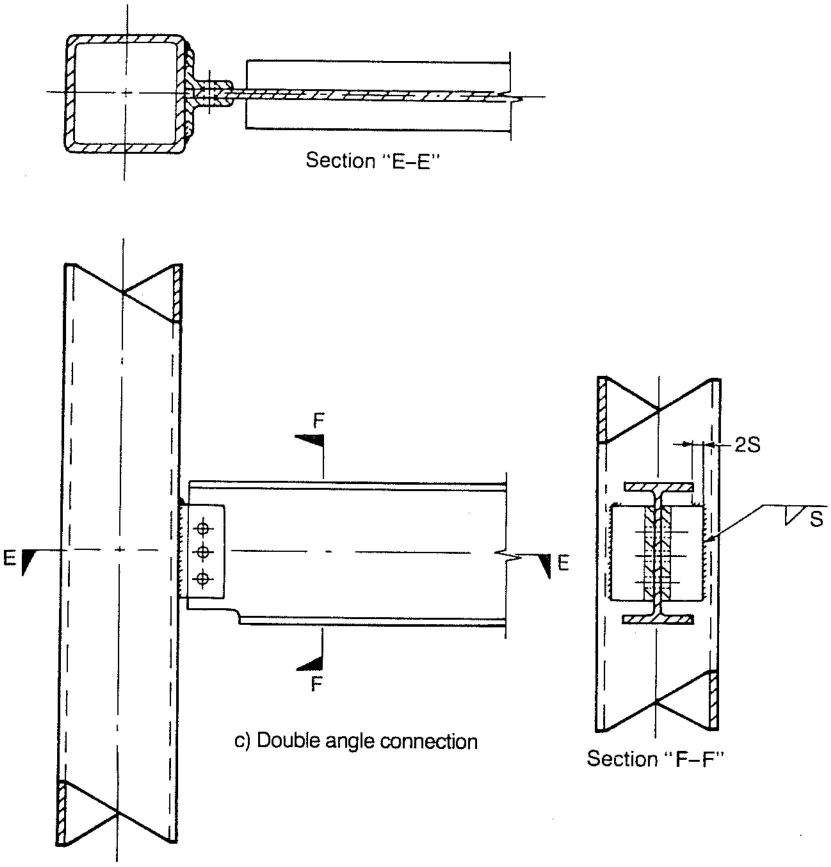
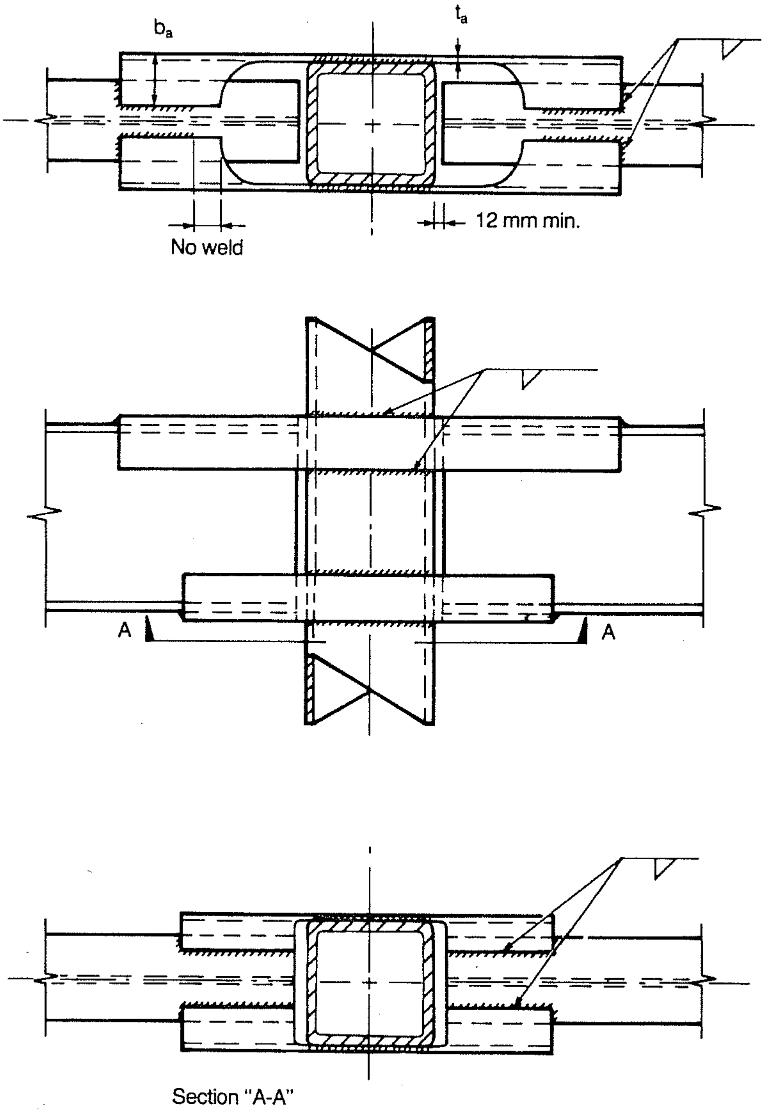


Figure 12

Double Angle or Knife Connection

from Stelco p. 89



b) Moment connection with strap angles

Figure 14

Tube Column with Strap Angles

from Stelco p. 91

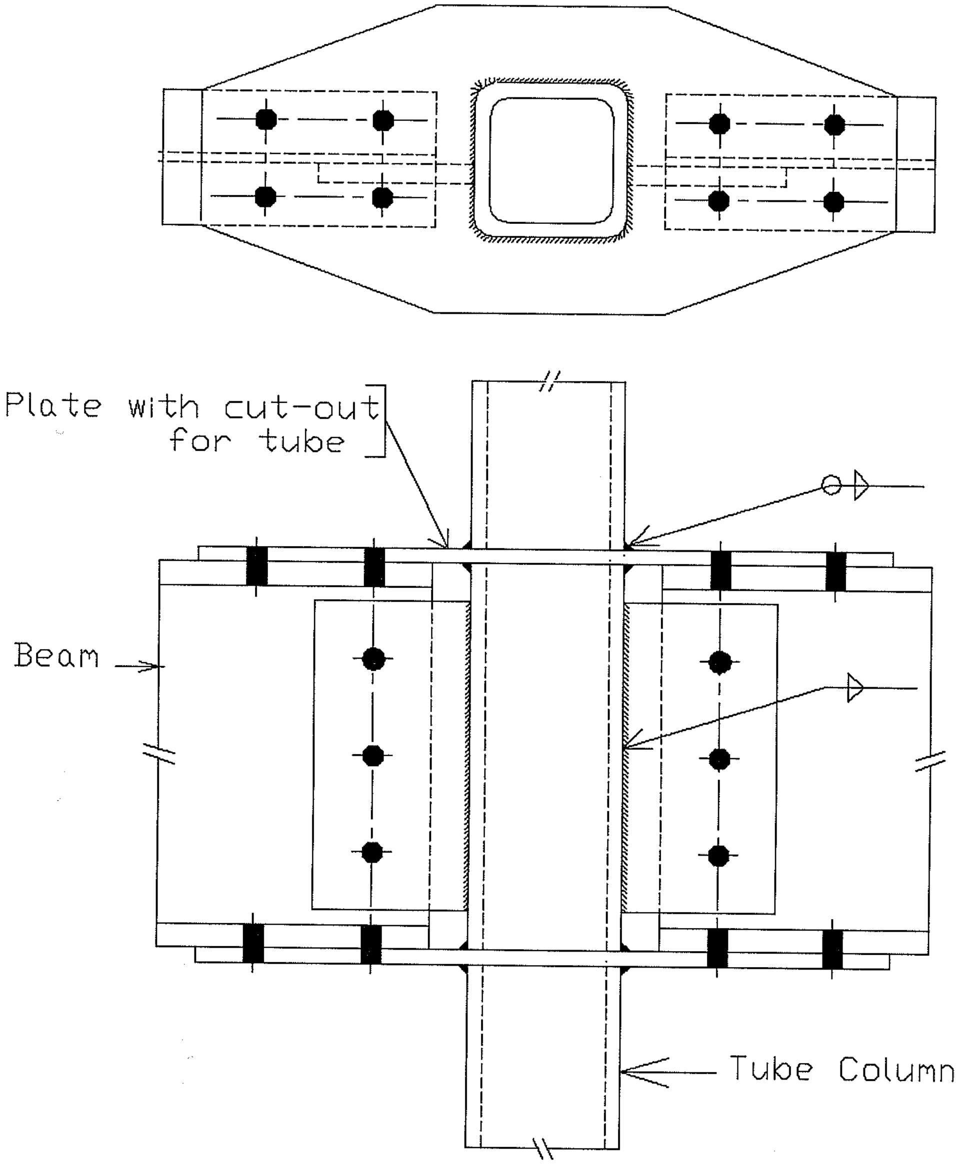


Figure 15

Welded Diaphragm Connection

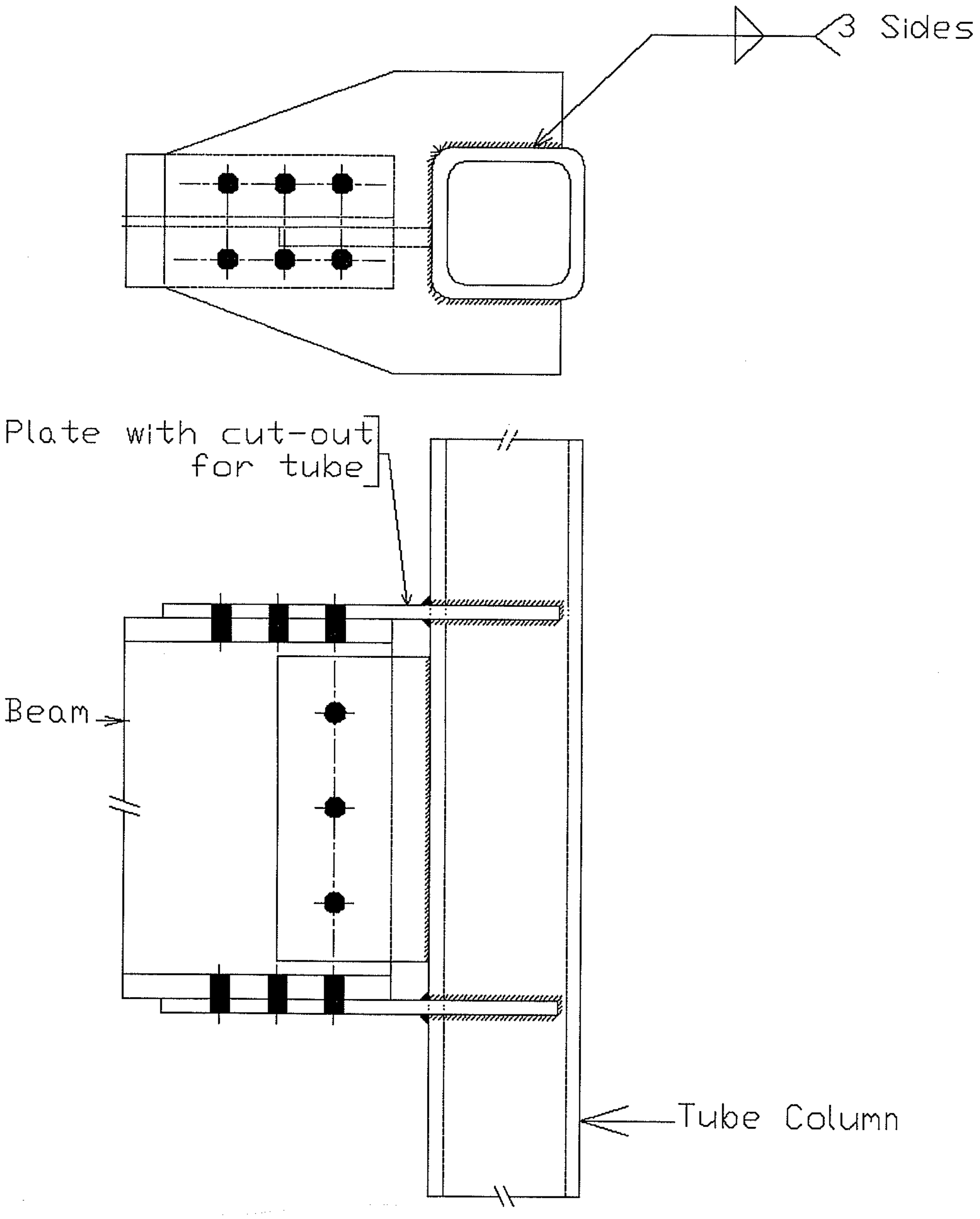
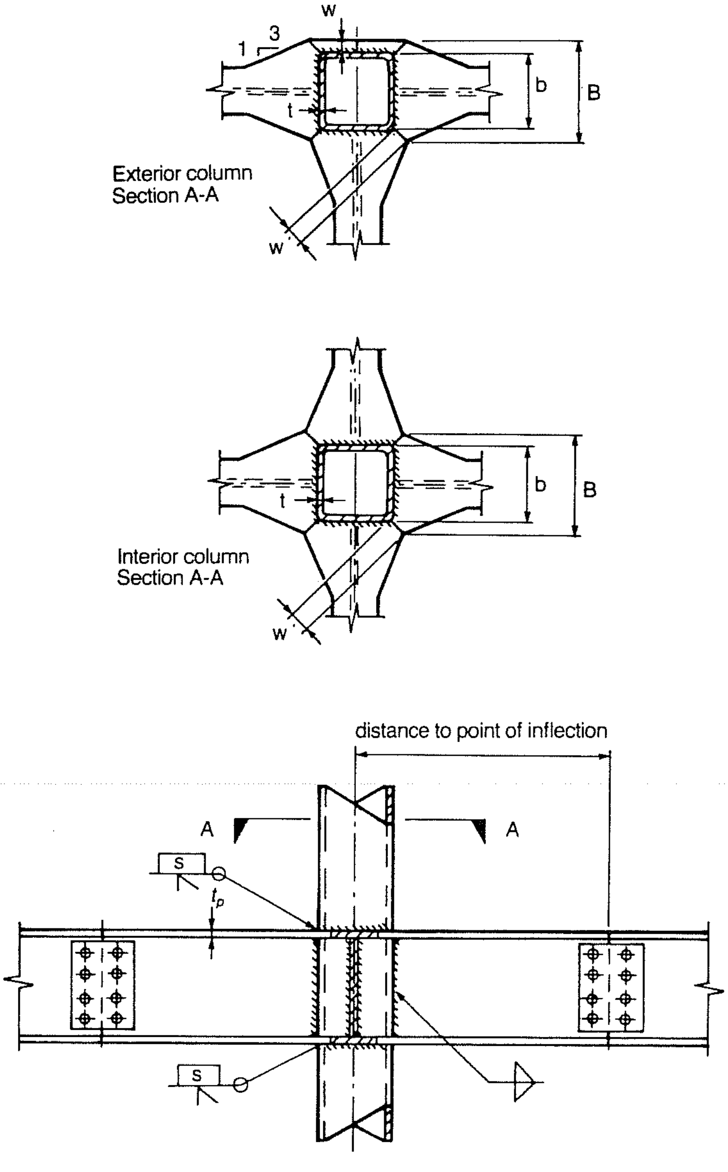


Figure 16

Welded Diaphragm End Connection



c) Welded diaphragm system

Figure 17

Welded Beam Stub System

from Stelco p.92

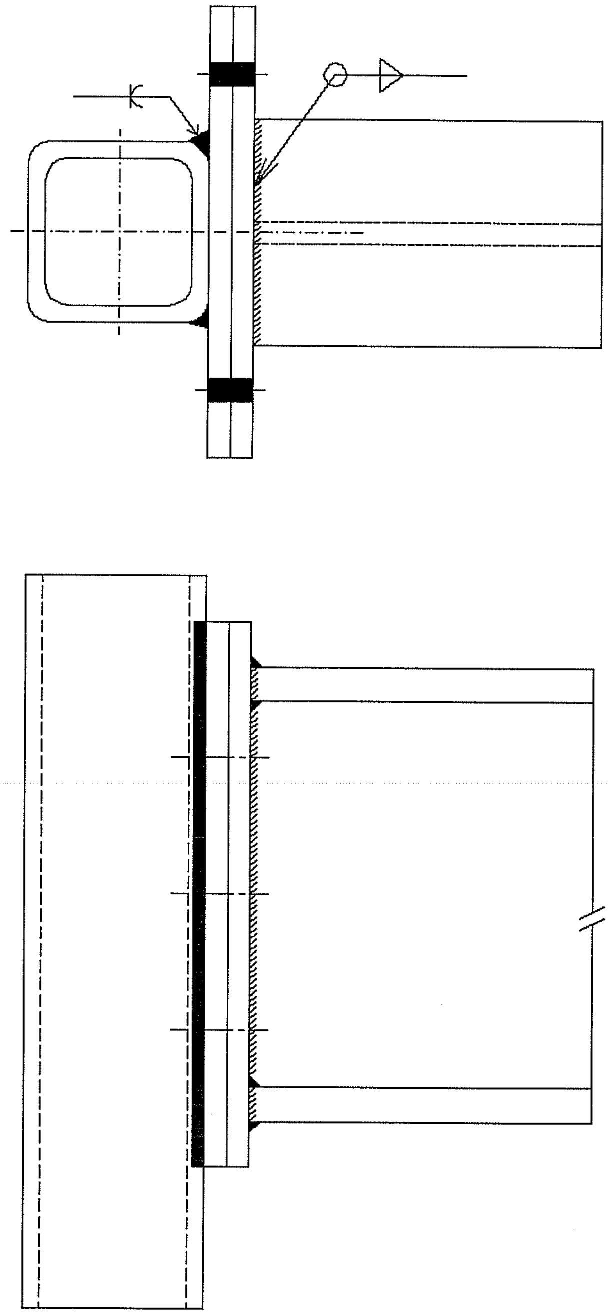


Figure 18

Tube Column with Beam End Plate

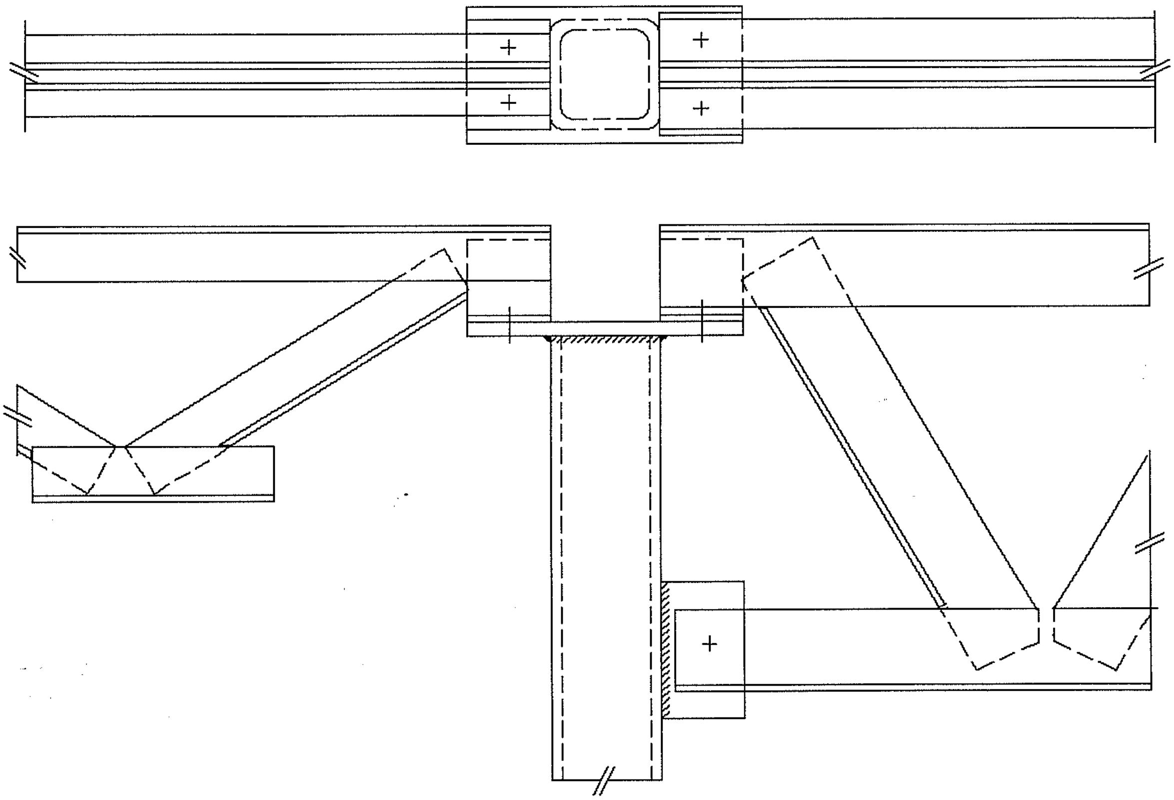
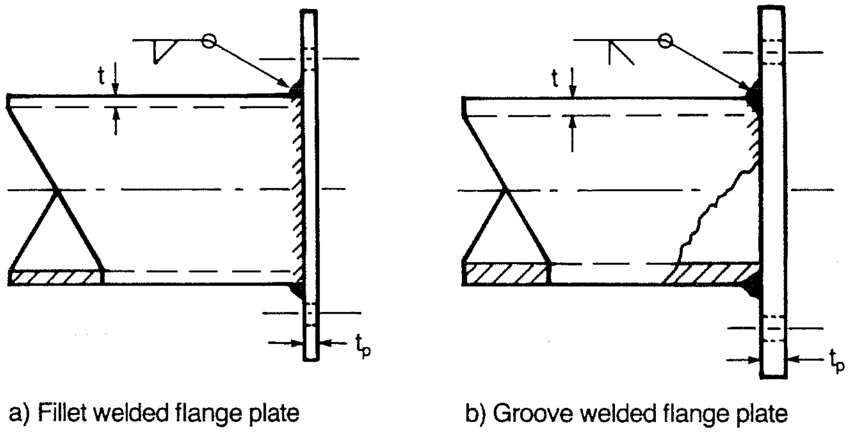


Figure 19

Tube Column to Open Joist

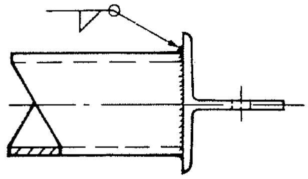


a) Fillet welded flange plate b) Groove welded flange plate

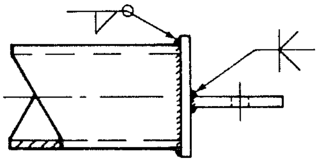
Figure 20

Welded Cap or Beam Plate

from Stelco p. 103



a) Rolled "T" section



d) Single shear, single tongue connection

Figure 22

Tee End Connections

from Stelco p. 101

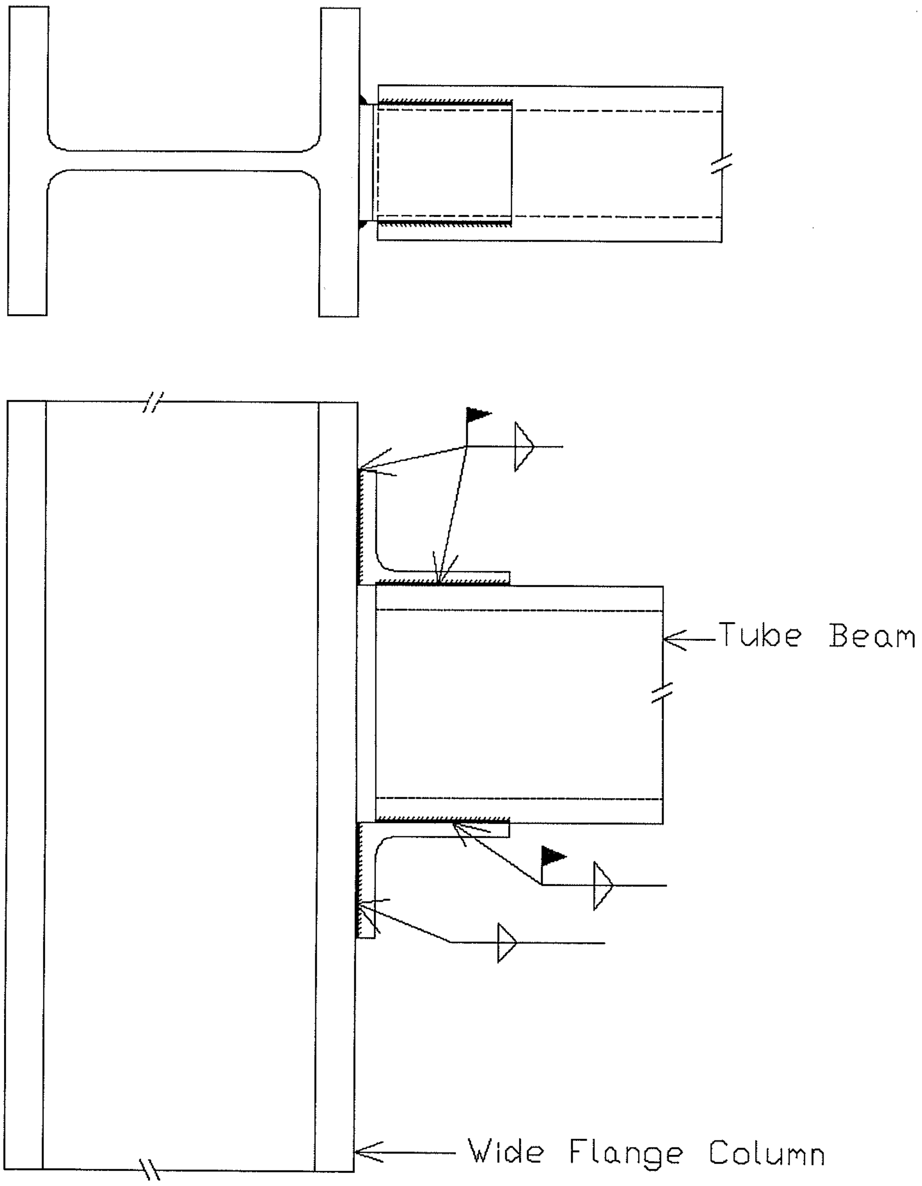


Figure 24

Seated Tube Beam Connection

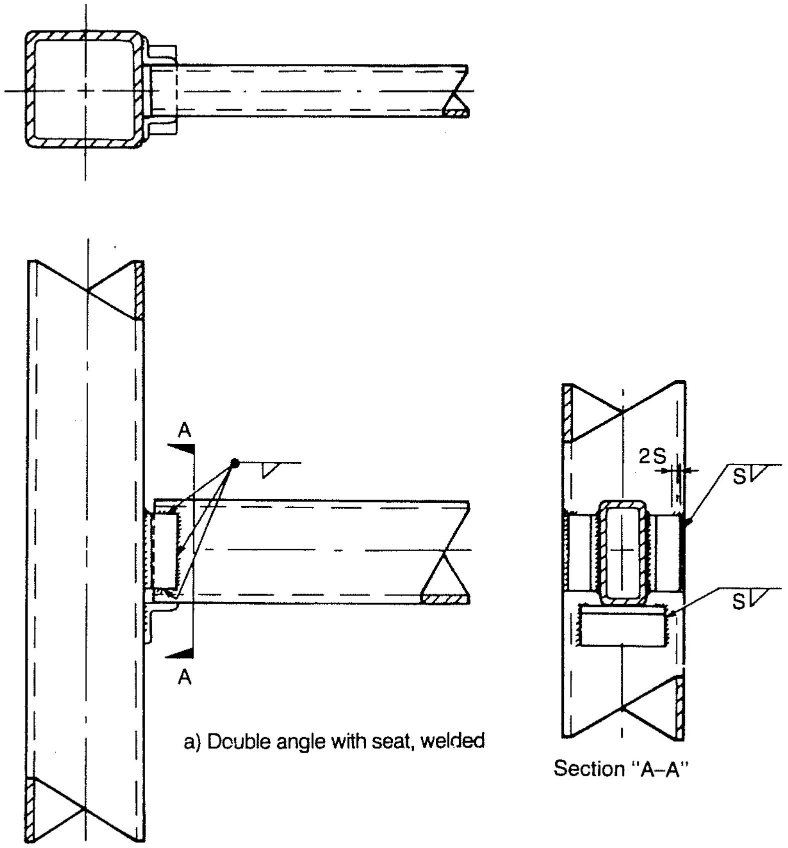


Figure 25

Double Angle with Seat

from Stelco p. 83

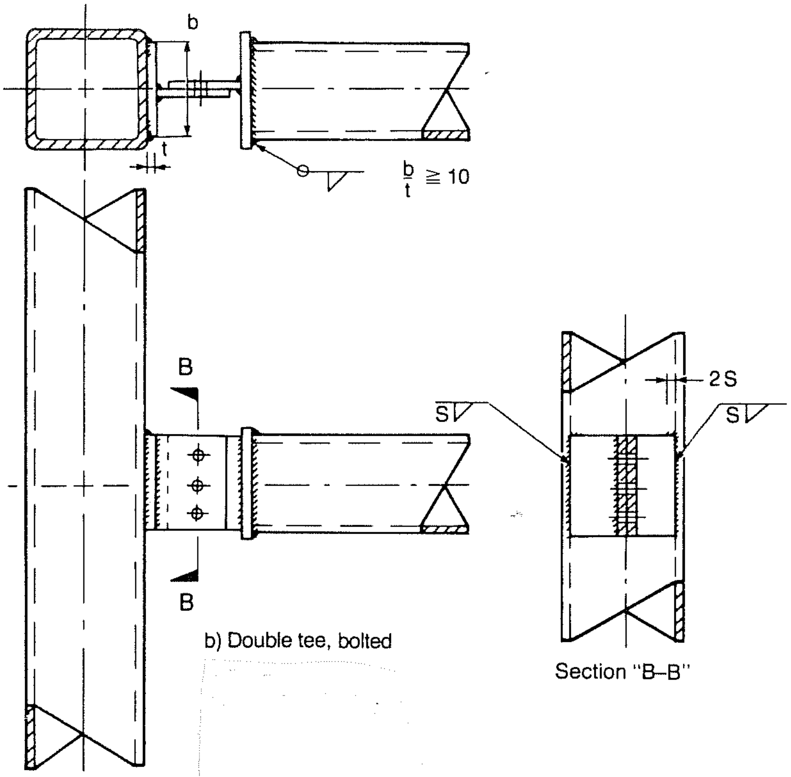


Figure 26

Double Tee, Bolted

from Stelco p. 84

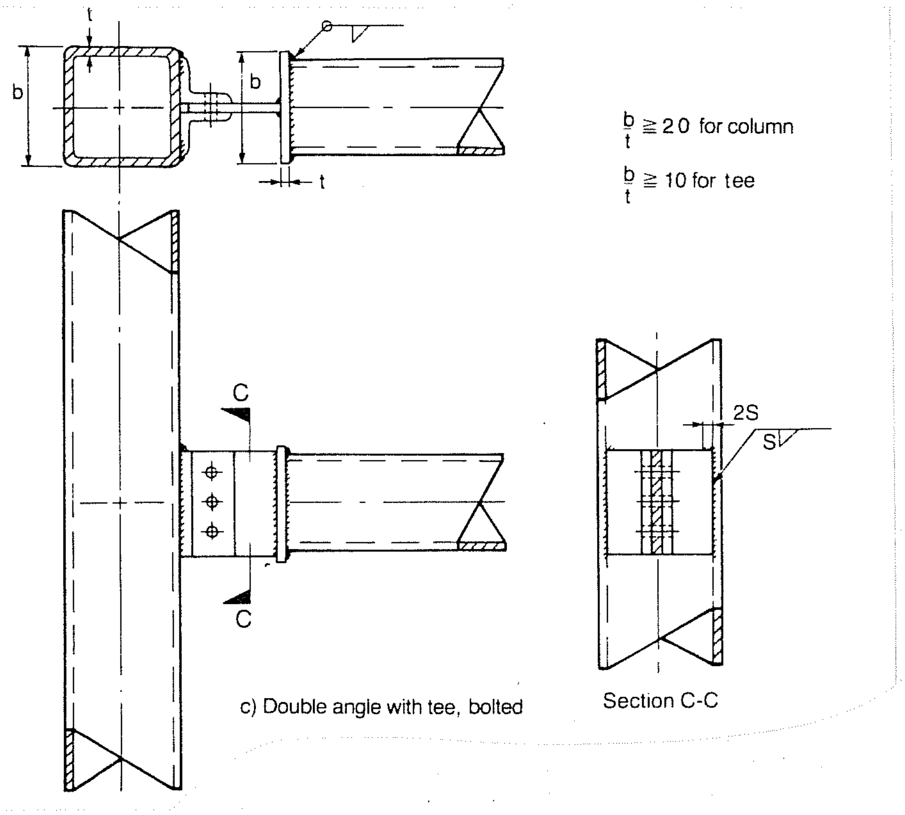
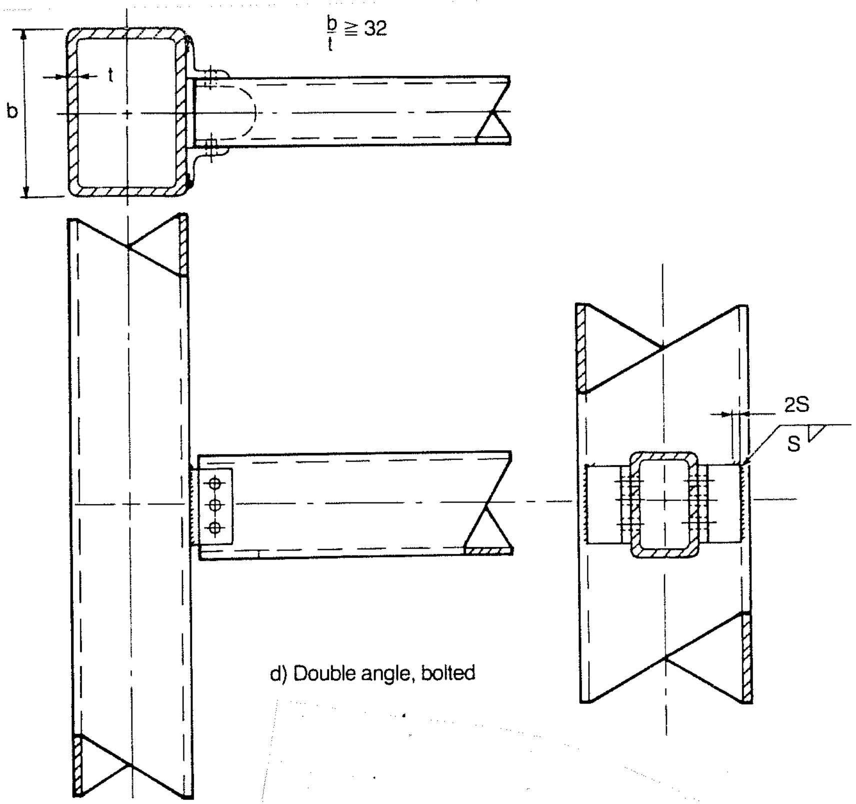


Figure 27

Double Angle with Tee, Bolted

from Stelco p. 84

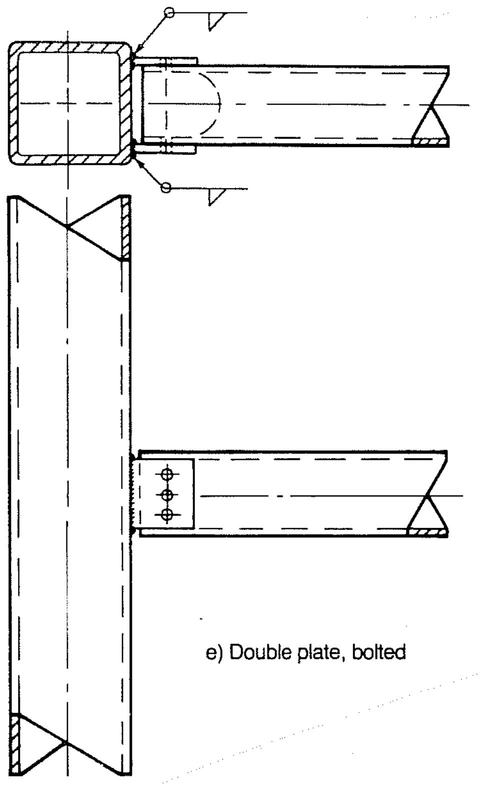


d) Double angle, bolted

Figure 28

Double Angle, Bolted

from Stelco p. 85



e) Double plate, bolted

Figure 29

Double Plate, Bolted

from Stelco p. 85

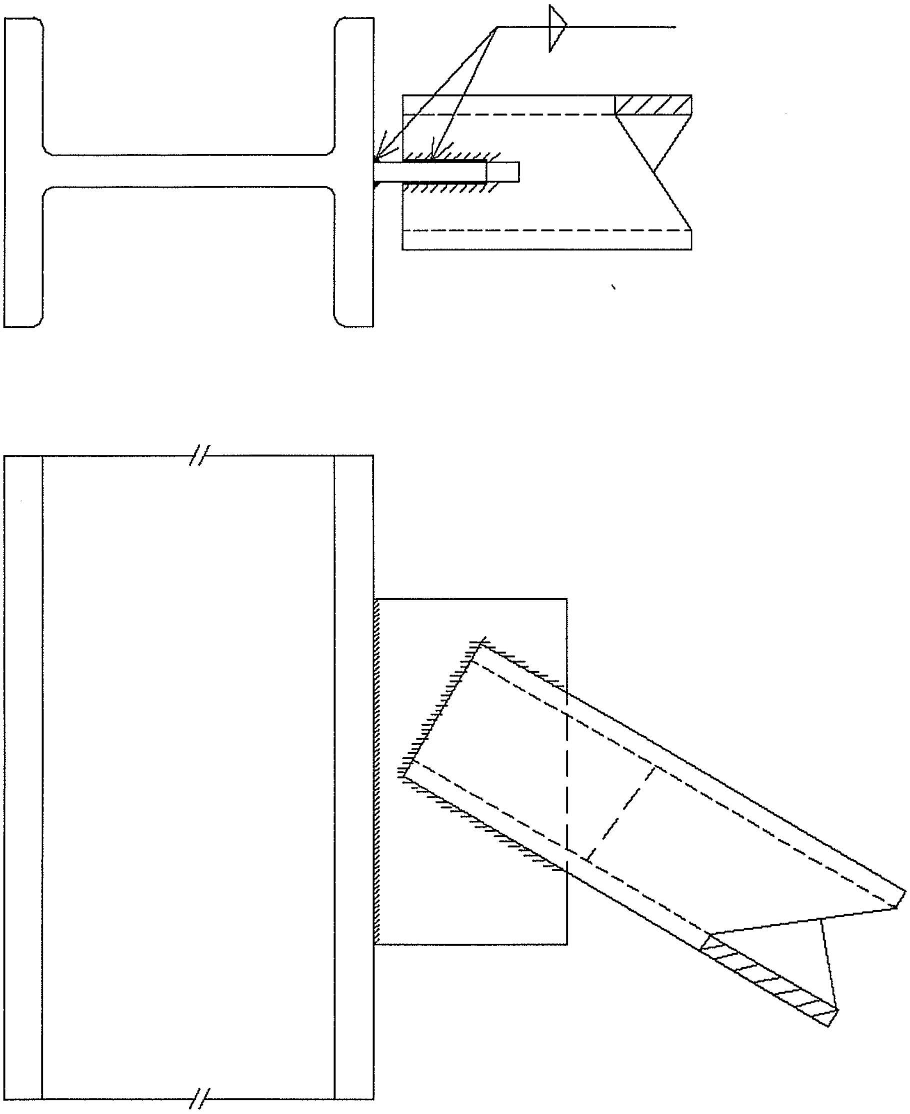


Figure 30

Slotted Beam Tube Connection

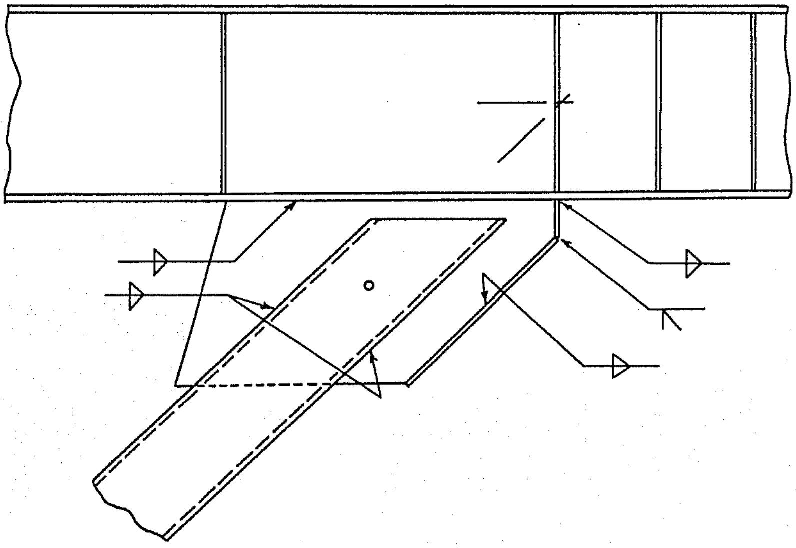


Figure 31

Eccentric Brace Connection

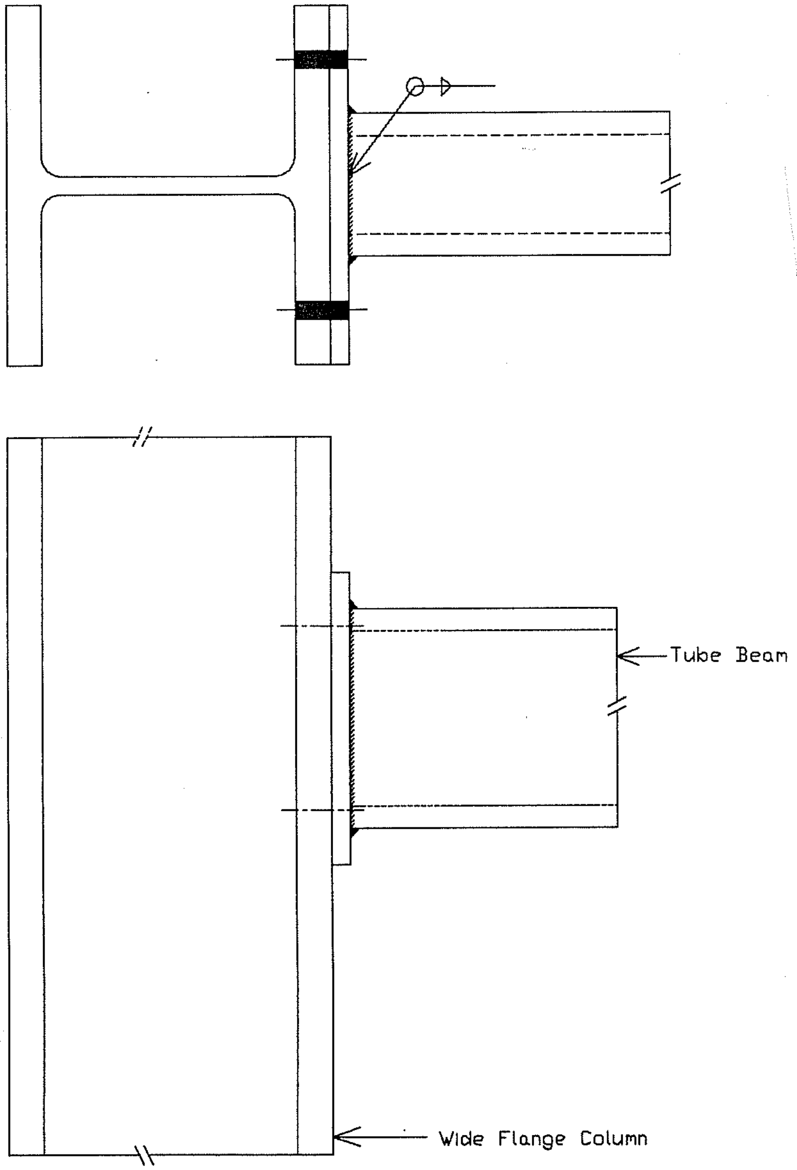


Figure 32

Column to Tube Beam Connection with an End Plate

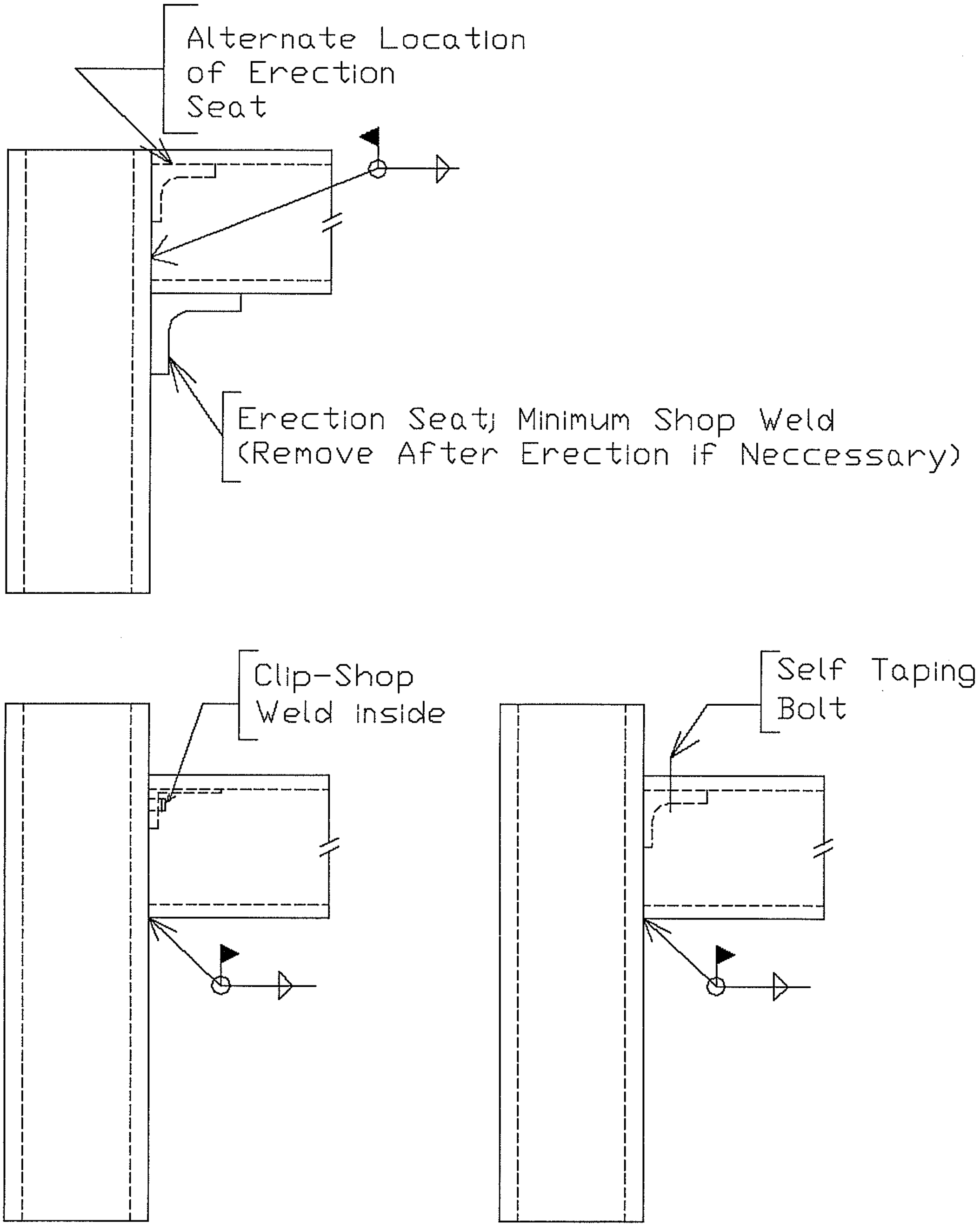


Figure 33

All Field Welded Connections

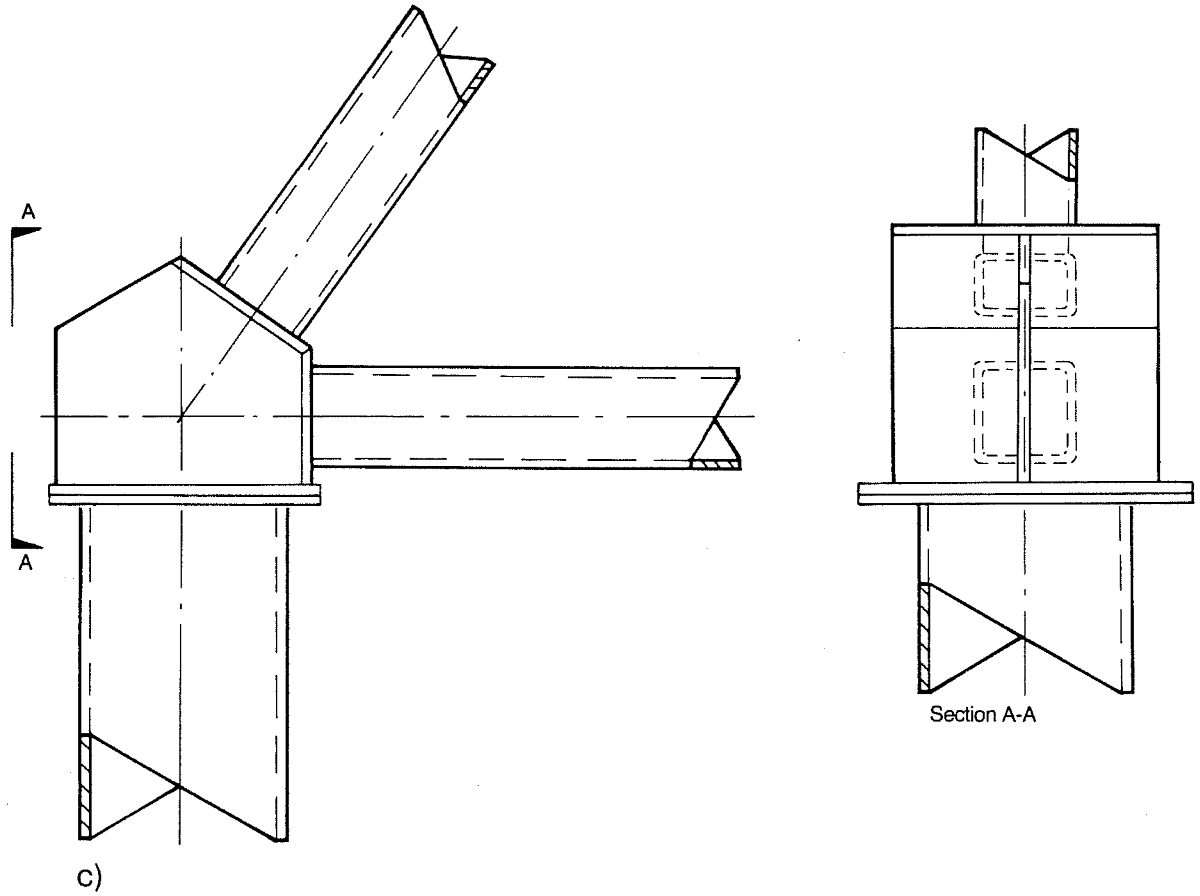


Figure 36

Truss to Column Connection

from Stelco p. 96

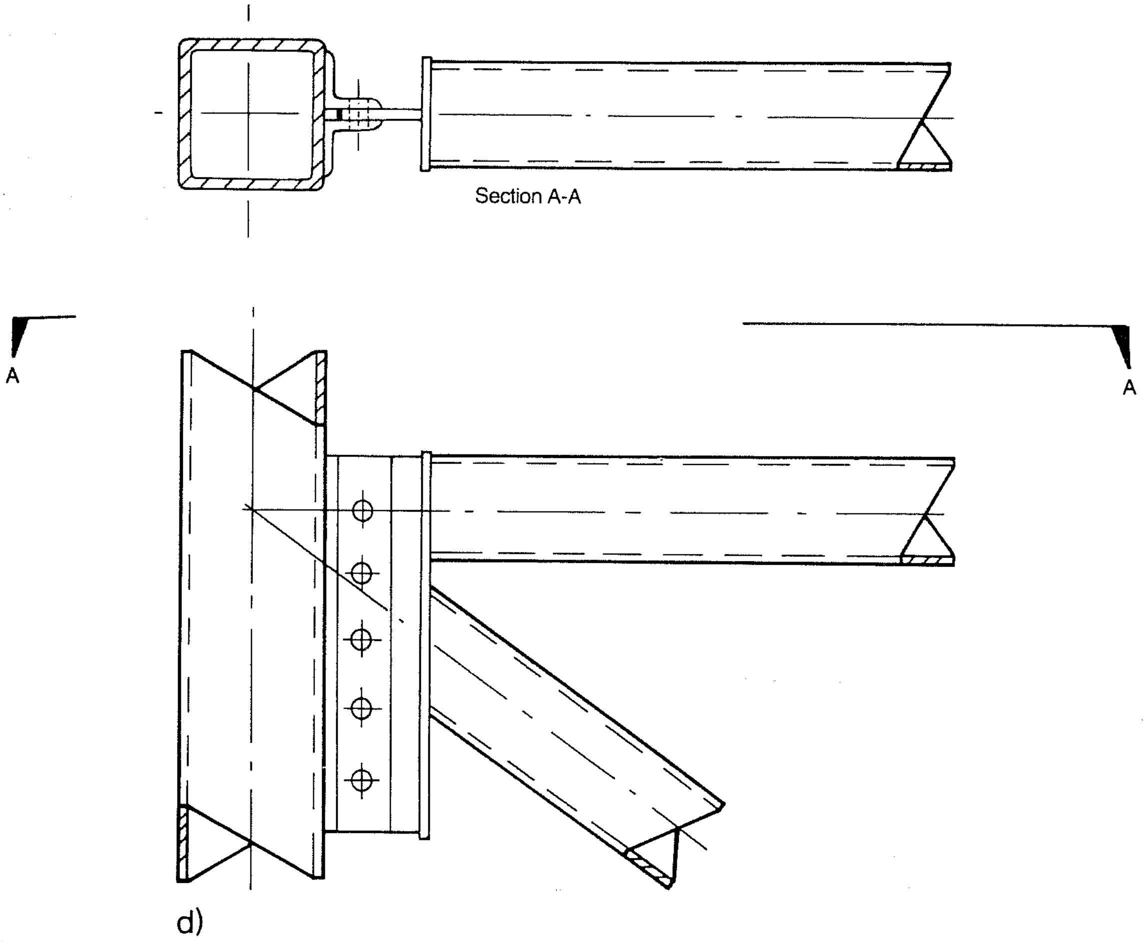


Figure 37

Truss to Column Connection

from Stelco p. 97

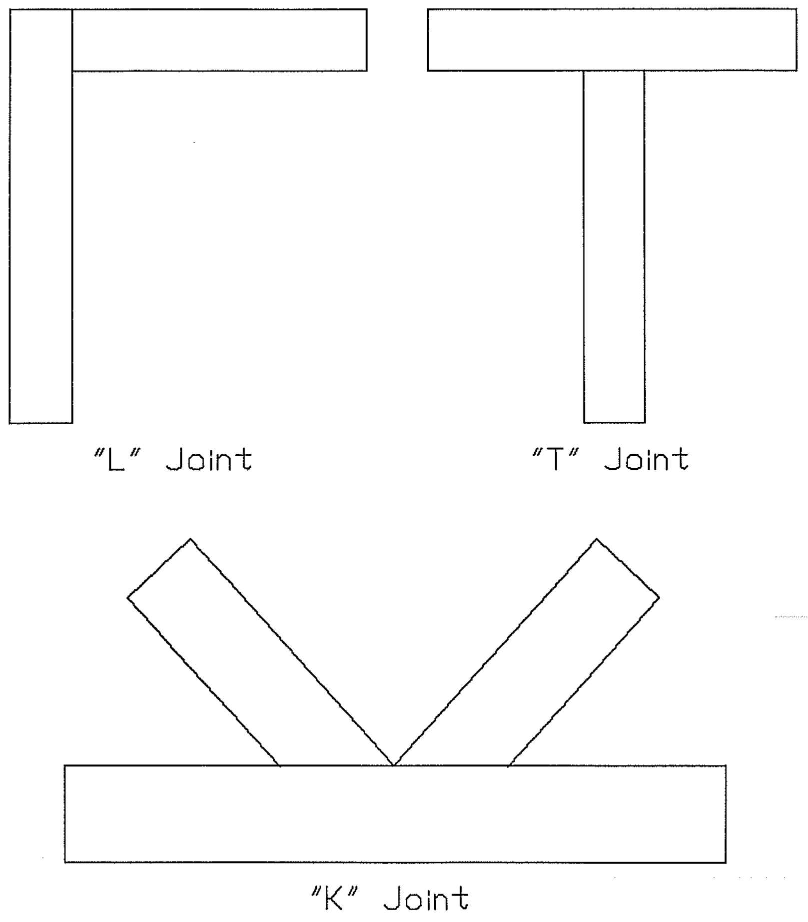


Figure 39

Types of Truss Joints

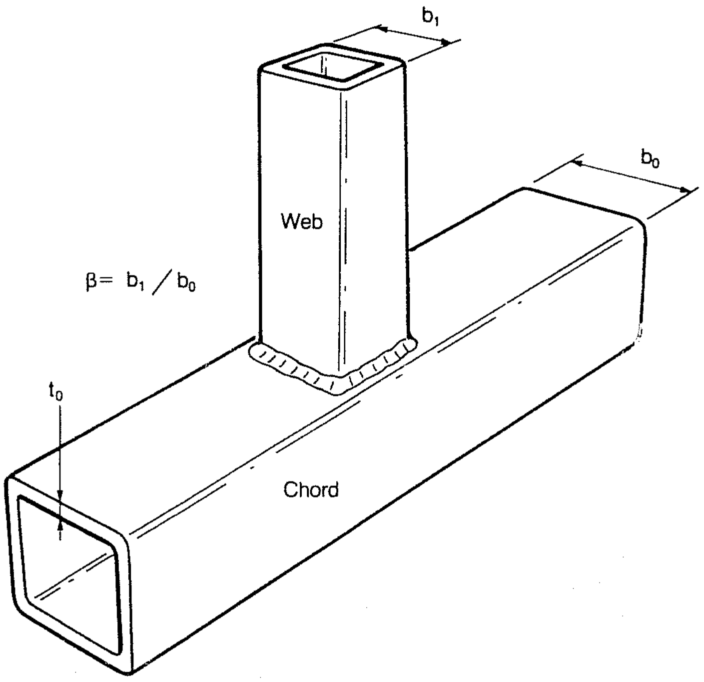
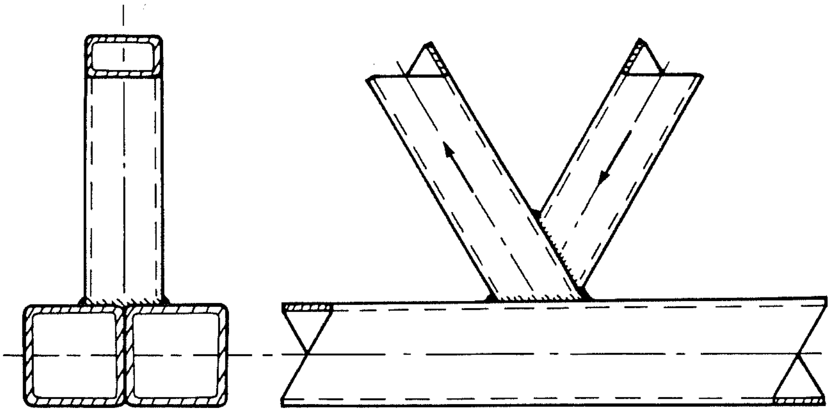


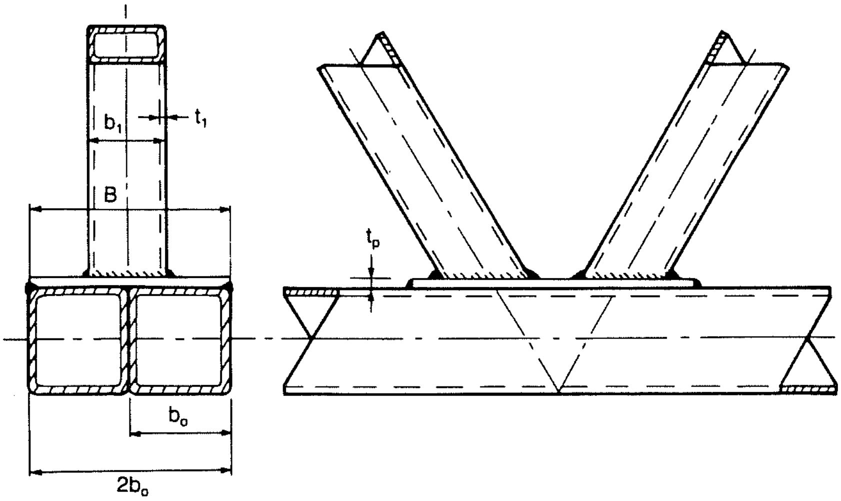
Figure 41

Typical Vierendeel Truss Joint

from Stelco p. 75



a) Unstiffened back-to-back double HSS chord joint



b) Stiffened back-to-back double HSS chord joint

Figure 42

Typical Double Tube Chord Welded Truss Joint

from Stelco p. 63

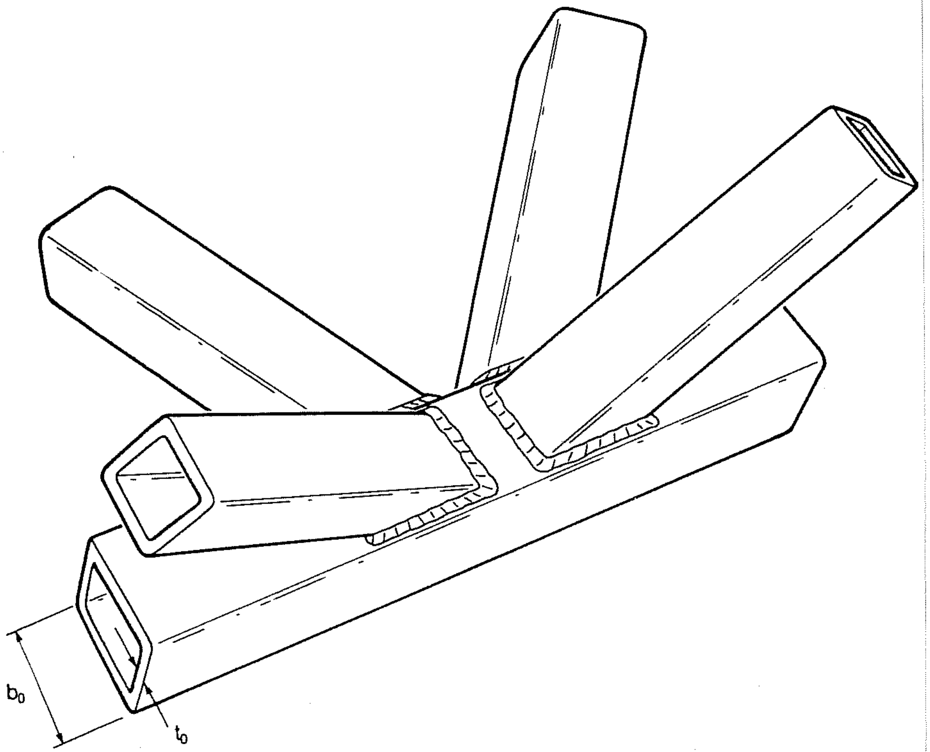


Figure 43

Typical Connection to Tension Chord of Triangular Truss

from Stelco p. 82

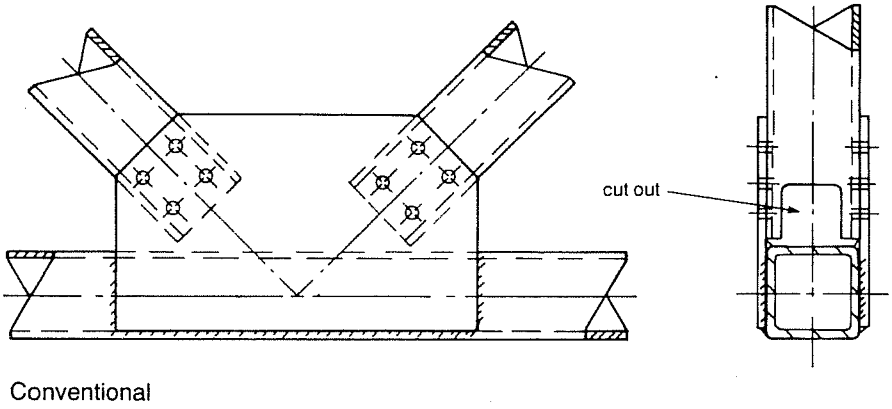


Figure 44

Conventionally Bolted Truss

from Stelco p. 69

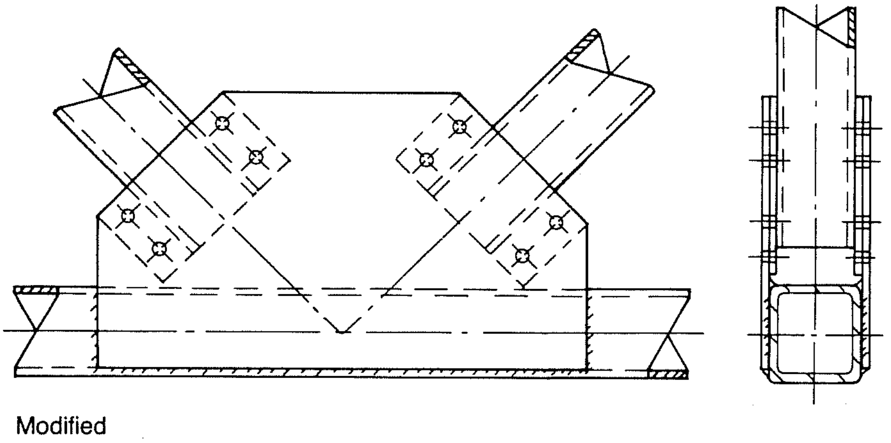


Figure 45

Modified Bolted Truss

from Stelco p. 69

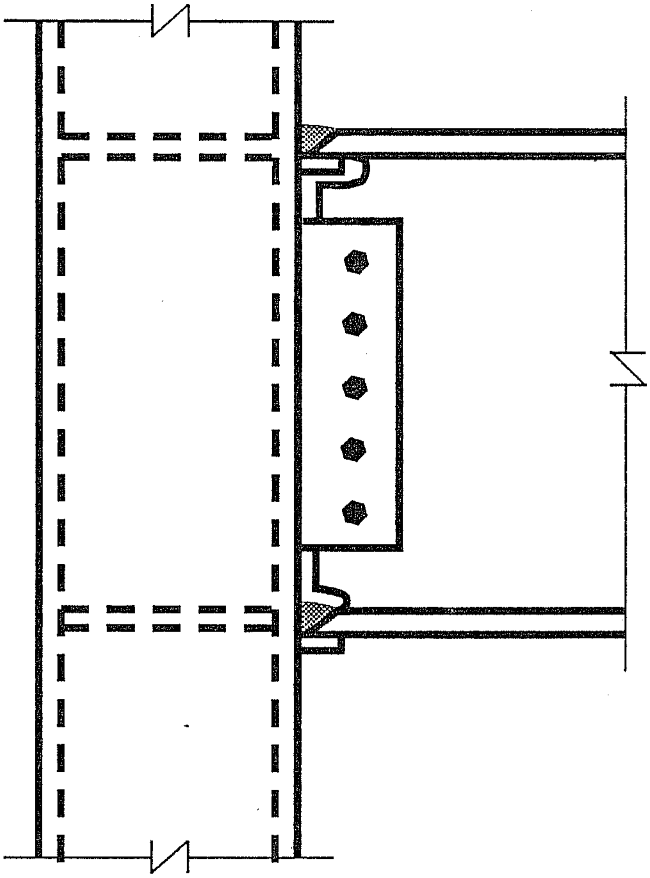
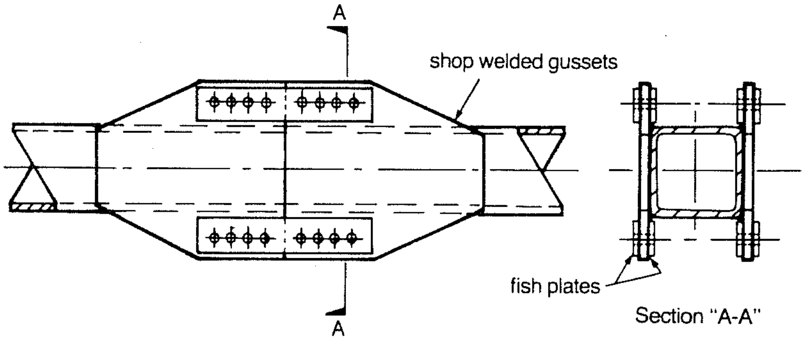


Figure 47

Wide Flange to Box Column Connection



Bolted splice with gusset and fish plates

Figure 48

Bolted Tube Splice

from Stelco p. 106

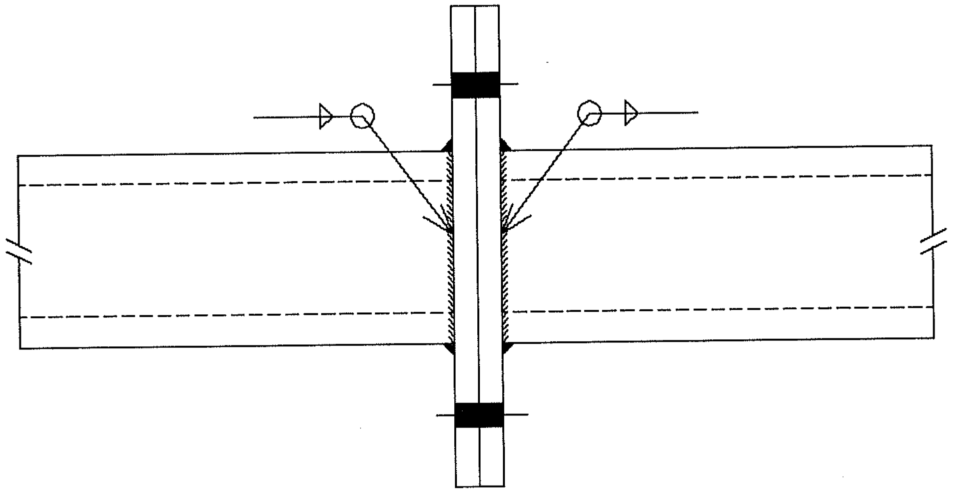


Figure 49

Bolted Tube Splice

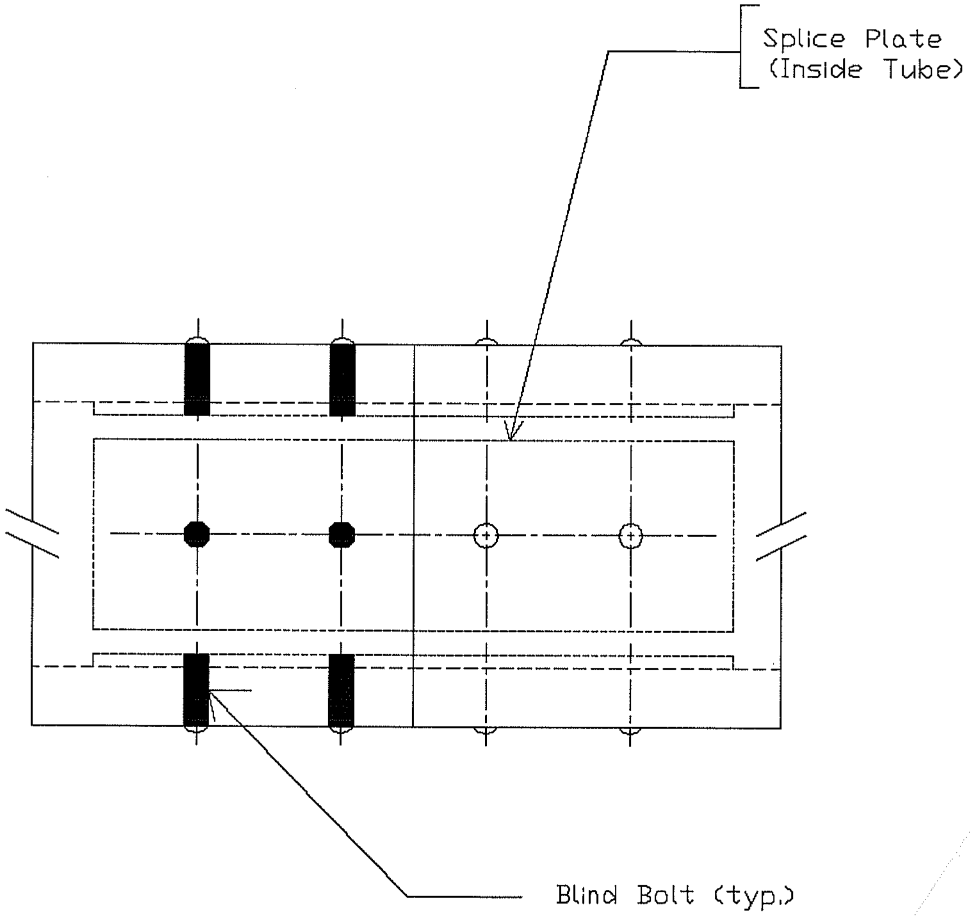


Figure 50

Proposed Blind Bolt Tube Splice

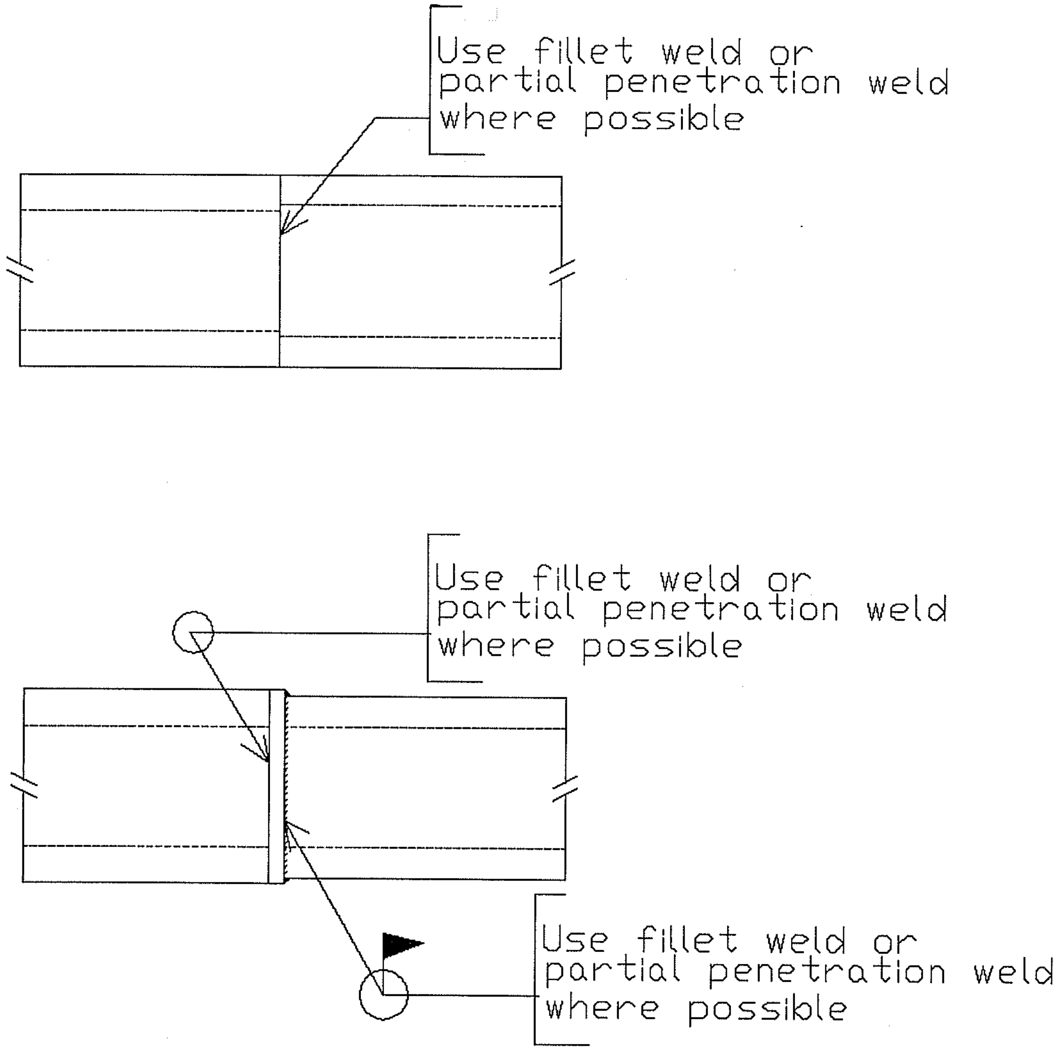
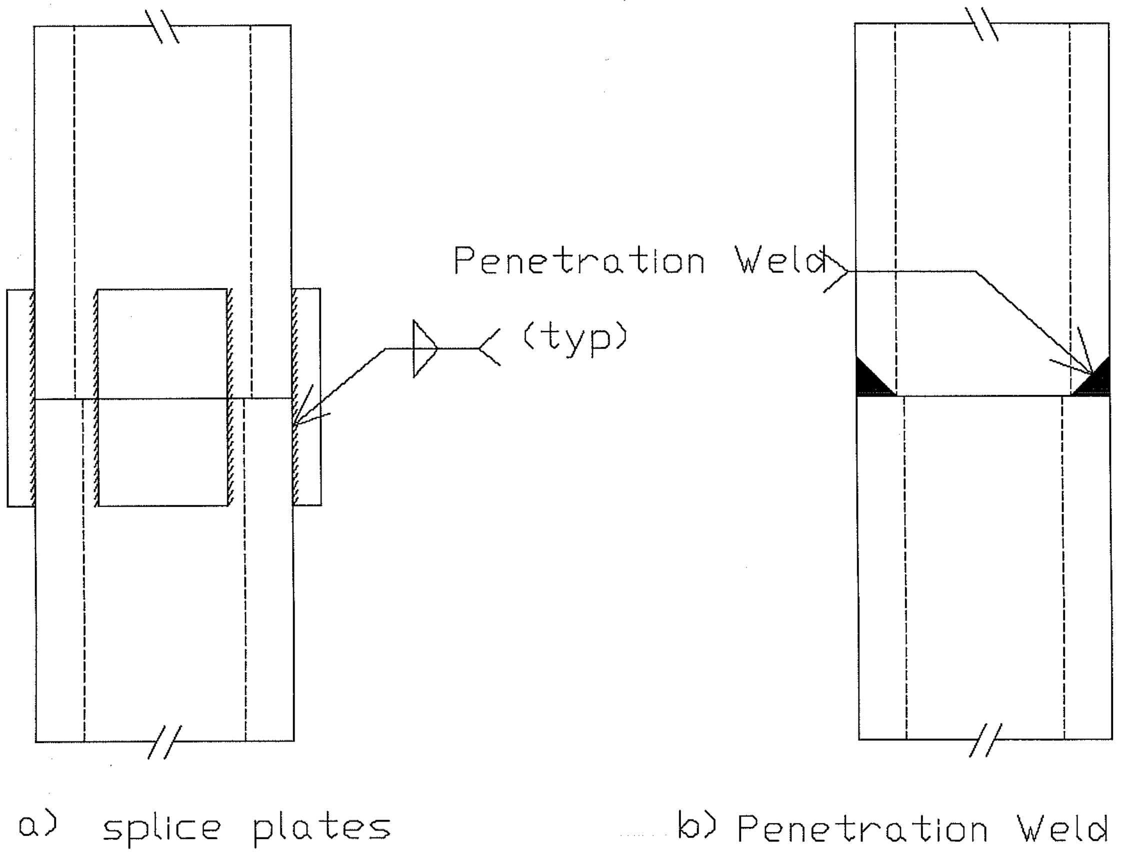


Figure 51

Welded Tube Splices



a) splice plates

b) Penetration Weld

Figure 52

Built Up Box Splices

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