Basic Boiler Construction

Learning Outcome

When you complete this module you will be able to:

Sketch and describe the general construction features of watertube and firetube boilers.

Learning Objectives

Here is what you will be able to do when you complete each objective:

1. Describe the design and manufacturing of boiler tube sheets, shells, and drums.
2. List and briefly describe the standard types of welded joints used in the construction of pressure vessels.
3. Describe the general design of riveted joints.
4. Describe the tools and standard methods used to attach boiler tubes to tubesheets, headers and drums.
5. Describe the need for, and application of boiler stays.
6. Describe boiler inspection and access openings.
7. Describe boiler drum connections.
8. List or identify the different types of internal firetube furnace designs.
9. Describe boiler foundations and supports.
10. Describe the design and construction of water-cooled furnace walls in firetube boilers.

INTRODUCTION

Boilers are vessels in which heat is transferred from one fluid to another, such as from hot flue gases to water. These fluids must be kept separate from each other and from the outside environment. Since the fluid pressures can be considerable, the boiler surfaces must be able to contain them. Boiler construction is thus largely the science of joining metal plates, tubing, and piping, in required configurations, so the vessel can withstand these pressure differences and stresses. In this module we will examine some of the common methods of construction, such as welding, staying, and tube expanding.

SHELLS AND DRUMS

In the case of a firetube boiler, the main part of the boiler is referred to as the shell and the boiler tubes are contained within this main part.

The watertube boiler, on the other hand, features a drum or drums instead of a shell and the tubes run between the drums or between drums and headers, rather than being contained within them.

Shells and drums are made up of steel plates, which are rolled to the correct curvature. The thickness of the plates ranges from 6 mm to 250 mm depending upon the pressure they have to withstand and the required diameter of the shell or drum. If the plate is thick, it is first heated and shaped into half-cylindrical sections which are then welded together to form the complete cylinder. If the plate is thin, it is rolled without heating to form the cylinder from a single sheet as shown in Fig. 1. The adjoining edges are then welded.

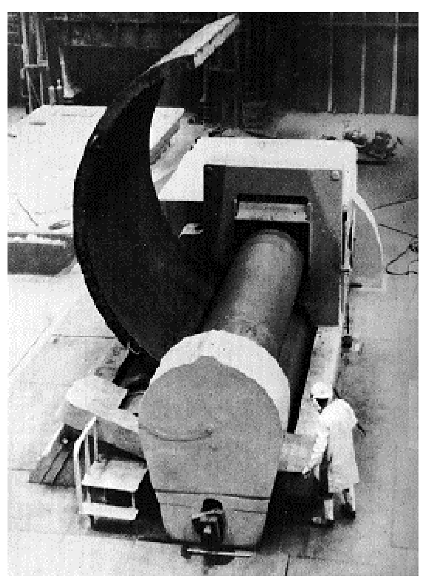

Figure 1
Rolling Boiler Plate

Fig. 2 shows the process of welding the adjoining edges or seam of a plate that has been rolled to form a shell.

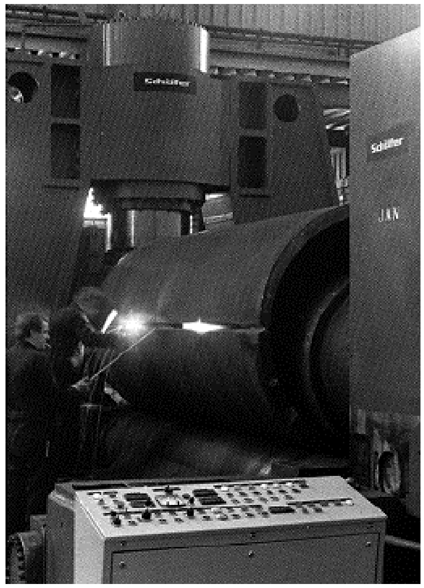

Figure 2
Welding a Shell Seam

After the shell or drum is formed and welded, the ends are closed off by means of heads or end plates, which are also made from steel plates.

In the case of a watertube boiler the heads are made in a dished rather than flat shape.

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Fig. 3 shows a large watertube boiler drum with dished or rounded heads. In the illustration, the weld joining one of the heads to the drum is being x-rayed in order to discover any possible faults within the weld.

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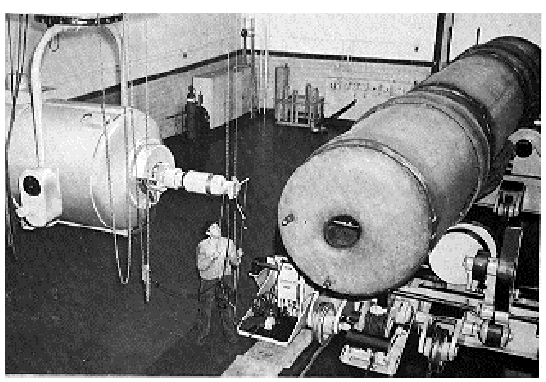

Figure 3
X-Ray Examination of Head to Shell Joint

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In the case of a firetube boiler, the heads must be flat rather than dished in order that the tube ends can be securely attached. Because the firetube boiler heads hold the tube ends, they are called tubesheets.

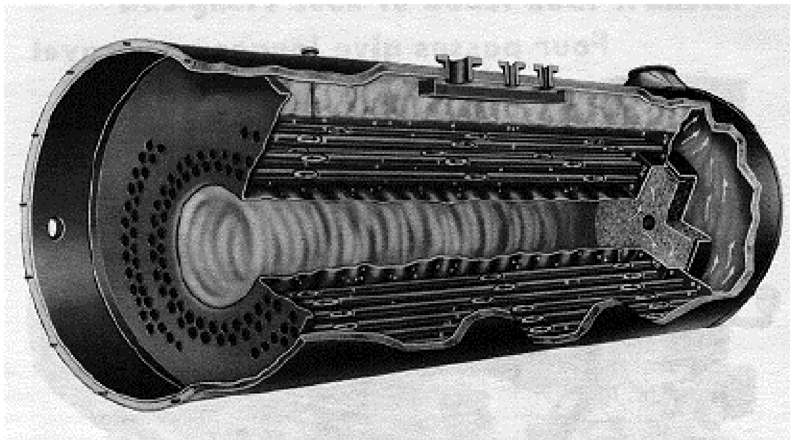

Figure 4
Tube Holes in Firetube Boiler Head

Fig. 4 shows the tube holes in the flat head of a three-pass firetube boiler. As with the watertube boiler, the heads are fastened to the shell by welding. The tube holes in a watertube boiler are located in the drum rather than in the head and Fig. 5 illustrates the assembly of tubes to the drilled holes.

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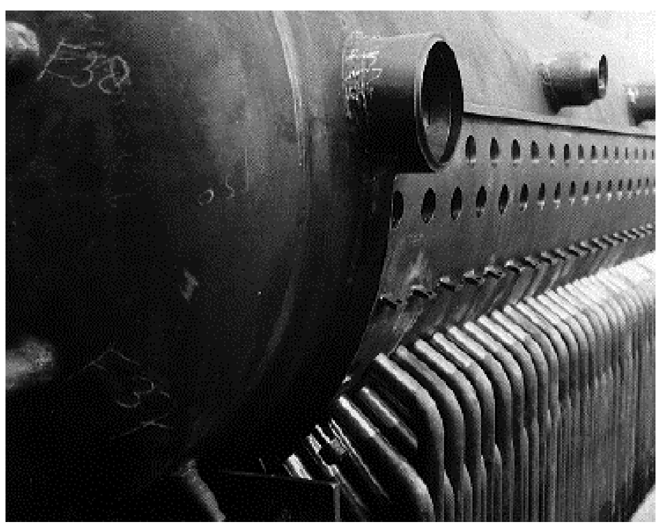

Figure 5
Tube Holes in WatertubeBoiler Drums

WELDED JOINTS

The five basic types of welded joints are sketched in Fig. 6. Of these five, the **butt joint** is the one used primarily in boiler fabrication although under certain circumstances the **lap joint** may sometimes be used.

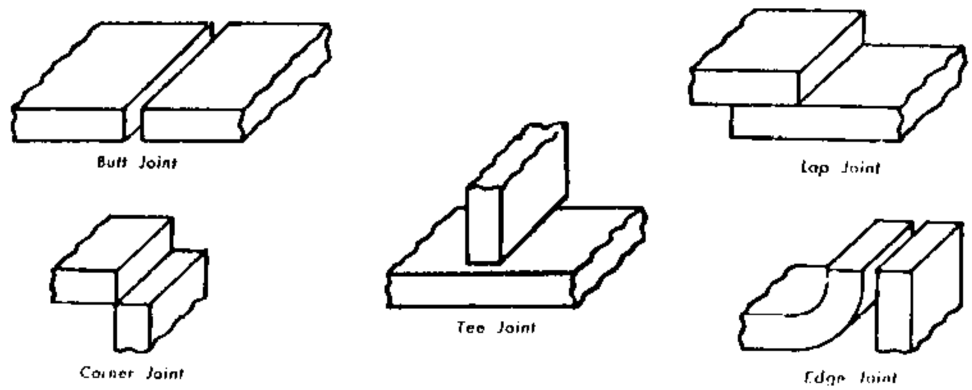

Figure 6
Types of Welded Joints

Two basic types of welds are sketched in Fig. 7. The groove weld is used in making a butt joint and the fillet weld is used in making the lap joint or the tee joint. Before the welding of a joint is carried out, the edges of the plates to be joined are bevelled or cut in such a way as to form a groove of the proper shape and size.

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Various shapes of grooves used are sketched in Fig. 8.

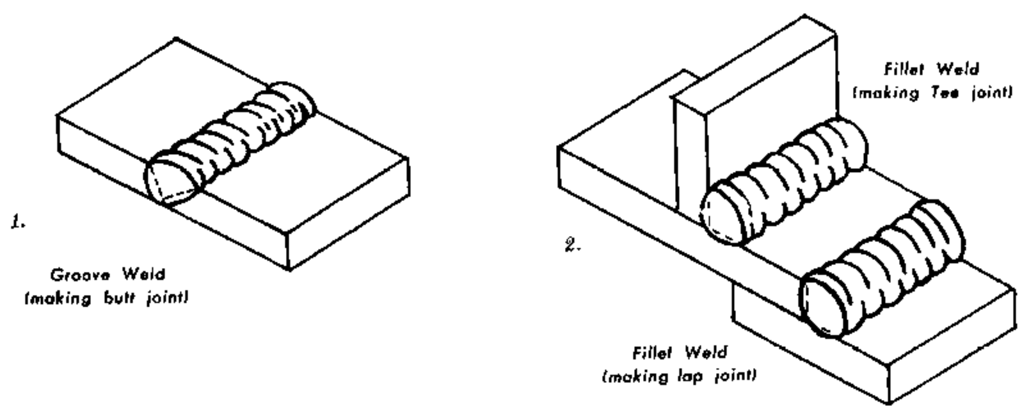

Figure 7
Basic Weld Types

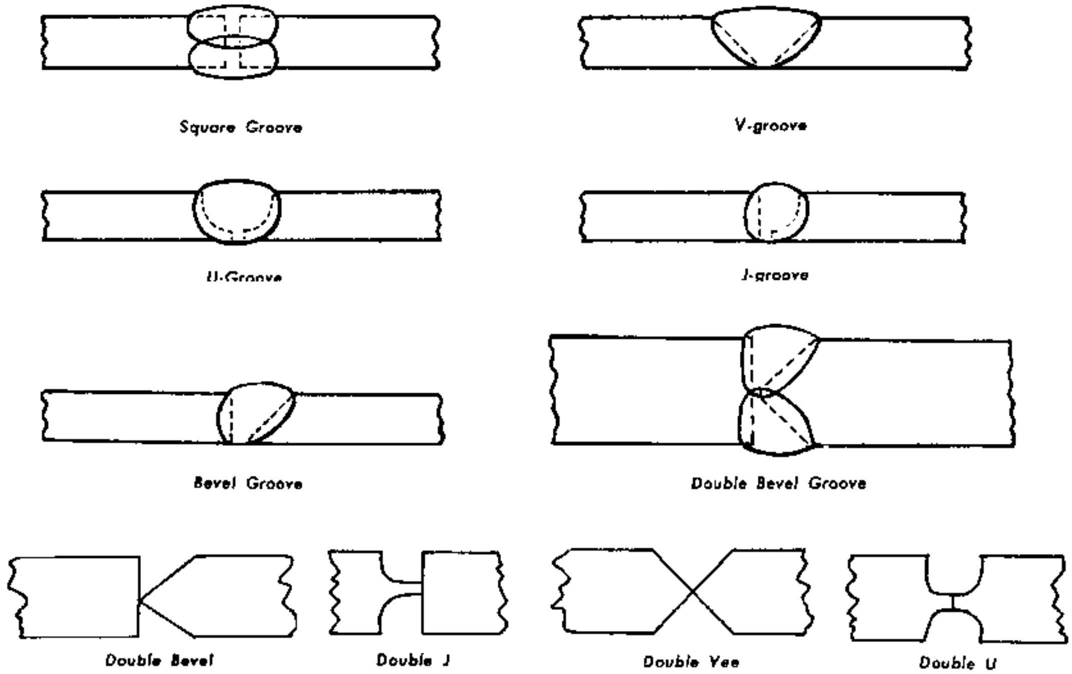

Figure 8
Types of Weld Groves

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The double grooves shown at the bottom of Fig. 8 are used for thick plates. With these types, the filler metal is applied to both sides of the joint and the weld is referred to as a **double-welded butt joint.**

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If the filler metal is applied from one side only, then the weld is referred to as a **single-welded butt joint.**

Fig. 9 is a sketch of a single-welded butt joint showing the terminology used for the various weld parts.

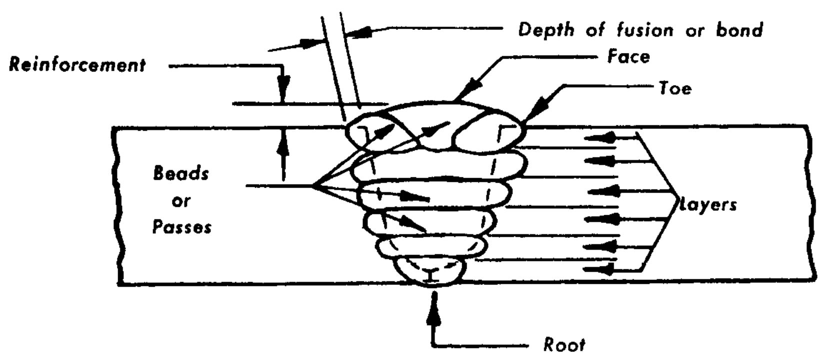

Figure 9
Weld Terminology

Fig. 10 (a) is a sketch of a double vee groove, which may be used for the longitudinal seam of a boiler shell or drum. Fig. 10 (b) is a sketch of a method of welding a head to a boiler drum, as viewed from the side of the drum.

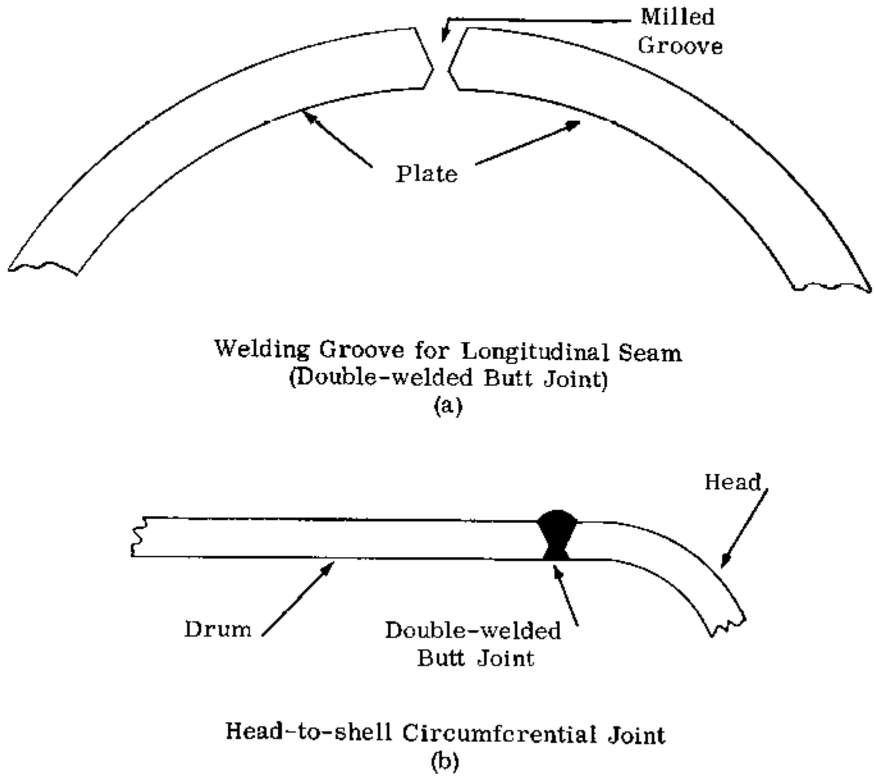

Figure 10
Welding Groove for Longitudinal Seam (Double welded Butt Joint)

A section of a typical weld is shown in Fig. 11. The numbers within the weld refer to the passes or beads used to produce the weld and the sequence in which they are applied. The numbers outside of the weld refer to the layers with those prefixed by the letter B being the layers applied to the underside of the weld.

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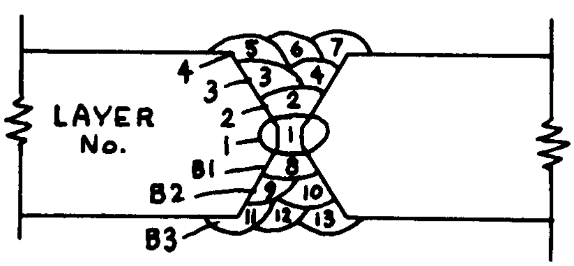

Figure 11
Typical Double Butt Weld

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Heat Treatment

During the welding process, stresses are set up in the metal. These stresses are due to temperature differences existing in the weld area and these stresses may be removed or reduced by heat treatment of the metal.

One method of heat treatment, called preheating, is to heat the parts, before welding, in a special oven or furnace. The preheat temperature ranges from 80°C to about 230°C depending upon the material and thickness.

Another method of heat treatment is to heat the parts after the welding has been completed. This method is referred to as **postweld heat treatment** or **stress-relieving**. In the case of a boiler drum, for example, after welding of the drum joints, the entire drum can be heated to a specified temperature (590°C or above) in a special furnace for a definite period of time. Then it is cooled off slowly at a controlled rate until its temperature drops to below 315°C.

Welding Inspection

During the fabrication of the boiler, an authorized Inspector must make sure that the welding procedures used by the manufacturer are correct. In addition, he must check that all welding is carried out by pressure vessel welders who are qualified to do the required type of welding. The Inspector also checks on the heat treatment used. As a further check, test plates of the same thickness and material as the drum are welded and then subjected to tension and bending tests to verify the drum welds will safely hold.

The drum welds are also radiographed (as shown in Fig. 12) for their entire length using x-rays or other radioactive material. In this way, any defects within the weld will be evident in the radiographic picture.

Figure 12
Radiographic Examination of Shell Weld

Riveted Joints

Riveting is no longer used in boiler fabrication but there are still some older, riveted boilers in operation.

There are two main types of riveted joint:

1. The Lap joint
2. The Butt joint

In the lap joint, the edges of the plates are overlapped and fastened by one or more rows of rivets. If one row of rivets is used, the joint is said to be single riveted; with two rows it is said to be double riveted, and so on.

Fig. 13(a) shows a single riveted lap joint, and Fig. 13(b) a double riveted lap joint.

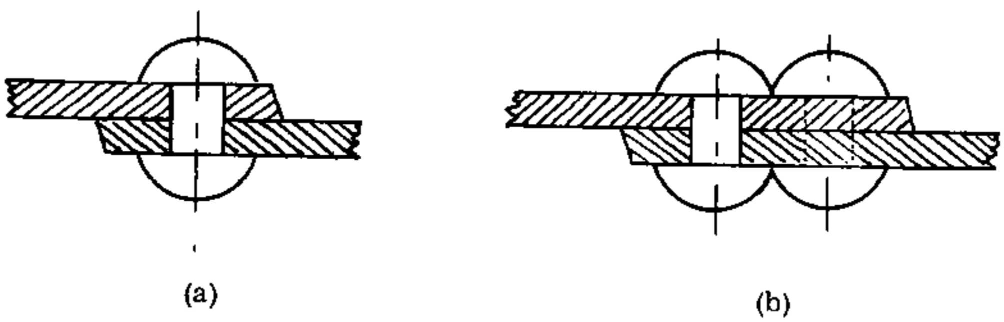

Figure 13
Riveted Lap Joints

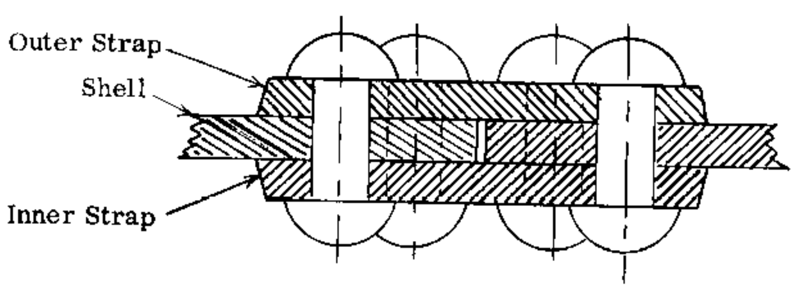

Figure 14
Double Riveted Butt Joint

In the butt joint construction, the edges of the shell plates do not overlap but butt together and cover straps are riveted to the plates covering the seam. Fig. 14 shows a double riveted butt joint with equal straps and Fig. 15 shows a treble riveted butt joint with unequal straps.

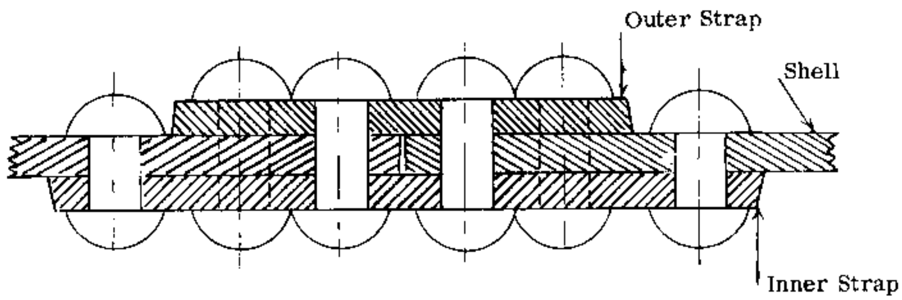

Figure 15
Treble Riveted Butt Joint

Lap joints are used for circumferential seams in all riveted boiler shells, but longitudinal seams are nearly always of butt joint construction. Butt joints are stronger and therefore more suitable for longitudinal seams, because the force tending to rupture a boiler at the longitudinal joint is greater than the force tending to rupture it at the circumferential joint. With the butt joint it is also possible to bend the plate in the form of a true circle as the ends of the shell plate butt or meet, but this cannot be done with the lap joint as the ends must overlap to make the joint.

BOILER TUBES

For moderate pressure service, tubes are made from strips of steel, which are formed into tube shape and the edges welded in an electrical resistance welding machine. In this method the welding is achieved due to the heat produced when an electric current flows through the metal at the tube edges.

Tubes used for high pressure service are usually seamless and are made by piercing a solid round billet of heated steel to form a rough tube. The tube is then finished by rolling.

The most common method used to fasten tubes to drums or tube sheets is to expand the tube ends into the tube holes in the drum or sheet. This expanding (or rolling as it is often called) is done by means of an expander, which consists of three rollers mounted in a cage which fits inside the tube end. A tapered mandrel fits between the rollers and when the mandrel is turned the rollers are rotated and forced out against the tube wall thus expanding the tube against the tube hole.

Fig. 16(a) shows an expander used for firetubes. The expander in Fig. 16(b) is used for watertube boilers and has a section of one of the rollers set at an angle in order to flare or bell the tube end. Fig. 16(c) shows a tube being expanded into a watertube boiler drum.

(a)

(b)

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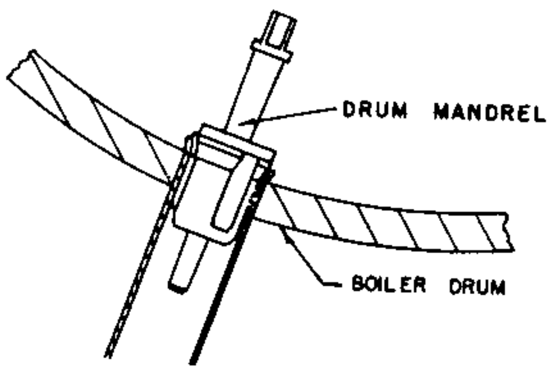

(c)

Figure 16(a) (b) (c)
Tube Expanders

In a watertube boiler the tubes are expanded and flared as shown in Fig. 17. In a firetube boiler, in addition to the expanding and flaring, the flared part is beaded over against the tube sheet. This beading of the tube end prevents it from being overheated and burned when the boiler is in service.

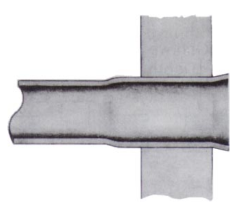

Figure 17
Expanded and Flared Tube (Watertube)

Fig. 18(a) shows the beaded over end of an expanded firetube. The tube in Fig. 18(b) has been expanded, beaded over, and then seal welded. The tube in Fig. 18(c) has been expanded into a grooved tube hole and then beaded over. This grooved type of construction is used for very high pressure service in both firetube and watertube boilers.

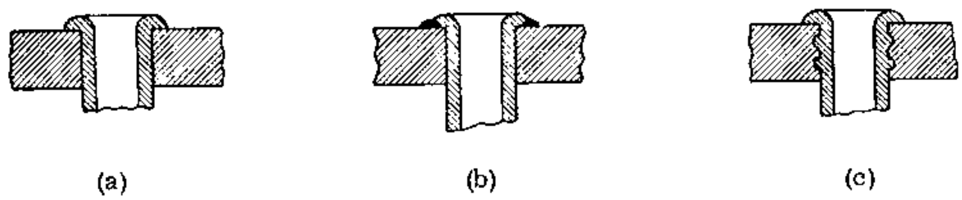

Figure 18
Tube Attachments for Firetube Boilers

Rather than using the expansion method of tube attachment, many high pressure watertube boilers use welded attachments. The boiler drums and headers have stubs welded to them in the factory and the tubes are welded to these stubs during the erection of the boiler in the field. These welded stubs will be discussed further under the heading "Drum Connections" later in this module.

Similarly, some firetube boilers use welded attachments for tubes. However in the case of the firetube boiler, the tubes are expanded both before and after the welding of the tubes. Fig. 19 shows some welded tube attachments for firetube boilers.

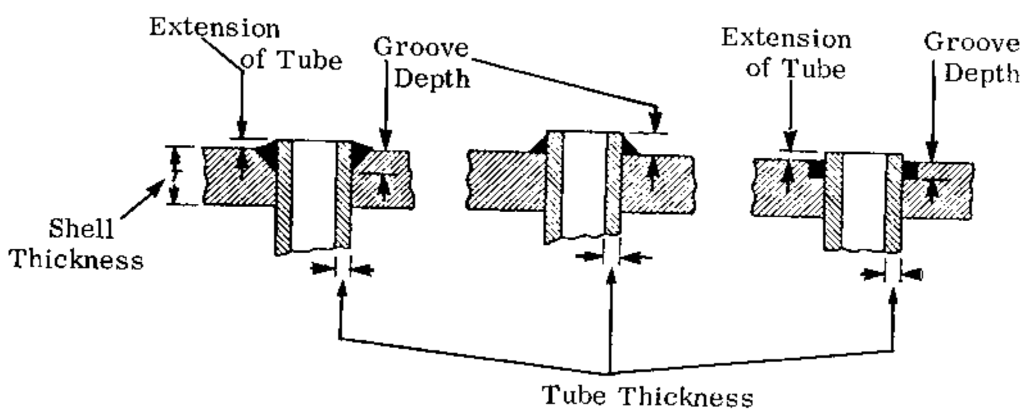

Figure 19
Welded Tube Attachments (Firetube)

Boiler Stays

Any flat surface that is exposed to pressure will tend to bulge due to the effect of the pressure. To prevent this bulging from occurring it is necessary to brace or support flat surfaces. The flat surfaces present in firetube boilers would include the tube sheets, waterlegs and crown sheets. These surfaces are supported by various types of stays.

In the watertube boiler, stays are not normally required because this type of boiler can be built without flat surfaces. For example, the boiler heads are dished rather than flat as in the firetube boiler.

The flat surfaces above and below the tubes in the tube sheets of a firetube boiler must be supported and Fig. 20 illustrates the shape of these surfaces.

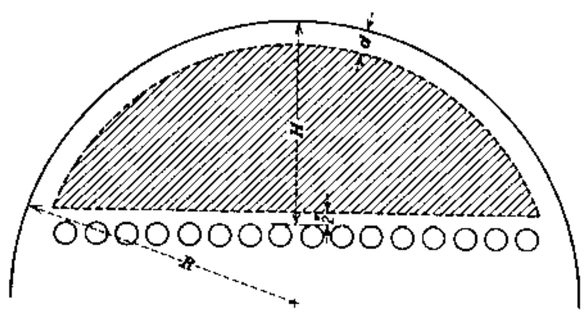

Figure 20
Tubesheet Area to be Stayed

The shaded area in Fig. 20 represents the area that must be supported above the tubes. There will also be a similar area below the tubes. The area containing the tubes is supported by the tubes themselves.

The area above the tubes is usually supported by **diagonal** stays, such as illustrated in Fig. 21.

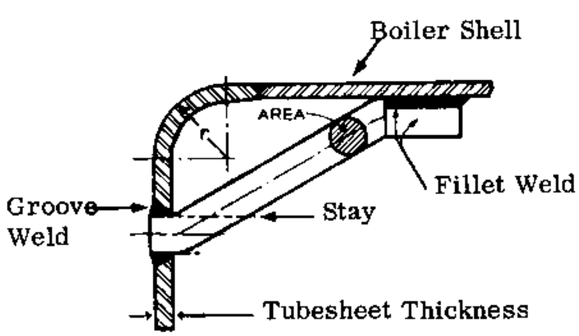

Figure 21
Diagonal Stay

As shown in Fig. 21, the diagonal stay is welded to the boiler head or tubesheet and to the boiler shell. In this way bulging of the flat tubesheet is prevented.

The area below the tubes is often supported by **longitudinal,** or **through,** stays which are long rods extending from the rear tubesheet to the front tubesheet. These stays are usually fastened to the tubesheets by welding or by means of nuts and washers as shown in Fig. 22.

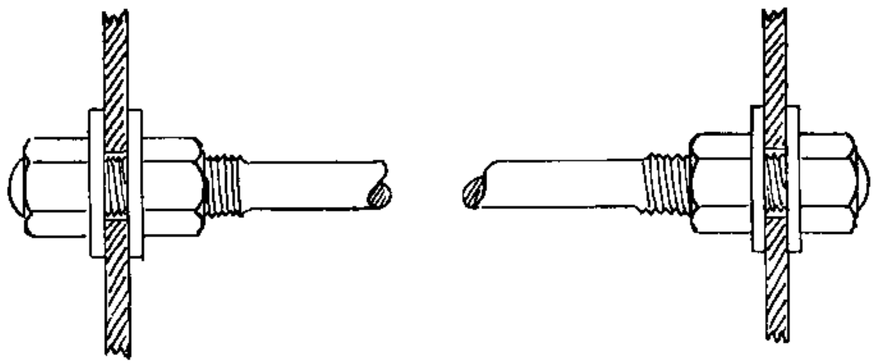

Figure 22
Through Stay Attached With Nuts and Washers

In the case of the rear tubesheet of an HRT boiler, the through stays are fastened by means of angle braces which distribute the stress over a large area. This method is shown in Fig. 23.

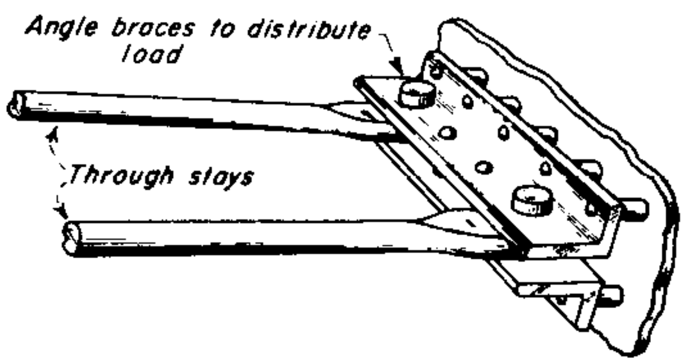

Figure 23
Angle Brace Attachment

In the case of a boiler featuring a waterleg such as the locomotive type or the firebox type, the flat sides of the waterleg must be supported by short stays known as staybolts. These are welded into position in the waterleg sides as shown in Fig. 24.

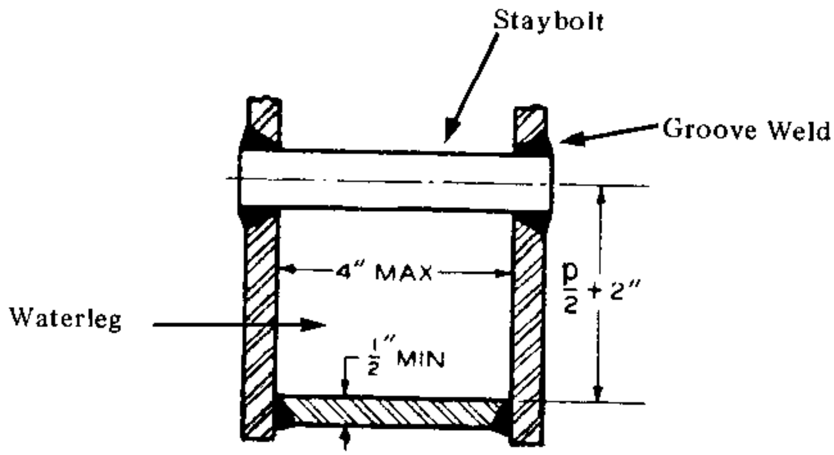

Figure 24
Waterleg Staybolt

ACCESS AND INSPECTION OPENINGS

In order to carry out inspection, cleaning and repair, it is necessary to provide access to various parts of the boiler. **Manholes** or **manways** are provided to allow entry into drums and **handholes** give access to smaller parts such as headers and waterlegs.

Manhole and handhole openings are usually elliptical in shape but may be circular. The size of an elliptical manhole must not be less than 280 mm by 380 mm or, alternately in different shapes, 250 mm by 405 mm. The diameter of a circular manhole must not be less than 380 mm. Handholes must not be less than 70 mm by 89 mm and it is recommended that larger sizes be used.

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When the boiler is in service, the manhole and handhole openings are closed by means of doors or cover plates. These doors, or covers, fit on the inside of the drum or header and are held in place by means of bolts and yoke pieces. When the boiler is in operation the pressure within the boiler helps to hold the door in place.

Fig. 25 shows the location of the manholes in a two drum packaged water-tube boiler.

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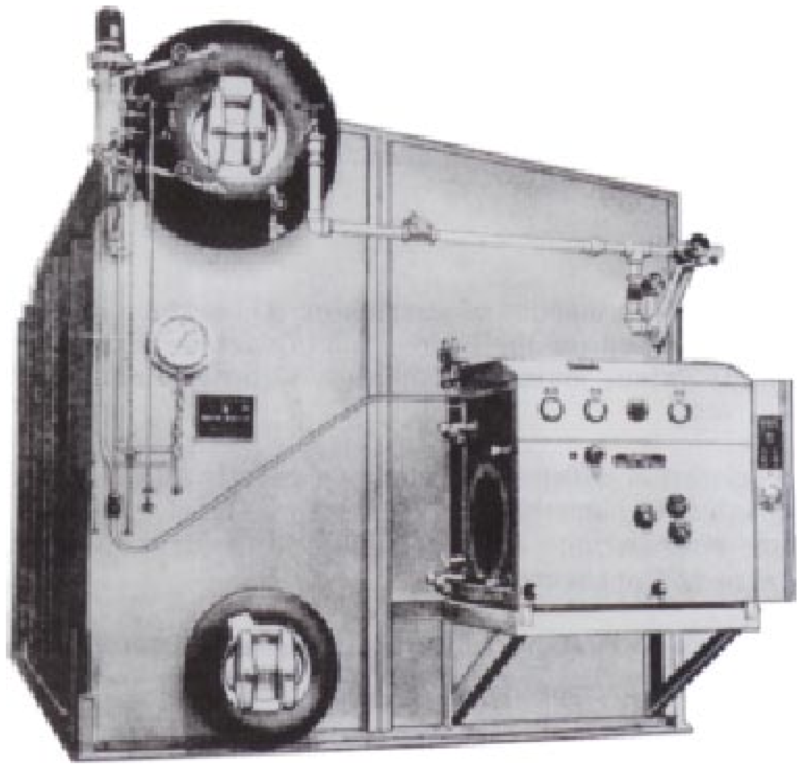

Figure 25
Packaged Boiler Showing Manhole Covers

Fig. 26 shows the general construction of a manhole cover.

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Figure 26
Manhole Cover

DRUM CONNECTIONS

Drum connections consist of nozzles or stubs, which are attached to the drum. They are used for connecting various fittings and attachments such as the safety valve, main steam outlet, water column, feedwater inlet, and pressure gage.

These connection nozzles or stubs are usually attached to the drum by welding, although on older boilers, they may be riveted. In some cases, threaded connections are screwed into the drum wall via a threaded hole, but these are restricted as to size and pressure.

As mentioned previously, tubes are frequently attached to drums by expanding but for higher pressure, welded tube stubs are used. Fig. 27 shows the types of welds used for attachment of nozzles that would hold safety valves and steam outlet connections.

Fig. 28 illustrates the welding of tube stubs to square and round headers.

The round header in Fig. 29 shows the arrangement of the welded tube stubs to which the tubes themselves are welded. Note that the handholes are welded into place because the header is designed for high pressures.

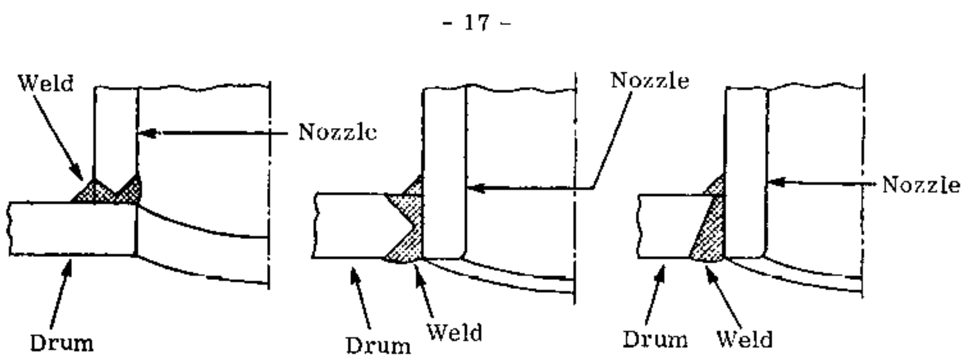

Figure 27
Welded Nozzle Attachments

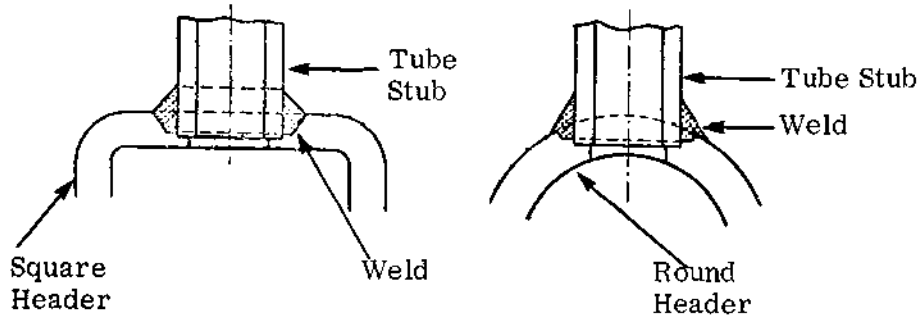

Figure 28
Welded Tube Attachments

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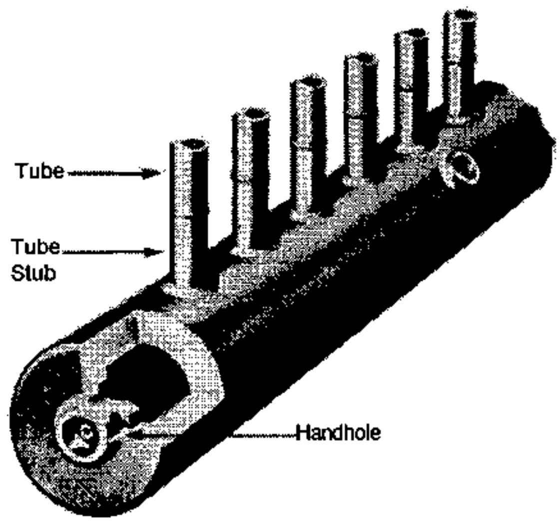

Figure 29
Header with Welded Tube Stubs

INTERNAL FURNACES

In the case of a firetube boiler having an internal furnace contained within the shell, the pressure within the boiler acts upon the outside of the furnace tending to collapse it. In order to maintain Code required strength with the use of thinner metal it is usually made in a corrugated form such as is shown in Fig. 30 and Fig. 31.

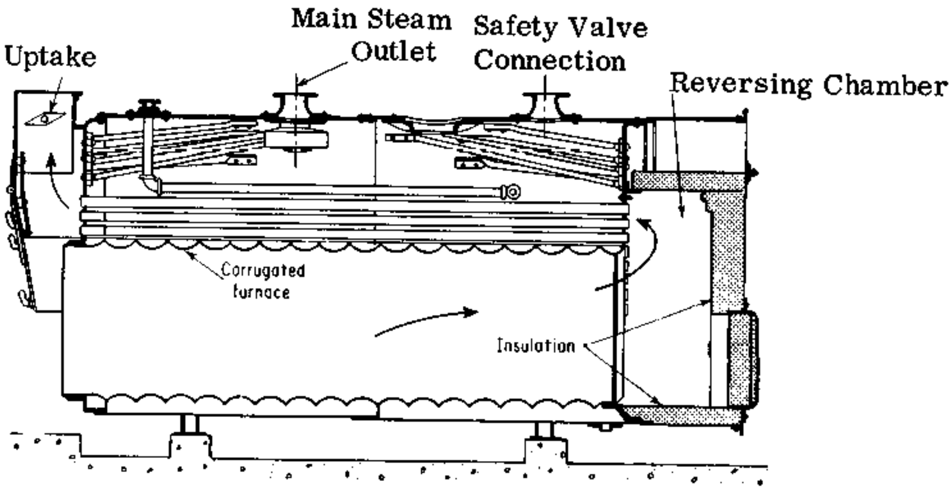

Figure 30
Internal Furnace Firetube Boiler

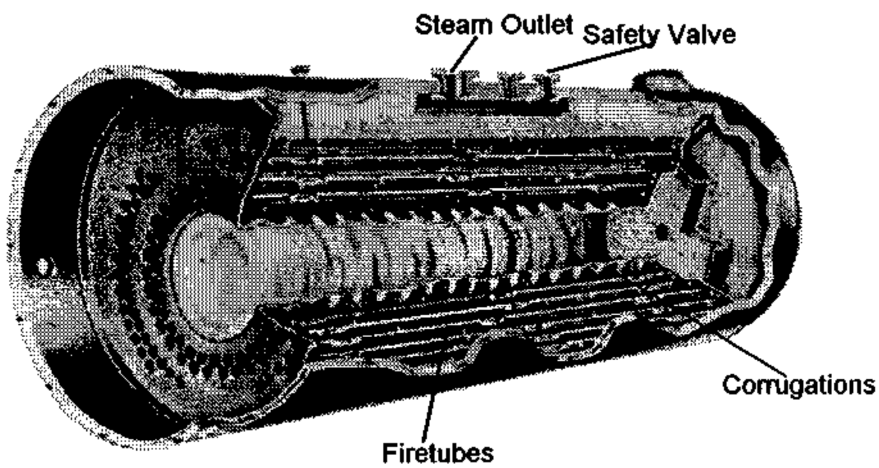

Figure 31
Packaged Firetube Boiler with Corrugated Furnace

Fig. 32 shows various cross section designs of corrugated and ring reinforced furnaces.

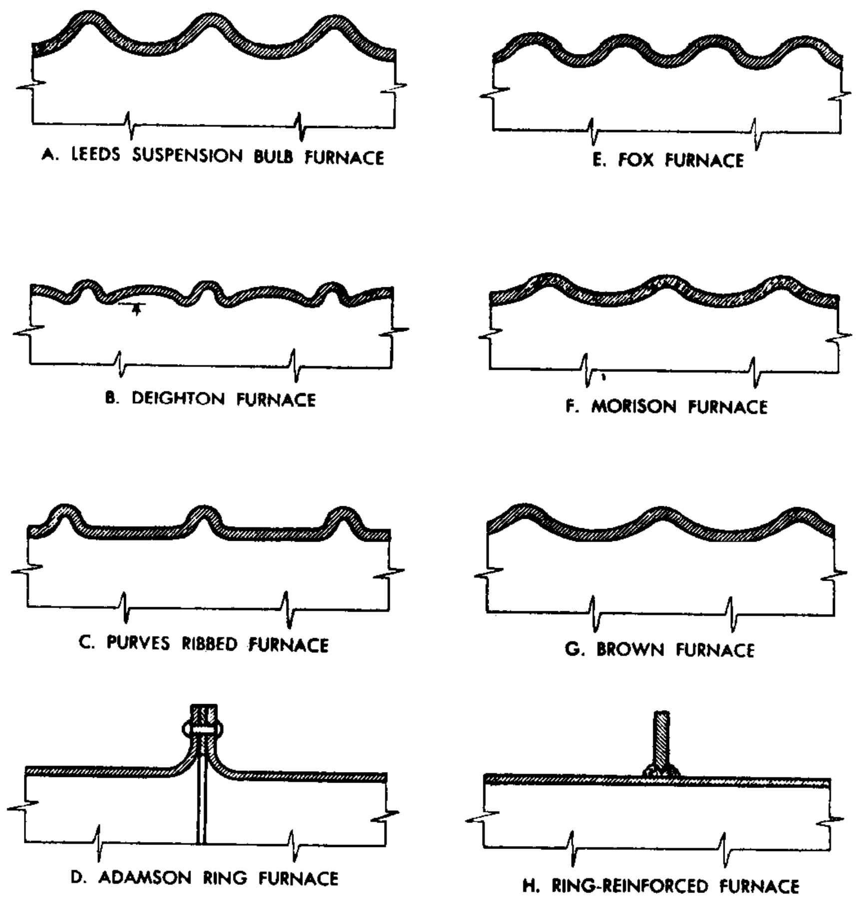

Figure 32
Furnace Designs

Fig. 33 shows methods of attaching furnaces to the boiler head by welding.

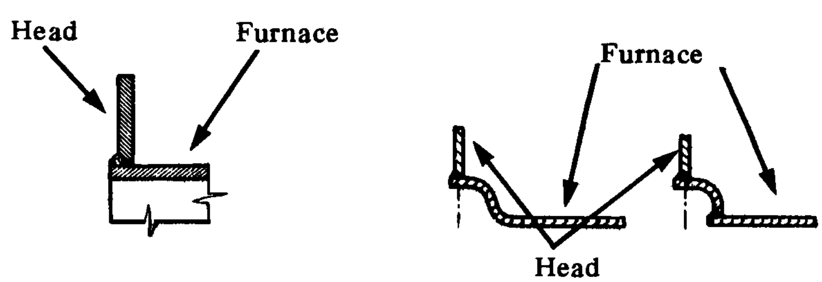

Figure 33
Furnace Welded Attachments

FOUNDATIONS AND SUPPORTS

Adequate foundations and supports are required for boilers in order to avoid any movement, which would put extra stress on the boiler and its connecting pipework. Also, for example, if the boiler settles at one end, the gage glass will not give an accurate indication of the water level in the boiler.

In the case of a packaged firetube boiler, the boiler room floor must be strong enough to act as a foundation because the boiler is usually mounted on a skid type steel base. The whole assembly can then be placed directly on the floor by an overhead crane as shown in Fig. 34.

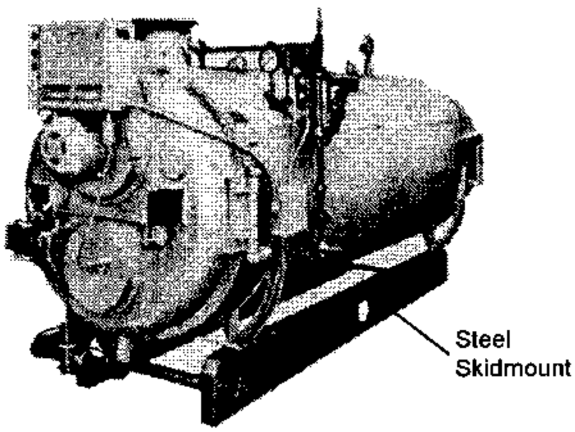

Figure 34
Floor Mounted Packaged Firetube Boiler (Cleaver Brooks)

Packaged watertube boilers are also frequently floor mounted as shown in Fig. 35.

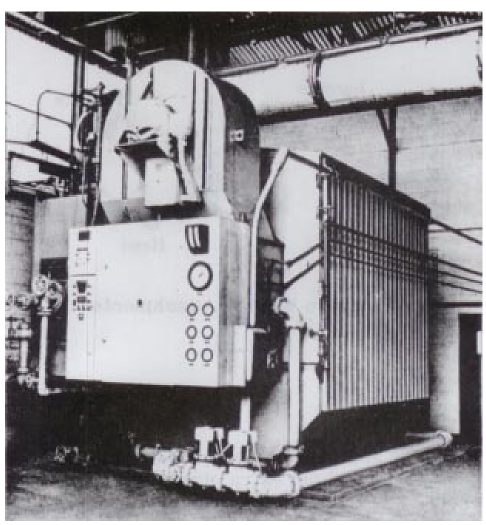

Figure 35
Watertube Boiler

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For large boilers, other than the packaged type and those that are built on-site, it is usually necessary to provide special concrete foundations. These large boilers may be either top-supported or bottom-supported. A top-supported boiler is shown in Fig. 36.

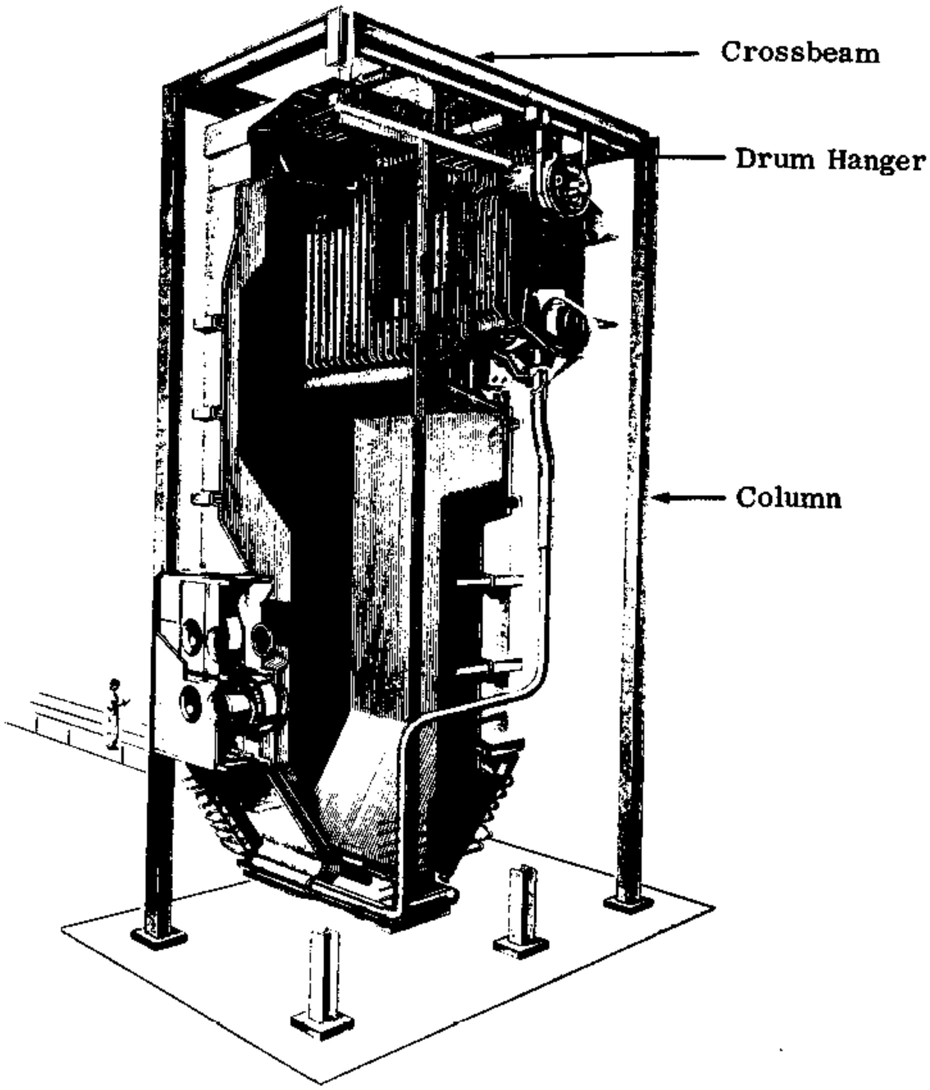


Figure 36
Top Supported Boiler

The bottom-supported boiler in Fig. 37 has concrete piers which support the bottom drum and bottom headers. The boiler tubes themselves are used to support the top drum.

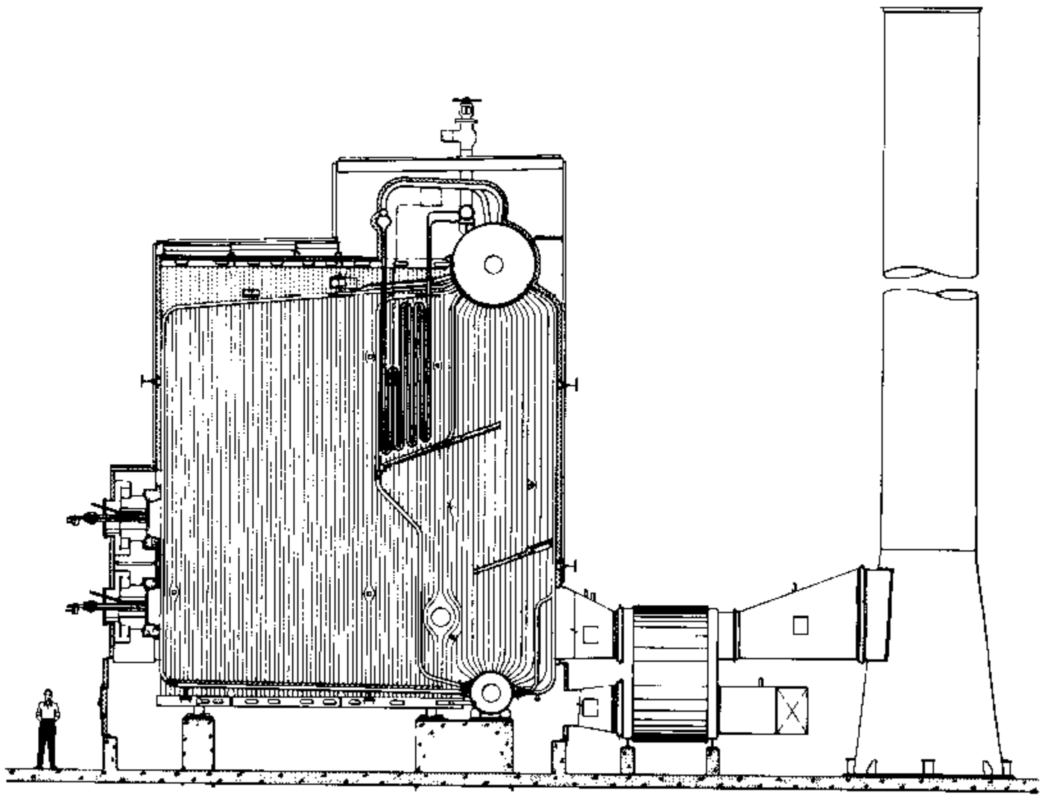
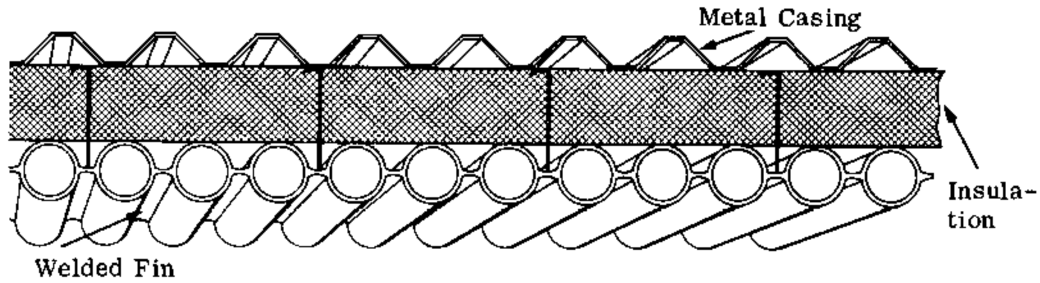


Figure 37
Bottom Supported Boiler

WATERCOOLED FURNACE WALLS

The furnace walls of early boilers such as the straight tube watertube boiler were made of brick. This brickwork has been eliminated in the modern watertube boiler by using the tubes to form the furnace walls. This type of furnace wall is called a **watercooled wall** or a **waterwall**.

Fig. 38 illustrates a modern design of watercooled furnace wall. Adjacent tubes are welded to metal fins to produce a solid panel, which is exposed to the furnace heat. The welded tubes and fins are backed by a layer of insulation and then an outer metal casing to protect the insulation. This construction is shown in Fig. 38(a). Fig. 38(b) shows details of the welded tubes.



(a)

(b)

Figure 38(a) (b)
Welded Fin Tube Waterwall (Combustion Engineering)

Other designs of watercooled furnace walls are seen in Fig. 39 and Fig. 40.

In the **tangent-tube wall** in Fig. 39, the inside of the furnace wall is made up of tubes which are side by side and touching each other to form a continuous surface. These tubes are backed by a layer of plastic insulation and then a steel casing. Block insulation is then placed against the steel casing and another steel casing forms the outside surface of the wall.

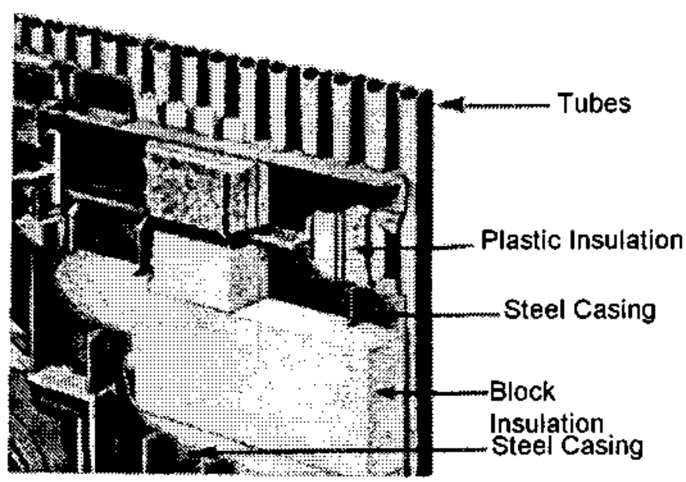


Figure 39
Tangent-Tube Wall

In the flat stud wall in Fig. 40, the tubes have flat studs welded to them on each side and these studs fill the space between adjacent tubes. The tubes and studs are backed up by refractory and insulation as shown in the illustration.

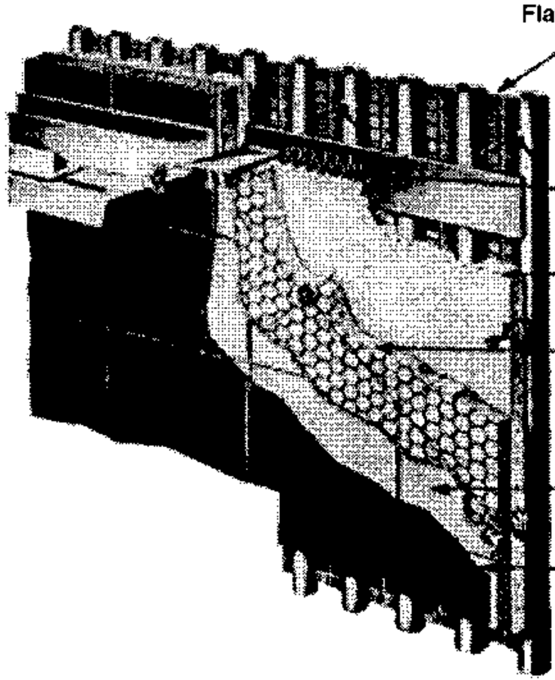


Figure 40
Flat Stud Tube Wall (Babcock and Wilcox)

Notes: