

JIS

JAPANESE INDUSTRIAL STANDARD

Construction of Steel Boilers for Land Use

JIS B 8201—1987

Translated and Published

by

Japanese Standards Association

Printed in Japan

In the event of any doubt arising,
the original Standard in Japanese is to be final authority.

Contents

	Page
1. General	1
2. Definitions of Terms	2
3. Materials	5
3.1 Materials in General	5
3.2 Restriction in Using Materials	6
3.3 Allowable Stress of Materials	7
3.4 Strength of Welded Zones to be Used in Calculations	8
3.5 Allowable Compressive Stress to be Used in Calculations	8
3.6 Allowable Shearing Stress to be Used in Calculations	8
4. Construction in General	8
4.1 Construction in General	8
4.2 Maximum Working Pressure for Each Portion	8
4.3 Hydrostatic Test	8
4.4 Methods of Hydrostatic Tests	9
4.5 Hydrostatic Proof Tests and Maximum Working Pressure for Special Shaped Portions	9
5. Shells	11
5.1 Thickness Limits of Shells	11
5.2 Minimum Thickness of Shells under Internal Pressure	11
5.3 Circumferential Joints of Shells	12
5.4 Efficiency of Ligaments between Tube Holes	13
5.5 Strength of Ligaments between Tube Holes Arranged in Longitudinal Direction	13
5.6 Strength of Ligaments between Tube Holes Arranged in Circumferential Direction	14
5.7 Strength of Ligaments between Tube Holes Arranged in Diagonal Direction	14
5.8 Efficiency of Ligaments between Tube Holes Arranged in Several Groups along Longitudinal Direction	14
5.9 Efficiency of Ligaments between Tube Holes Arranged Irregularly	14
5.10 Minimum Thickness of Spherical Shells	17
5.11 Minimum Thickness of Conical Shells	17
6. Head Plates and Flat Plates	21
6.1 Thickness Limits of Head Plates	21

	Page
6.2 Restrictions for Shapes of Heads	21
6.3 Minimum Thickness of Dished Heads or Full-Hemispherical Heads with the Pressure on the Concave Side, without Stay	22
6.4 Minimum Thickness of Semi-Ellipsoidal Heads with Pressure on the Concave Side	23
6.5 Openings in Heads without Compensation	23
6.6 Falt Heads	23
6.7 Minimum Thickness of Unstayed Dished Heads with the Pressure on the Convex Side	24
6.8 Minimum Thickness of Unstayed Flat Plates	24
6.9 Unstayed Flat Heads with Openings	27
7. Tube Sheets	28
7.1 Minimum Thickness of Tube Sheets Where Tubes are Rolled	28
7.2 Minimum Thickness of Tube Sheets of Fire-Tube Boilers	28
7.3 Minimum Thickness of Flat Tube Sheets of Fire-Tube Boilers ...	28
7.4 Minimum Pitch of Fire Tubes of Fire Tube Boilers	31
7.5 Reinforcements for Lower Portions of Tube Sheets in Externally-Fired Horizontal Tubular Boilers	31
7.6 Minimum Thickness of Tube Sheets in Combustion Chambers	31
7.7 Fillet-Welding for Tube Sheets of Fire-Tube Boilers	31
7.8 Mounting of Flat Tube Sheets or Flat Head Plates to Flue for Flue Boilers	32
8. Fire Boxes and Furnaces	32
8.1 Thickness Limitations of Fire Boxes and Furnaces	32
8.2 Seams of Cylindrical Fire Boxes or Furnaces	32
8.3 Minimum Thickness of Cylindrical Fire Boxes or Plain Furnaces	32
8.4 Stack Tubes for Vertical Boilers	33
8.5 Flanges for Plain Horizontal Furnaces with Adamson Rings	33
8.6 Minimum Thickness of Corrugated Furnaces	33
8.7 Clearances between Furnaces and Fire Tubes	34
8.8 Welding of Fire Box Sheets	34
9. Stays and Stayed Plates	35
9.1 Load Supported by Stays or Stay Tubes	35
9.2 Limits for Pitches of Stays	36
9.3 Strength of Plates Supported by Stays	36
9.4 Strength of Plates with Doubling Plates	38
9.5 Attachment of Stay Bolts	38

	Page
9.6 Telltale Holes in Stay Bolts	38
9.7 Strength of Stay Bolts and Bar Stay	38
9.8 Strength of Stay Tubes	38
9.9 Attachment of Stay Tubes	39
9.10 Nuts on Stays	39
9.11 Attachment of Bar Stays	39
9.12 Attachment of Stays by Pin Joints	39
9.13 Strength of Diagonal Stays	39
9.14 Strength of Gusset Stays	40
9.15 Construction of Girder Stays	40
9.16 Minimum Thickness of Girder Stays	40
9.17 Strength of Sling Stays	40
9.18 Attachment of Stays by Welding	41
10. Openings	41
10.1 Manholes, Cleaning Holes, Inspection Openings and Their Sizes	41
10.2 Direction of Elliptical Openings	41
10.3 Substitutions for Manholes	41
10.4 Manholes for Externally-Fired Horizontal Tubular Boilers	41
10.5 Cleaning Holes and Inspection Openings for Combined Furnace and Fire-Tube Boilers	41
10.6 Cleaning Holes for Vertical Boilers or Vertical Cross-Tube Boilers	41
10.7 Bearing Surfaces of Gasket and Thickness of Gasket for Manholes and Handholes	42
10.8 Minimum Thickness of Manhole Covers	42
11. Compensations for Openings	43
11.1 Openings Not Requiring Compensations	43
11.2 Calculations for Compensations	46
11.3 Effective Limits of Compensations	49
11.4 Effective Areas of Compensations	49
11.5 Compensations for Multiple Openings	50
11.6 Strength of Reinforcing Members	51
11.7 Strength of Welds Attaching Reinforcing Members	51
12. Tubes, Headers, Nozzles and Flanges	51
12.1 Strength of Fire Tubes	52
12.2 Minimum Thickness of Water Tubes, Superheater Tubes, Reheater Tubes, Steel Economizer Tubes, etc.	52

	Page
12.3 Minimum Value of Thickness of Fire Tubes, Water Tubes, Superheater Tubes, Reheater Tubes, Steel Economizer Tubes, etc.	53
12.4 Minimum Thickness of Steam Pipes	53
12.5 Maximum Working Pressure for Corrugated Steam Pipes	54
12.6 Main Steam Pipes	54
12.7 Minimum Thickness of Feedwater Pipes	54
12.8 Minimum Size of Feedwater Pipes	54
12.9 Minimum Thickness of Blowoff Pipes	55
12.10 Sizes of Blowoff Pipes	55
12.11 Minimum Thickness of Cast-Iron Tubes for Economizers	55
12.12 Strength of Cylindrical Headers	55
12.13 Rectangular Headers	55
12.14 Strength of Nozzles	58
12.15 Flanges	58
12.16 Socket-Type Joints	58
12.17 Attaching of Pipes, Nozzles, etc.	58
12.18 Strength for Attachment of Nozzles	59
13. Welding	59
13.1 Scope of Specification for Welding	59
13.2 Welding Design in General	59
13.3 Qualification and Condition Required for Weld Performer	71
13.4 Welding Materials	71
13.5 Performance of Welding	72
13.6 Postweld Heat Treatment	72
13.7 Mechanical Tests of Welds	73
13.8 Non-Destructive Tests of Welds	76
14. Workmanship and Installations	77
14.1 Cutting Plates	77
14.2 Forming of Shell Plate Ends	77
14.3 Local Heating	77
14.4 Roundness of Shells and Heads	77
14.5 Deviation in Dished Head or Semi-Ellipsoidal Heads	79
14.6 Thickness of Flanges of Heads	79
14.7 Tube Holes	79
14.8 Holes for Staybolts	79
14.9 Attaching of Fire Tubes	79

	Page
14.10 Attachment of Water Tubes, Superheater Tubes and Others	80
14.11 Tubes in Welded Zones	81
14.12 Annealing of Ends of Bar Stay	81
14.13 Requirements for Installations	81
14.14 Attachment of Lugs and Hangers	81
14.15 Protections for Blowoff Piping	81
14.16 Protection for Steel Members and Concretes	81
14.17 Explosion Doors	81
15. Safety Valves	81
15.1 Capacities and Number of Safety Valves	82
15.2 Mountings of Safety Valves	82
15.3 Settings of Safety Valves	82
15.4 Tolerances of Popping Pressures	82
15.5 Blowdown Pressures	82
15.6 Limits of Sizes of Safety Valves and Pressure Relieving Devices	83
15.7 Size of Safety Valves and Pressure Relieving Devices	83
15.8 Safety Valves for Boilers with Superheaters	85
15.9 Safety Valves for Reheaters or Independent Superheaters	85
15.10 Types and Construction of Safety Valves	85
15.11 Area of Steam Passages in Valve Bodies	85
15.12 Discharge Pipes of Safety Valves	85
15.13 Relief Valves and Relief Columns for Hot-Water Boilers	86
15.14 Size of Relief Valves or Safety Valves for Hot-Water Boilers ...	86
15.15 Size of Relief Columns	86
16. Water Gauges, Pressure Gauges and Thermometers	87
16.1 Number of Water Gauges	87
16.2 Construction of Glass Water Gauges	87
16.3 Equipment of Water Gauges	87
16.4 Water Columns	87
16.5 Connections with Water Columns	88
16.6 Connections to Water Gauges	88
16.7 Marking of Normal Water Level	88
16.8 Gauge Cocks	88
16.9 Pressure Gauges	88
16.10 Size and Graduations of Pressure Gauges	88

B 8201-1987

	Page
16.11 Fitting of Pressure Gauges	89
16.12 Fitting of Test Gauges	89
16.13 Altitude Gauges	89
16.14 Thermometers	89
17. Stop Valves and Blowoff Valves	89
17.1 Number of Stop Valves	90
17.2 Stop Valves	90
17.3 Drainages of Valves	90
17.4 Size and Number of Blowoff Valves	90
17.5 Shape and Strength of Blowoff Valves	90
18. Feedwater Installations	90
18.1 Feedwater Installations	91
18.2 Kinds of Feedwater Installations	91
18.3 Feedwater Installation for Multiple Boilers	91
18.4 Feedwater Valves and Check Valves	91
18.5 Size of Feedwater Valves	92
18.6 Places of Feeding Water Valves	92
18.7 Automatic Feedwater Regulators	92
18.8 Automatic Fuel Cutoff Devices for Once-Through Boilers	92
19. Marking	92
Attached Table	93
Applicable Standards	107

JAPANESE INDUSTRIAL STANDARD

J I S

Construction of Steel Boilers for Land Use

B 8201-1987

1. Scope

This Japanese Industrial Standard specifies the steel steam boilers and hot-water boilers for land use, hereinafter referred to as the "boiler(s)", together with the auxiliary equipments.

- (1) Boilers include those used for mobile services and wagon uses except railway rolling stocks.
- (2) Boilers do not include the following:
 - (a) Boilers used for locomotives and other railway rolling stock services.
 - (b) Electric boilers. However, this standard is applicable to their mechanical components.
 - (c) Steam boilers serviceable at not exceeding $1 \text{ kgf/cm}^2 \{0.1 \text{ MPa}\}$ maximum working pressure and with shell inside diameter not exceeding 200 mm and shell length not exceeding 400 mm or with heating surface not exceeding 0.5 m^2 .
 - (d) Hot water boilers not exceeding 10 m $\{0.1 \text{ MPa}\}$ water head and with heating surface not exceeding 4 m^2 .
- (3) This Standard is applicable to the following boilers as far as there is no inconsistency in their construction.
 - (a) High pressure or high temperature steam boilers constructed of principal materials not specified in this Standard.
 - (b) Boilers with special construction.
- (4) Boilers shall include a steam supply stop valve, its relating stop valve, feed water valve (which means the valve located between the boiler and economizer, or a valve located at the economizer inlet if foregoing valve is not available), its relating check valve and blowoff valve (which means the valve located far from the boiler body when two valves are installed) and also include the boiler body, superheater, economizer, miscellaneous pipings, etc. located between the above-mentioned valves.
- (5) Auxiliary equipments include an independent superheater, reheater, economizer (when a stop valve is installed between the boiler and economizer), main steam piping, feedwater piping, blowoff piping and other similar pipings.

Remark: Units and numerical values given in { } in this Standard are based on the International System of Units (SI) and given for informative reference.

Applicable Standards: See pages 107 and 108.

2. Definitions of Terms

The principal terms used in this Standard are defined as follows, in addition to the definitions specified in JIS B 0126.

- (1) boiler The equipment in which steam or hot water can be generated by fire, combustion gas or other high temperature gases, hereinafter referred to as the "combustion gas".
- (2) pressure The pressure higher than the atmospheric pressure, which means pressures to be indicated at pressure gauges.
- (3) maximum working pressure of boiler The pressure which does not exceed the minimum value among the maximum working pressures of various component portions of the boiler, and at which, it is specified the boiler is serviceable safety on the constructional basis of boiler. The pressure means a pressure measured at the boiler shell (at the outlet for the once-through boiler).
- (4) minimum thickness The thickness calculated by the formula specified in this Standard, which contains thickness (which means corrosion or erosion allowance).
- (5) heating surface The area of the surface one side of which is in contact with combustion gas and another side of which is in contact with water (including mixture of air and water wet steam), and which is measured at the combustion gas side. Those of superheaters and economizers are excluded unless otherwise provided.

For water-tube boilers, the heating surface of boiler body shall be calculated as follows:

- (a) The area measured at the combustion gas side of the surface of shell, water tube or header one side of which is in contact with combustion gas and other side of which is in contact with water (including the mixture of air and water) [Fig. 2.1 (a), (b), (c), (d) and (e)].
- (b) For longitudinally finned tube both sides of which are in contact with combustion gas, the area made by adding to the outside surface area of the tube the product obtained by multiplying one side surface area of the fin by a coefficient specified in Table 2.1 according to the kind of heat transfer [Fig. 2.1 (f)].

Table 2.1

Kind of heat transfer	Coefficient (α)
When both side surfaces are exposed to radiation	1.0
When one side surface is heated by radiation and another side by convection	0.7
When both side surfaces are heated by convection	0.4

- (c) For longitudinally finned tube, one side of which is in contact with combustion gas, the area made by adding the product obtained by multiplying one side surface area of the fin by a coefficient specified in Table 2.2 according to the kind of heat transfer to the tube outside area contacted to combustion gas [Fig. 2.1 (g)].

Table 2.2

Kind of heat transfer	Coefficient (α)
When heated by radiation	0.5
When heated by convection	0.2

- (d) For circumferentially or spirally finned tube, the area made by adding 20 % of the one side area of the fin (in the case of a spirally finned tube, the area obtained by assuming that the fins are mounted circumferentially by winding number of the actual spirally mounted fin) to the tube outside surface area [Fig. 2.1 (h) (i)].
- (e) For water tubes covered by refractory materials (including fire bricks) one side of which is in contact with combustion gas, the semi-circular area of tubes in the case of the thickness of refractory not more than 10 mm, and the area made of the semi-circular area multiplied by 0.65 in the case of the thickness of refractory over 10 mm and not more than 30 mm.

For the tubes both surfaces or circular area of which is contact with combustion gas, the area two times each of above areas.

In any case, when the thickness of refractory materials exceeds 30 mm, the area made from each of above areas reduced commensurately with the thickness (t mm) and then multiplied by $30/t$ [Fig. 2.1 (j) and (m)].

- (f) For Bailey type water cooled furnace wall, the developed area of the surface which is in contact with combustion gas [Fig. 2.1 (k)].
- (g) For refractory-covered that tubes one side of which is in contact with combustion gas, the semi-circular area of the tube and for the tubes the entire surface of which is in contact, the circular area of the tube. Provided that in the case where the thickness of refractory exceeds 30 mm, the above areas reduced commensurately with the thickness (t mm) and then multiplied by $30/t$ respectively [Fig. 2.1 (l) and (m)].
- (h) For stud tubes which are in contact with combustion gas, the area obtained by adding 15 % of the sum of stud side surfaces to the tube outside surface area [Fig. 2.1 (n)].
- (i) For shells or headers whose surfaces being in contact with combustion gas area covered by refractory, the surface area in case of the thickness of refractory not more than 10 mm, the surface are multiplied by 0.65 in case of the thickness of refractory more than 10 mm and not more than 30 mm and the surface area multiplied by $0.65 \times 30/t$ in case of the thickness of refractory more than 30 mm [Fig. 2.1 (o)].

Fig. 2.1 Heating Surface

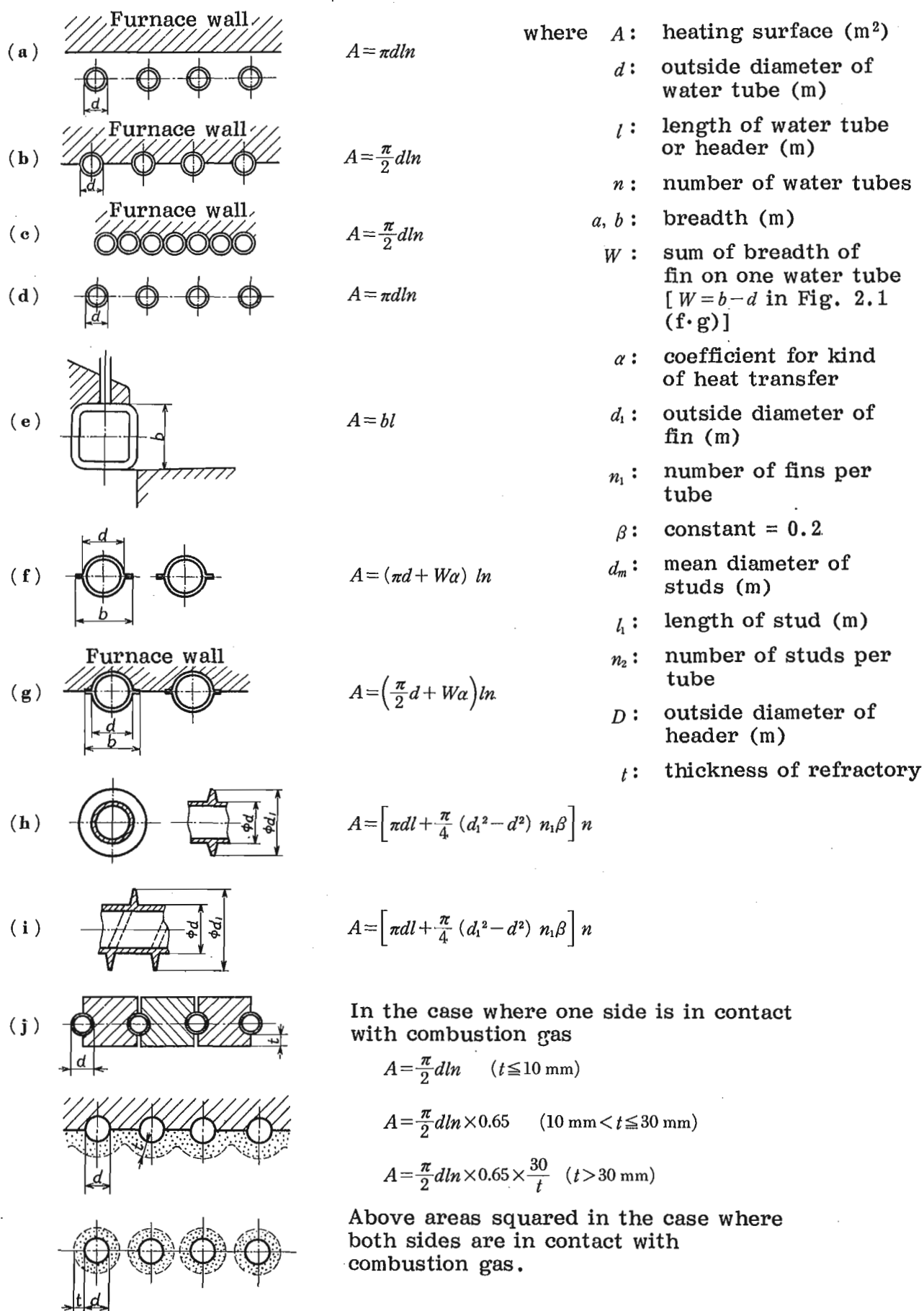
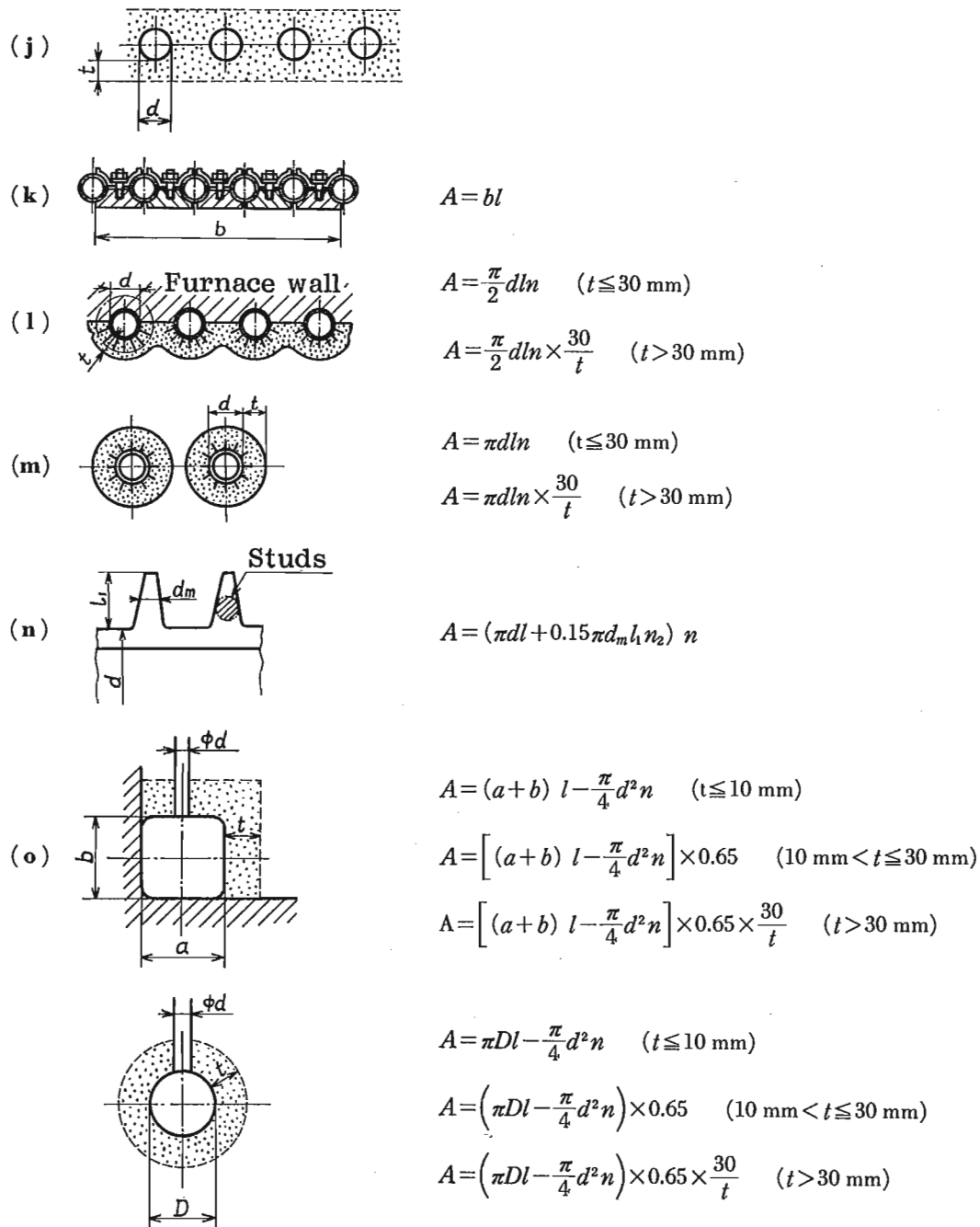


Fig. 2.1 (Continued)



(6) steel material It shall be carbon steel, unless otherwise specified.

(7) fire It shall be the gas considered as under combustion.

3. Materials

3.1 Materials in General Principal materials used in the construction of boilers or auxiliary equipment based on this Standard shall comply with the following specifications, according to the uses.

- (1) Standard Materials Materials specified in this Standard are shown in the columns of standard number and symbol in the attached table.

- (2) Materials conforming to Standard other than those shown in this Standard Materials different from that specified in (1) may be used when it is assured that they are same or superior to the specified material from the viewpoint of quality of boiler. In this case, the manufacturer of boiler shall make an agreement with the purchaser on its specification, and the materials shall conform to the specification.
- (3) Tolerances Though the tolerance of dimension and the tolerance of mass shall be based on the Japanese Industrial Standard specifying each material, the actual thickness shall not be less than the minimum thickness. However, in case of the steel plate, if the actual thickness is less than the minimum thickness it may be used provided that the difference between the actual thickness and the minimum thickness is less than 0.25 mm.

3.2 Restriction in Using Materials Limitation in using materials is as follows:

- (1) Materials shown in the attached tables shall not be used in a condition that the temperature exceeds the range corresponding to the allowable tensile stress values given in the table.
- (2) Materials for welding shall be that whose carbon content does not exceed 0.35 % and which is suitable for welding.
- (3) For the boilers whose maximum working temperature does not exceed 350°C, the following materials may substitute in fabrication of shells, heads and equivalents whose longitudinal or circumferential joint is welded.
 - (a) For the boilers whose maximum working pressure does not exceed 16 kgf/cm² {1.6 MPa}, SPV 24, SPV 32 or SPV 36 specified in JIS G 3115 may be used.
 - (b) For the boilers whose maximum working pressure does not exceed 10 kgf/cm² {1 MPa}, the materials of Class 1 and Class 2 specified in JIS G 3106 may be used.
- (4) Carbon steel pipes for ordinary piping (JIS G 3452) may be used for steam pipings, feedwater pipings and blowoff pipings operating at the maximum work pressure of boiler not exceeding 10 kgf/cm² {1 MPa}. However, when these materials are used for feedwater pipings between boiler body and check valve, and for blowoff pipings between boiler and blowoff valve (when two valves are installed, the one located farther from boiler), it is restricted to the case of the boiler not exceeding 7 kgf/cm² {0.7 MPa} in the maximum working pressure.
- (5) Gray iron castings, pearlitic malleable iron castings, black heart malleable iron castings, malleable iron castings and ductile iron castings shall not be used in the following cases, except economizers.
 - (a) The portion subjected to pressure and exposed to fire.
 - (b) Gray iron castings and pearlitic malleable iron castings: At the portion subjected to the pressure exceeding 16 kgf/cm² {1.6 MPa} or the temperature exceeding 230°C.

- (c) Black heart malleable iron castings, malleable iron castings and ductile iron castings: at the portion subjected to the pressure exceeding 24 kgf/cm^2 {2.4 MPa} or the temperature exceeding 360°C .
- (6) BC 3 of Bronze Castings (JIS H 5111) shall not be used for water and steam at the temperature exceeding 235°C . Other copper alloys may be used for proper portions according to the property of materials.
C 1100 and C 1201 of JIS H 3300 shall not be used for water and steam at the temperature exceeding 206°C . However, using copper as gaskets is allowable.

3.3 Allowable Stress of Materials The allowable tensile stress values of materials to be used in the calculation are shown in attached table. For the materials which are not shown in those tables and approved to be used, the values shall be determined as follows:

- (1) Allowable Tensile Stress at Design Temperature Not Reaching Creep Area
 - (1.1) Iron and Steel Materials Allowable tensile stress of iron and steel materials [except iron castings and steel materials shown in (1.2)] shall be the minimum value among the following ones. However, the austenitized stainless steel materials used as the members for which the fairly large deformation is permissible can take the value of 90 % of 0.2 % offset yield stress at the design temperature.
 - (a) 1/4 of minimum value of tensile strength at ordinary temperature
 - (b) 1/4 of the value of tensile strength at design temperature
 - (c) Minimum yield point or 1/1.6 of 0.2 % offset yield stress at ordinary temperature
 - (d) Yield point or 1/1.6 of 0.2 % offset yield stress at design temperature
 - (1.2) Bolts Allowable tensile stress value of bolt shall be the smallest of the values obtained in (1.1) or the following, in case of the use for iron and steel materials. However, the allowable tensile stress values of the bolts conforming the JIS B 1051 in case of the use for carbon steels and low-alloy steel materials can take 1/3 of the proof load stress corresponding to the strength division given in the Japanese Industrial Standard within the temperature range not exceeding 300°C (not exceeding 250°C in case of free cutting carbon steels).
 - (a) 1/5 of minimum tensile strength at ordinary temperatures
 - (b) Minimum yield point or 1/4 of 0.2 % offset yield stress at ordinary temperature
- (2) Allowable Tensile Stress at Design Temperature within Creep Area
The value shall be the minimum one among the following:

- (a) Mean value of the stress causing the creep of 0.01 % in 1000 h at the design temperature
- (b) 1/1.5 of mean value of the stress causing rupture in 100000 h at the design temperature
- (c) 1/1.25 of minimum value of the stress causing rupture in 100000 h at the design temperature.

3.4 Strength of Welded Zones to be Used in Calculations The strength to be used in calculation for welded zones of steel materials shall comply with the provisions in Clause 13.

3.5 Allowable Compressive Stress to be Used in Calculations The allowable compressive stress of materials to be used in calculations shall be equal to the allowable tensile stress.

3.6 Allowable Shearing Stress to be Used in Calculations The allowable shearing stress of materials to be used in calculations shall be 80 % of the allowable tensile stress.

4. Construction in General

4.1 Construction in General Boilers and auxiliary equipment shall have enough strength, shall support the weight of water filled in and shall be sufficiently safe against the partial stress caused by boiler supports and the heat effect and, moreover, they shall bear the loads on them if they are so constructed as to be loaded.

4.2 Maximum Working Pressure for Each Portion The maximum working pressure for each portion shall be as follows:

- (1) It shall be the maximum working pressure of the boiler or more. However, it shall be not less than the sum of the maximum working pressure of the boiler and the maximum water head to be applied to each portion by circulating or flowing through for forced-circulating boilers or once-through boilers.
- (2) Steam pipings, feedwater pipings and blowoff pipings shall comply with 12.4 to 12.9, and the provisions similar to the foregoing item shall be set up for once-through boilers.
- (3) In any event, it shall be 2 kgf/cm² {0.2 MPa} or more. And, for pipings, feedwater pipings and blowoff pipings, it shall be 7 kgf/cm² {0.7 MPa} or more.

4.3 Hydrostatic Test The boiler shall be confirmed that it is in good order by the hydrostatic test under the following test pressure.

- (1) When the maximum working pressure of the boiler does not exceed 4.3 kgf/cm² {0.43 MPa}, it shall be twice this pressure. However, when the test pressure is less than 2 kgf/cm² {2 MPa}, it shall be 2 kgf/cm² {0.2 MPa}.
- (2) When the maximum working pressure of the boiler exceeds 4.3 kgf/cm² {0.43 MPa} and does not exceed 15 kgf/cm² {1.5 MPa}, it shall be the pressure of 1.3 times this pressure plus 3 kgf/cm² {0.3 MPa}.

- (3) When the maximum working pressure of the boiler exceeds 15 kgf/cm^2 $\{1.5 \text{ MPa}\}$, it shall be 1.5 times this pressure.
- (4) For the once-through boiler at each position of which the maximum working pressure are different, it shall be required, in addition to the requirements given in each item above-mentioned, that the water pressure of 1.25 times the maximum working pressure of each portion are applied to any portion of boiler.
It shall also be required that the stress greater than 0.9 time the yield point (or 0.2 % offset yield stress) of the material is not generated at any point of boiler during the hydrostatic test.
- (5) For hot-water boilers with no possibility of being subjected to pressure higher than the maximum working pressure of the boiler, it shall be this pressure plus 1 kgf/cm^2 $\{0.1 \text{ MPa}\}$. However, it shall be 2 kgf/cm^2 $\{0.2 \text{ MPa}\}$ when the test pressure is less than 2 kgf/cm^2 $\{0.2 \text{ MPa}\}$.

4.4 Methods of Hydrostatic Tests Safety valves, except ones attached by welding, shall be removed or blinded by inserting plate beneath the valves, and sealed. After air is thoroughly vented and water is poured so that it is in contact with all the parts, pressure shall be gradually elevated up to the test pressure and this condition shall be held until the inspections finish. In this case, the hydrostatic test pressure shall be controlled not to exceed 6 % above the specified test pressure. During and after the hydrostatic test, attention shall be taken to prevent the freezing of water.

Castings shall be inspected for pinholes, blowholes and cracks after machining by applying the specified test pressure for 10 min or longer according to the thickness.

4.5 Hydrostatic Proof Tests and Maximum Working Pressure for Special Shaped Portions The maximum working pressure permitted to a portion for which the strength cannot be calculated owing to the special shape, position of opening, etc. shall be established by a hydrostatic proof test. The hydrostatic proof test shall be in accordance with one of the following methods. Of these methods (1) strain measurement test and (2) displacement measurement test shall be applicable only to the elastic materials as carbon steels or alloy steels, stress and strain are approximately proportional under the yield strength, and the ratio of minimum specified value of the yield strength to the minimum specified value of the tensile strength is 0.625 or smaller.

(1) Method of Strain Measurement Tests

- (1.1) This method may be performed by installing resistance strain meters or measuring devices of other types capable of measuring strain to 0.005 % at several points presumed to be the weakest portions, and by applying or releasing the hydrostatic pressure.
- (1.2) At first, the hydrostatic pressure shall be increased to approximately half the anticipated maximum working pressure. And after reading and recording the strains at each point and the pressure, the hydrostatic pressure shall be released to zero and the strains shall be read and recorded. Again, the hydraulic pressure shall be increased by approximately 1/10 of the anticipated maximum working pressure plus the approximately 1/2 of the hydraulic pressure, and the same process shall be conducted.

Thereafter, the same pressure (1/10 of the maximum working pressure) shall be increased stepwise and the same procedure shall be repeated.

- (1.3) When the permanent strain is caused on any point or the test pressure has reached the hydrostatic pressure (P_0) which is calculated by clause (1.4) by the anticipated maximum working pressure, the test shall be terminated. This test shall be so performed that the permanent strain does not exceed 0.2 %.
- (1.4) The maximum working pressure shall be calculated by the following formulae.
- (a) When the actual yield strength of the material is examined by the test piece,

$$P = 0.5 \times P_0 \times \frac{Y_a}{Y_0} \times \frac{\sigma_a}{\sigma_0}$$

- (b) When the actual yield strength is not examined

$$P = 0.4 \times P_0 \times \frac{\sigma_a}{\sigma_0}$$

where in common

P : maximum working pressure (kgf/cm²) {MPa}

P_0 : hydrostatic pressure at the test termination (kgf/cm²) {MPa}

Y_a : specified minimum value of the yield strength (kgf/mm²) {N/mm²}

Y_0 : actual yield strength on the test piece (kgf/mm²) {N/mm²}

σ_a : allowable tensile stress of the material at the temperature in service (kgf/mm²) {N/mm²}

σ_0 : allowable tensile stress of the material at the test temperature (kgf/mm²) {N/mm²}

(2) Method of Displacement Measurement Tests

- (a) This method may be performed by installing a dial gauge or a measuring device capable of measuring displacement to 0.25 mm, between several selected points presumed to be the weakest portions, or between these points and the fixed point, and by applying or releasing the hydrostatic pressure.
- (b) Applying, measuring, and recording of the hydrostatic pressure shall conform to (1) (1.2).
- (c) When the permanent strain is caused on any point or the displacement curve comes off a straight line of pressure-displacement curve, the test shall be terminated.
- (d) The maximum working pressure shall conform to (1) (1.4). And for the material made by carbon steels with the specified minimum value of tensile strength not exceeding 50 kgf/mm² {490 N/mm²}, it may be calculated by the following formula.

$$P = 0.5 \times P_0 \times \frac{\sigma}{\sigma + 3.5} \times \frac{\sigma_a}{\sigma_0}$$

where σ : specified minimum value of the tensile strength (kgf/mm²) {N/mm²}

P , P_0 , σ_a and σ_0 are as defined in (1) (b).

(3) Method of Burst Tests

(a) This method shall be performed by stepwise increasing the hydrostatic pressure up to failure by rupture on the test model of the same material, shape and size as the pressured part for which the maximum working pressure is sought.

(b) The maximum working pressure shall be as follows:

$$P = 0.2 \times B \times \frac{\sigma}{(\sigma_t \text{ OR } \sigma_m)} \times \frac{\sigma_a}{\sigma_0}$$

where B : bursting pressure (kgf/cm²) {MPa}

σ_t : actual tensile strength of the test piece (kgf/mm²) {N/mm²}

σ_m : specified maximum value of the tensile strength (kgf/mm²) {N/mm²}

P , σ_a and σ_0 are as defined in (1) (1.4) and σ as in (2) (d).

(4) Method for Portions Subjected to External Pressure When the pressured part has not been deformed remarkably by the external hydrostatic pressure not less than 3 times the anticipated maximum working pressure at the pressure elevating period, and has not been permanently deformed at the pressure decreasing period, the anticipated maximum working pressure may be used as the maximum working pressure.

5. Shells

5.1 Thickness Limits of Shells The minimum thickness of shells shall be the following values or more:

- (1) 6 mm for shells not exceeding 900 mm in inside diameter. But 8 mm for shells fitted with a stay.
- (2) 8 mm for shells exceeding 900 mm and not exceeding 1350 mm in inside diameter.
- (3) 10 mm for shells exceeding 1350 mm and not exceeding 1850 mm in inside diameter.
- (4) 12 mm for shells exceeding 1850 mm in inside diameter.

5.2 Minimum Thickness of Shells under Internal Pressure The minimum thickness of the cylindrical portion of a shell or header under internal pressure shall be determined by the following formula:

- (1) In the case based upon outside diameter

$$t = \frac{PD_o}{200\sigma_a\eta + 2kP} + \alpha \quad \left\{ t = \frac{PD_o}{2\sigma_a\eta + 2kP} + \alpha \right\}$$

(2) In the case based upon inside diameter

$$t = \frac{PD_i}{200\sigma_a\eta - 2P(1-k)} + \alpha \quad \left\{ t = \frac{PD_i}{2\sigma_a\eta - 2P(1-k)} + \alpha \right\}$$

where, in (1) and (2)

t : minimum thickness of the shell (mm)

P : maximum working pressure (kgf/cm²) {MPa}

D_o : outside diameter of the portion where t is calculated (mm)

D_i : inside diameter of the portion when t is calculated (mm)

σ_a : allowable tensile stress of the material (kgf/mm²) {N/mm²}

η : efficiency of the longitudinal joint or ligament between openings. However, when the distance between an opening and the deposited metal of a welded longitudinal joint is 6 mm or under, or an opening is perforated on the longitudinal joint, it shall be the product of the efficiency of the affecting welded joint and the efficiency of the ligament between openings.

α : 1 mm or more as additive thickness

k : as shown in Table 5.1.

Table 5.1

Material \ Temperature °C	480 or under	515	535	565	590	620 or over
Ferritic steel	0.4	0.5	0.7	0.7	0.7	0.7
Austenitic steel	0.4	0.4	0.4	0.4	0.5	0.7

Remark: Value of k at the point between listed temperatures may be determined by proportional calculation.

(3) When the thickness of the shell exceeds 1/2 of the inside radius and the temperature does not exceed 374°C, the following formula shall be used, regardless of (1) and (2):

$$t = R(\sqrt{Z} - 1) + \alpha$$

$$Z = \frac{100\sigma_a\eta + P}{100\sigma_a\eta - P} \quad \left\{ Z = \frac{\sigma_a\eta + P}{\sigma_a\eta - P} \right\}$$

where R : t inside radius of the portion to be calculated (mm),
 t , P , σ_a , η and α are as defined in 5.2 (1) and (2).

5.3 Circumferential Joints of Shells The circumferential joint of shell shall have the strength 50 % or more of the strength of the longitudinal joint. However, the strength of the circumferential joint in the following cases shall be 35 % or more of the strength of longitudinal joint.

- (1) When the area of a head under pressure is diminished due to mountings of smoke tubes or longitudinal stays, and because the head is held by smoke tubes or longitudinal stays the longitudinal force acting on circumferential joint is 50 % or under of that to be obtained in the case of having none of them.
- (2) A circumferential joint connecting a head with a shell in the case that the area of the head under pressure is 50 % or under of the cross-sectional area of the shell.

5.4 Efficiency of Ligaments between Tube Holes The provisions of 5.5 to 5.9 for the efficiency of ligaments shall be applied to the holes which require no reinforcement according to 11.1. When the holes are reinforced by 11.2 to 11.4, they shall not be applied.

And these provisions shall be applied also to the holes similar to tube holes.

5.5 Strength of Ligaments between Tube Holes Arranged in Longitudinal Direction When tube holes are arranged in a shell longitudinally along a straight line, the efficiency of this portion of shell shall be determined as follows:

- (1) When Pitches of Tube Hole Are Equal (Fig. 5.1) The efficiency of this portion shall be determined by the following formula:

$$\eta = \frac{p-d}{p}$$

where η : efficiency
 p : pitch of the tube holes (mm)
 d : diameter of the tube hole (mm)

- (2) When Pitches of Tube Holes Are Unequal (Figs. 5.2 and 5.3) The efficiency of this portion shall be determined by the following formula:

$$\eta = \frac{l-nd}{l}$$

where η : efficiency
 l : length of the part forming a unit containing unequal pitches (mm)
 d : diameter of the tube hole (mm)
 n : number of the tube holes in length l

Fig. 5.1 Arrangement of Tube Holes with Equal Pitches

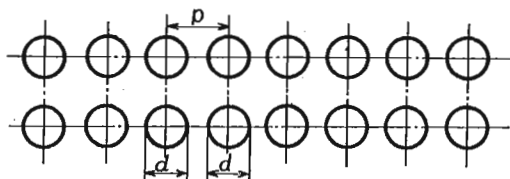


Fig. 5.2 Arrangement of Tube Holes with Unequal Pitches (1)

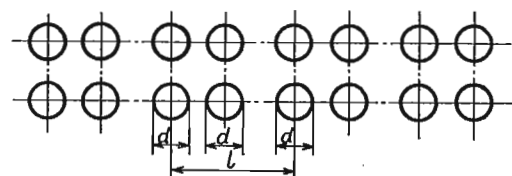
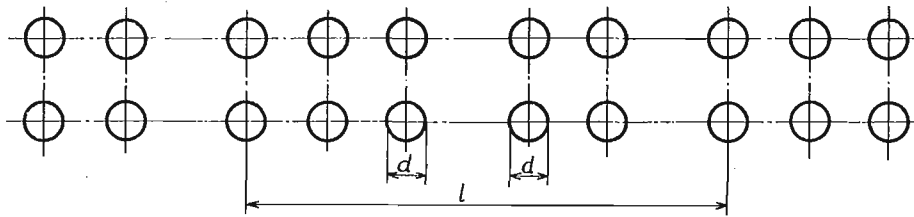


Fig. 5.3 Arrangement of Tube Holes with Unequal Pitches (2)



5.6 Strength of Ligaments between Tube Holes Arranged in Circumferential Direction The strength of ligaments between tube holes arranged in circumferential direction of a shell shall be 1/2 or more of the required strength of ligaments between tube holes arranged in longitudinal direction.

Remark: Circumferential pitch of tube holes shall be measured either on the plate before rolling or on the plate at its median thickness after rolling.

5.7 Strength of Ligaments between Tube Holes Arranged in Diagonal Direction When tube holes are arranged in diagonal direction of a shell, the strength of ligaments is the product obtained by multiplying the strength of longitudinal shell section which has no tube holes by the efficiency shown in Fig. 5.4.

When tube holes are arranged diagonally in shells, the efficiency of diagonal ligaments converted to the longitudinal direction is given by the efficiency shown between line AA and line BB in Fig. 5.4. However, when the point showing the efficiency is found on the right side of line AA in Fig. 5.4, the efficiency of longitudinal direction shall be used, and when the point is found on the left side of line BB, the efficiency of circumferential direction shall be used and, in this case, the efficiency shall be determined by the following formula:

$$\eta = \frac{p-d}{p}$$

where η : efficiency

p : longitudinal pitch or circumferential pitch (mm)

d : diameter of the tube hole (mm)

5.8 Efficiency of Ligaments between Tube Holes Arranged in Several Groups along Longitudinal Direction When several groups of tube holes are arranged regularly in longitudinal direction of a shell and each group is arranged in the same distribution, the efficiency of ligaments of each group shall be not less than the efficiency based on the calculation of the minimum thickness of the plate.

5.9 Efficiency of Ligaments between Tube Holes Arranged Irregularly When tube holes are arranged in a shell irregularly in a straight line in longitudinal direction, the average efficiency of the portion having tube holes shall satisfy the undermentioned provisions.

These provisions shall be applied to the ligaments having the tube holes which are not arranged in a straight line. However, the efficiency of this case shall be used to the portion with or without holes, whichever is the lesser.

- (1) For a length l_1 equal to the inside diameter of a shell (when the inside radius of the shell exceeds 1500 mm, it shall be 1500 mm), the minimum value obtained by the following formula shall be not less than the efficiency used in the calculation of the minimum thickness of the plate.

$$\eta = \frac{a+b+c+\dots}{l_1}$$

- (2) For a length l_2 equal to the inside diameter of a shell (when the inside diameter of the shell exceeds 750 mm, it shall be 750 mm), the minimum value obtained by the following formula shall be not less than 80 % of the efficiency used in the calculation of the minimum thickness of the plate.

$$\eta = \frac{a+b+c+\dots}{l_2}$$

where in these formulae,

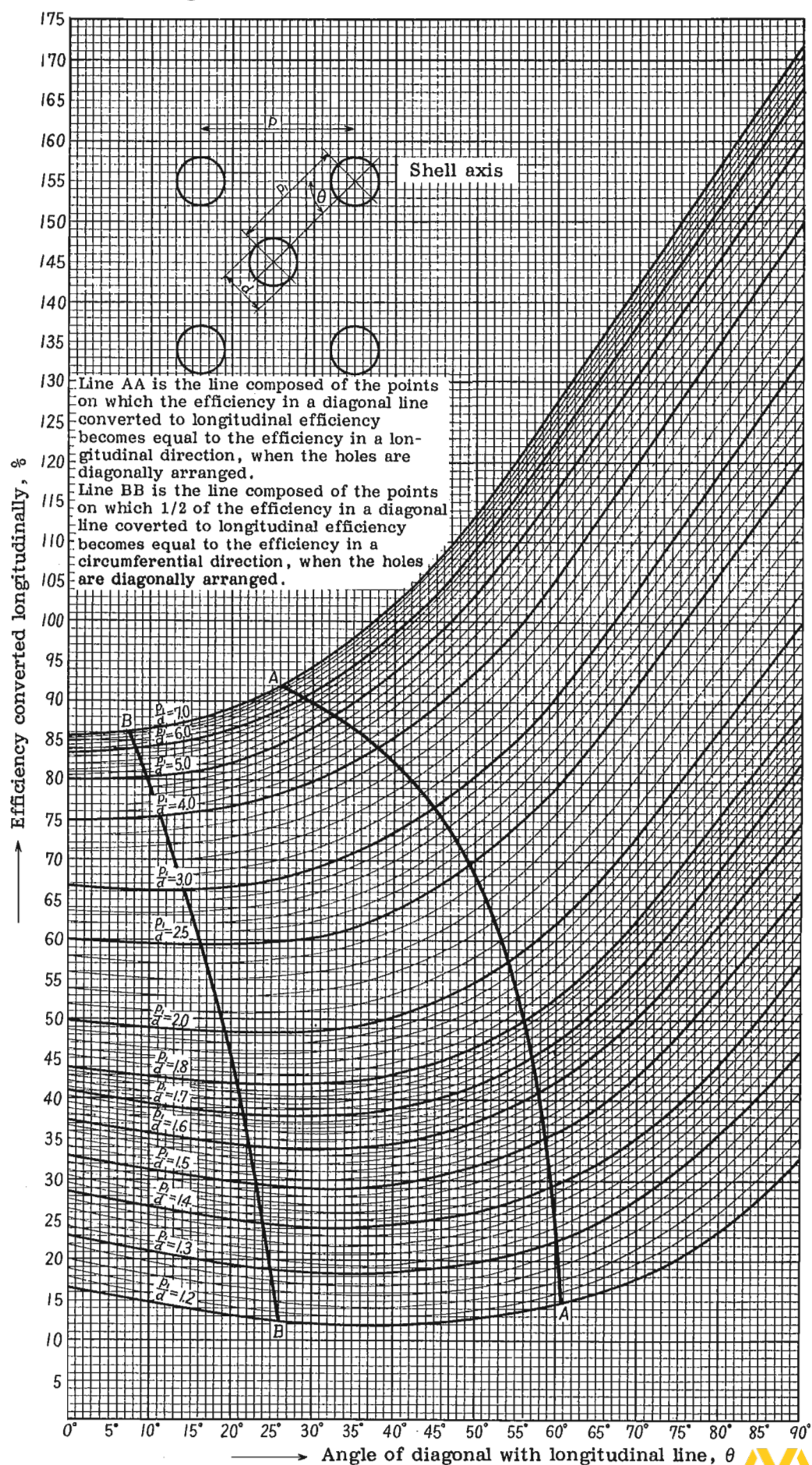
η : efficiency of the ligament

$a, b, c, \dots$: width of ligaments between tube holes arranged in longitudinal direction of shell (mm)

When tube holes are placed in a diagonal line, this shall be the product obtained by multiplying the length projected by the distance between the centers of tube holes positioned in diagonal line in longitudinal direction by the efficiency given in Fig. 5.4.

When the efficiency determined by the above provisions is smaller than the minimum efficiency calculated by taking l_1 as a distance between centers of tube holes located at both ends within the same length as the inside diameter of the shell (when only one tube hole is located within the same length as the inside diameter of the shell, it may be the distance between the centers of the hole and the adjacent tube hole), it need not be smaller than this minimum efficiency.

Fig. 5.4 Efficiency of Ligaments between Tube Holes Arranged in Diagonal Direction



5.10 Minimum Thickness of Spherical Shells The minimum thickness of a spherical shell under internal pressure shall be determined by the following formulae:

- (1) When the thickness of a shell does not exceed 0.356 time the inside radius,

$$t = \frac{PD_i}{400\sigma_a\eta - 0.4P} + \alpha \quad \left\{ t = \frac{PD_i}{4\sigma_a\eta - 0.4P} + \alpha \right\}$$

- (2) When the thickness of a shell exceeds 0.356 time the inside radius and the temperature does not exceed 375°C,

$$t = R (\sqrt[3]{Z} - 1) + \alpha$$

$$Z = \frac{2(100\sigma_a\eta + P)}{200\sigma_a\eta - P} \quad \left\{ Z = \frac{2(\sigma_a\eta + P)}{2\sigma_a\eta - P} \right\}$$

where in (1) and (2)

η : efficiency of the joint in the case that the shell is fabricated by jointing, as given in 13.2.3.

$t, D_i, \sigma_a, \eta, P, \alpha$ and R shall be as defined in 5.2.

5.11 Minimum Thickness of Conical Shells The minimum thickness of each conical portion of shell [conical shell is composed of conical portion, large diameter end and small diameter end (Fig. 5.5)] under internal pressure shall be determined by the following formula.

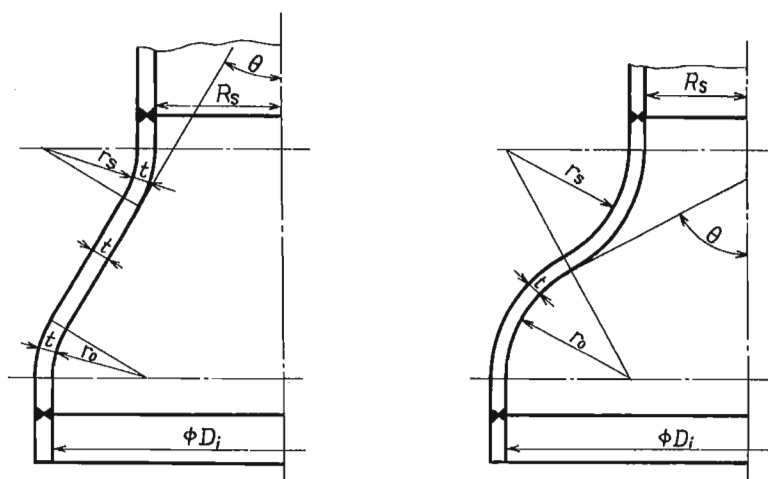
- (1) **Conical Portion** For conical portion, it is given by the following formula:

$$t = \frac{PD}{200\cos\theta(\sigma_a\eta - 0.006P)} + \alpha \quad \left\{ t = \frac{PD}{2\cos\theta(\sigma_a\eta - 0.6P)} + \alpha \right\}$$

where

- D : inner diameter measured perpendicularly to the axis and the largest inner diameter of the portion where the minimum thickness is taken into account (mm)
- η : in the case where there is a joint other than a circumferential joint on the conical portion, the efficiency of that joint
- θ : one half of the apex angle of conical portion (degree),
 D_i, R_s, r_0 and r_s shall be as defined in Fig. 5.5.
 t, P, σ_a and α shall be as defined in 5.2.

Fig. 5.5 Conical Portion



$$r_o \geq 3t \text{ and } r_o \geq 0.06(D_i + 2t)$$

$$r_s \geq 3t$$

- (2) **Large Diameter End** Thickness of the plate of large diameter end which joins with the adjacent cylindrical shell as shown in Fig. 5.6 after rounding it is given by the following formula:

$$t = \frac{PD_1 W}{400 \cos \theta (\sigma_a \eta - 0.001P)} + \alpha \quad \left\{ t = \frac{PD_1 W}{4 \cos \theta (\sigma_a \eta - 0.1P)} + \alpha \right\}$$

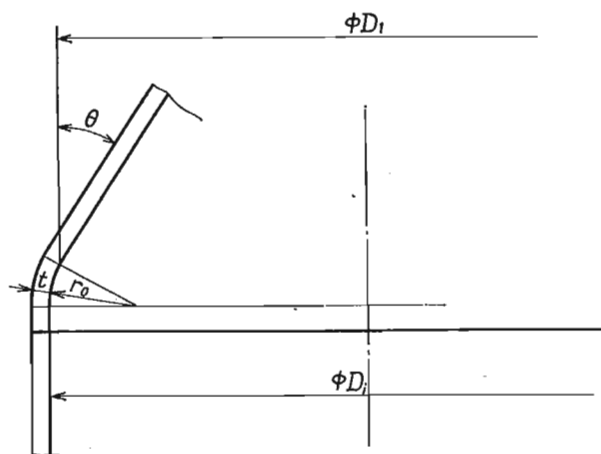
- where t : minimum thickness of plate at the roundish portion (mm)
- D_1 : inner diameter of the portion where the conic portion joins the rounded portion at its foot, and it is measured perpendicularly to the axis.
- W : coefficient relating to the shapes of conic portion and roundness, and it is determined by the following formula:

$$W = \frac{1}{4} \left(3 + \sqrt{\frac{D_1}{2 \cos \theta r_o}} \right)$$

r_o : inner diameter of roundish portion (mm)

P , η and θ shall be in accordance with 5.11 (1).

Fig. 5.6 Large Diameter End



$$r_o \geq 3t \text{ and } r_o \geq 0.06(D_i + 2t)$$

- (3) Small Diameter End Thickness of the plate of small diameter end which joins the adjacent cylindrical shell as shown in Fig. 5.7 is given by the following formula:

$$t = \frac{K t_s}{\eta} + \alpha$$

- where t : minimum thickness of plate of small diameter end (mm). It shall, in any case, be the thickness not less than the minimum thickness of the cylindrical shell joining the small diameter end (based on 5.2).
- t_s : minimum thickness of plate of cylindrical shell (mm) obtained from 5.2 considering the cylindrical shell which joins the small diameter end as a seamless cylindrical shell
- K : coefficient obtained from Fig. 5.8 corresponding to the value of θ and $\frac{P}{100\sigma_a} \left\{ \frac{P}{\sigma_a} \right\}$
- η : efficiency of welded joints of small diameter end. When circumferential joint and longitudinal joint are provided, efficiency of welded joint specified in 13.2.3 applies to each joint. θ , P , σ_a and α are in accordance with 5.11 (1).

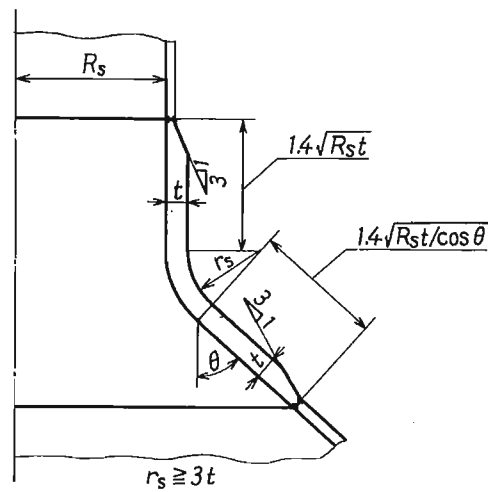
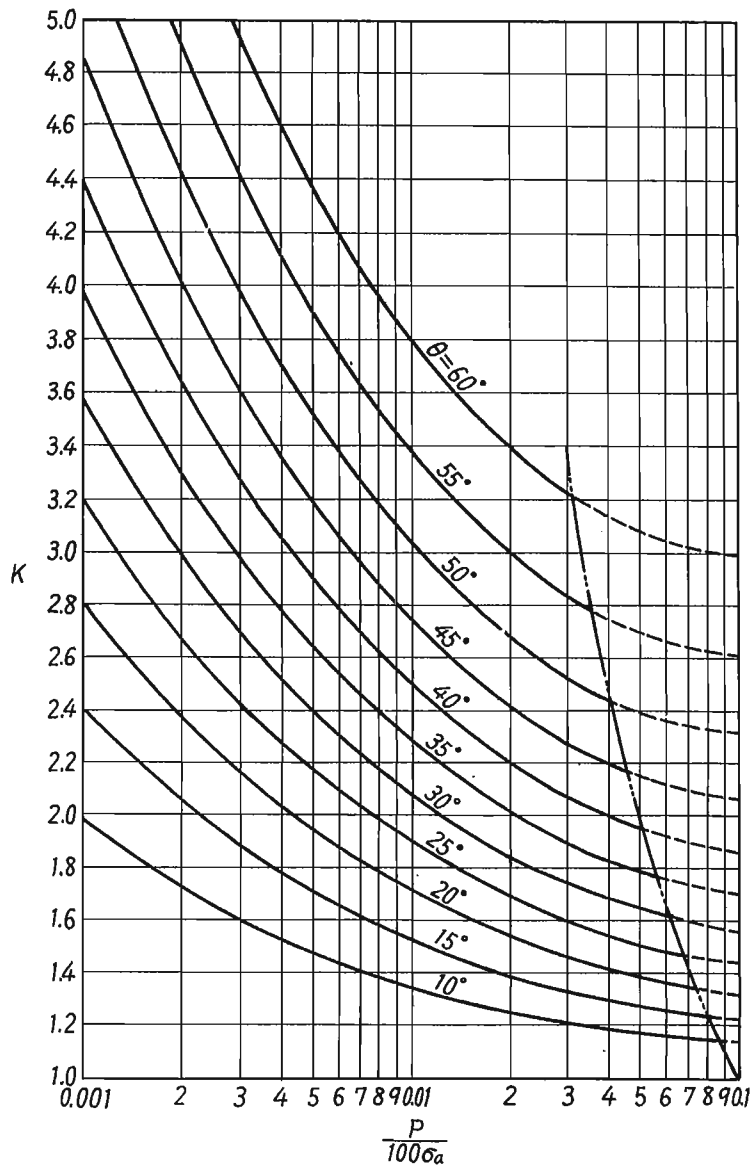
In this case, the plate thickness within the following range shall all be not less than t (see Fig. 5.7).

- (a) To cylindrical shell: $1.4\sqrt{R_s t}$ in longitudinal direction from small diameter end
- (b) To conical portion: $1.4\sqrt{R_s t / \cos \theta}$ in generatrix direction from small diameter end

where R_s : inner diameter of cylindrical shell at small diameter end

Remark: When θ exceeds 60° , thickness shall be calculated in same way as for flat plates specified in 6.8 and 11.2.2.

Fig. 5.7 Small Diameter End

Fig. 5.8 Values of K 

Remark: Study otherwise when the values fall within the range indicated with the two dot chain line.

6. Head Plates and Flat Plates

6.1 Thickness Limits of Head Plates The minimum thickness of head plates, except for a full-hemispherical head, shall be not less than the thickness of the seamless shell required in calculation. In any event the thickness of head plates shall be 6 mm or over, and be 8 mm or over when the stay is attached.

6.2 Restrictions for Shapes of Heads The shape of heads shall comply with the following provisions (Fig. 6.1) except the full-hemispherical head.

(1) For Dished Heads $r > 50 \text{ mm}$, $r \geq 3t$, $l \geq 2t$. However, l need not be over 38 mm.

(a) For heads without flue $R \leq D$, $r \geq 0.06 D$ (for head to sustain the pressure on the convex side, $r \geq 0.1 D$).

(b) For heads with flues $R \leq 1.5 D$, $r \geq 0.04 D$.

When R is larger than D ($1.5 D$, when the flue is fitted), it shall be considered as flat face.

(2) For Semi-Ellipsoidal Heads

(a) $\frac{a}{b} \leq 3$, $l \geq 2t$. However, l need not be over 38 mm.

(b) When a head is of an approximate semi-ellipsoidal shape, its inner surface shall lie on the outside of an ellipse drawn with a major axis equal to the inside diameter of the head and with $1/2$ of minor axis equal to the depth of the head, and the maximum deviation from this ellipse shall not exceed 0.0125 time the inside diameter of the head.

(3) For Flat Heads

$r \geq 3t$, $l \geq 2t$. However, l need not be over 38 mm.

where in the above formulae

t : thickness of the head (mm)

D : outside diameter of the head (mm)

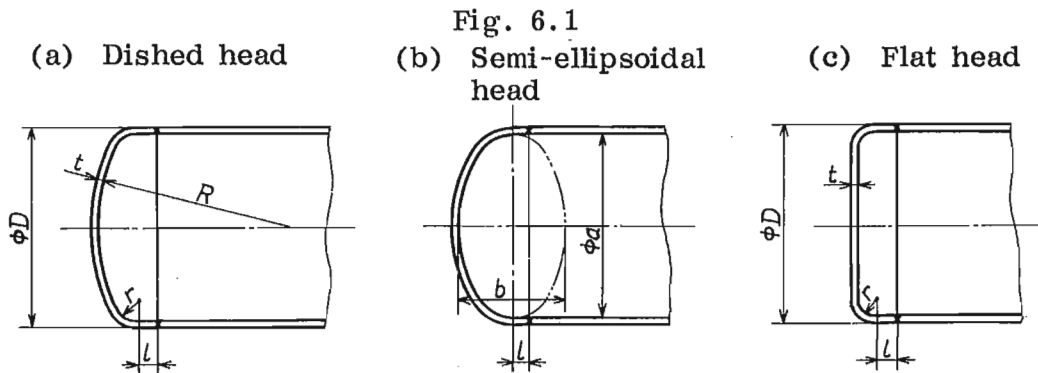
l : length of the parallel portion of the head flange measured from the weld line (Fig. 5.1) (mm)

r : inside corner radius of the head (mm)

a : inside major axis of the semi-ellipsoidal head (mm)

b : inside minor axis of the semi-ellipsoidal head (mm)

R : inside radius of center segment of the dished head (mm)



6.3 Minimum Thickness of Dished Heads or Full-Hemispherical Heads with the Pressure on the Concave Side, without Stay The minimum thickness of dished heads or full-hemispherical heads with the pressure on the concave side without stay shall be determined by the following formula.

(1) For Blank Heads

$$t = \frac{PRW}{200\sigma_a\eta - 0.2P} + \alpha \quad \left\{ t = \frac{PRW}{2\sigma_a\eta - 0.2P} + \alpha \right\}$$

(2) For Heads with Openings

- (a) Reinforcements of openings shall conform to the provisions in 11. In this case, the minimum thickness of the head shall conform to the formula in (1), except the following case of (b).
- (b) In case a head has a flanged opening exceeding 150 mm in the largest dimension, which is reinforced conforming to 11.2.1 (2), the thickness of the head shall be increased by not less than 15 % of the thickness calculated by the formula in (1) and by at least 3 mm.

In this case, when the inside radius of the head R is less than 80 % of the inside diameter of the shell (including the case of full-hemispherical heads) and the head plate thickness is calculated by above formula, R shall be considered as 80 % of the inside diameter of the shell. However, the head fitted with flue shall conform to the following (3).

(3) For Dished Heads with Flues

$$t = \frac{PR}{150\sigma_a\eta} + \alpha \quad \left\{ t = \frac{PR}{1.5\sigma_a\eta} + \alpha \right\}$$

where, in (1) and (3)

- t : minimum thickness of the head (mm)
- P : maximum working pressure (kgf/cm²) {MPa}
- R : inside radius of the full-hemispherical head or inside radius of the central segment of the dished head (mm)
- σ_a : allowable tensile stress of the material (kgf/mm²) {N/mm²}

η : efficiency of the joint in the head.
For full-hemispherical heads, the efficiency of the joint in the head and also the efficiency of the joint attaching the head to the shell shall be taken into consideration.

W : coefficient relating to the shape

$$W = \frac{1}{4} \left(3 + \sqrt{\frac{R}{r}} \right) \quad \text{for dished head}$$

r : inside corner radius of the dished head (mm)
 $W = 1$ for full-hemispherical heads

α : not less than 1 mm, for additive thickness

6.4 Minimum Thickness of Semi-Ellipsoidal Heads with Pressure on the Concave Side The minimum thickness of semi-ellipsoidal heads with the pressure on the concave side shall be determined by the following formula:

(1) For Blank Heads

$$t = \frac{PDV}{200\sigma_a\eta - 0.2P} + \alpha \quad \left\{ t = \frac{PDV}{2\sigma_a\eta - 0.2P} + \alpha \right\}$$

where

t : minimum thickness of the head (mm)

P : maximum working pressure (kgf/cm²) {MPa}

D : inside major axis of the head (mm)

η : efficiency of the joint in the head

σ_a : allowable tensile stress of the material
(kgf/mm²) {N/mm²}

α : not less than 1 mm, for additive thickness

V : coefficient relating to the shape

$$V = \frac{1}{6} \left[2 + \left(\frac{D}{2h} \right)^2 \right]$$

h is 1/2 of inside minor axis of the head (mm)

(2) For Heads with Openings

(a) Reinforcements of openings shall conform to the provisions in 11. In this case, the minimum thickness of the head shall conform to the formula in (1), except the following case of (b).

(b) In case a head has an opening exceeding 150 mm in the largest dimension which is reinforced by flanging-in, 6.3 (2) (b) shall be applied. In this case, R shall be considered as 80 % of the inside diameter of the shell and W shall be 1.77.

6.5 Openings in Heads without Compensation The openings in a head without compensation shall conform to the provisions in 11.1 (2).

6.6 Flat Heads The flat head shall conform to 6.8, 6.9 or 9.3.

6.7 Minimum Thickness of Unstayed Dished Heads with the Pressure on the Convex Side The minimum thickness of an unstayed dished head made of steel plate with the pressure on the convex side shall be 1.7 times the minimum thickness of the head with the pressure on the concave side.

6.8 Minimum Thickness of Unstayed Flat Plates

6.8.1 The minimum thickness of unstayed flat plates, such as heads, cover plates or bottom plates, shall be determined by the following formula: [Except the cases shown in Fig. 6.2 (i) and (j)].

(1) Circular Flat Plates

$$t = d \sqrt{\frac{CP}{100\sigma_a}} + \alpha \quad \left\{ t = d \sqrt{\frac{CP}{\sigma_a}} + \alpha \right\}$$

(2) Non-Circular Flat Plates

$$t = d \sqrt{\frac{ZCP}{100\sigma_a}} + \alpha \quad \left\{ t = d \sqrt{\frac{ZCP}{\sigma_a}} + \alpha \right\}$$

where, in (1) and (2)

t : minimum thickness of the flat plate (mm)

P : maximum working pressure (kgf/cm²) {MPa}

d : diameter or shortest span, measured as indicated in Fig. 6.2 (mm)

σ_a : allowable tensile stress of the material (kgf/mm²) {N/mm²}

α : not less than 1 mm for additive thickness

Z : $3.4 - 2.4 \frac{d}{D}$ (maximum 2.5)

where, D is the longest span, measured perpendicularly to the shortest span (mm)

C : factor depending on the method of attachment of flat plates as formulated in the following.

- (a) For flat plates bolted with full-face gasket to a shell, a flange or a side plate as shown in Fig. 6.2 (a), it shall be 0.25.
- (b) For flat plates butt-welded to a shell or a pipe conforming to the requirements for circumferential joints as shown in Fig. 6.2 (b) with d 600 mm or under, thickness of flat plate 0.05 to 0.25 d and not less than the thickness of shell plate, and inside corner radius 0.25 t or over, it shall be 0.13.
- (c) For flat plates forged integrally with shell or pipe or butt-welded to a shell conforming to the requirements for circumferential joints as shown in Fig. 6.2 (c) and having thickness of flange portion 2 times the thickness of shell plate or more and $r \geq 3t$, $C = 0.17$
- (d) For flat plates forged integrally with shell or pipe or butt-welded to a shell conforming to the requirements for circumferential joints as shown in Fig. 6.2 (d). $C = 0.17$

However, in the case where the flange length is not less than l given by the following formula and the slope of the tapered section is not greater than $1/3$, $C = 0.10$ is allowable.

$$l = \left(1.1 - 0.8 \frac{t_s^2}{t^2} \right) \sqrt{dt}$$

where l : length of the flange, measured from the tangent line of the knuckle (mm)
 t_s : actual thickness of the shell plate (mm)
 t : actual thickness of the flat plate (mm)
 d : diameter, measured as indicated in Fig. 6.2 (d) (mm)

Even in the case where the flange length is less than l of above formula, if the actual thickness of shell plate is not less than the value of the following formula over the length of $2\sqrt{dt_s}$ from the jointed end and the slope of tapered section of flange is not greater than $1/3$, $C = 0.15$ may be adopted.

- (e) For non-circular flat plates as shown in Fig. 6.2 (e), it shall be 0.33.

For circular flat plates as shown in Fig. 6.2 (e), it shall be 0.33 (minimum 0.2).

$$m = \frac{t_{sr}}{t_s}$$

where t_{sr} : required thickness of the shell or pipe (mm)
 t_s : actual thickness of the shell or pipe (mm)

In the case shown in Fig. 6.2 (e) where the flat plate is welded to the inside of a shell or pipe conforming to the requirements for welding, and the size of the weld t_w is not less than $2 t_{sr}$ and also $1.25 t_s$ (but, it need not be greater than the required thickness of the flat plate t), the deposited weld metal shall penetrate to the inner surface of the flat plate. In this case, no radiographic examination is needed.

- (f) For flat plates as shown in Fig. 6.2 (f), it shall be 0.33.

- (g) For flat plates as shown in Fig. 6.2 (g), it shall be 0.33 m (minimum 0.2).

In the case shown in Fig. 6.2 (f) or (g) where the flat plate is butt-welded to the end of a shell or pipe, and the distance between the end of the shell and the outer surface of the flat plate t_e is not less than $2 t_{sr}$ and also $1.25 t_s$, the portion of the flat plate shall act as a backing strip and the deposit metal shall penetrate to the inner surface of the shell plate; and in the case of (g), the fillet welding shall be applied to the inside. In these cases, no radiographical examination is needed. Where, m shall be the same as in the preceding paragraph (e).

- (h) For circular flat plates screwed into the inside of a shell or pipe not exceeding 350 mm inside diameter as shown in Fig. 6.2 (h) or for circular flat plates having flange screwed over to the outside of a shell or pipe, it shall be 0.75. In this case, the stress on the screwed portion due to the pressure on the flat plate shall not exceed the allowable stress. Seal welding may be applied, if required.

6.8.2 The minimum thickness of the flat plate which is fitted by bolts to the flange of a shell or pipe giving rise to the moment as shown in Fig. 6.2 (i) and (j) shall be determined by the following formulae.

(1) Circular Flat Plates

$$t = d \sqrt{\frac{CP}{100\sigma_a} + \frac{1.9Wh_G}{\sigma_a d^3} + \alpha} \quad \left\{ t = d \sqrt{\frac{CP}{\sigma_a} + \frac{1.9Wh_G}{\sigma_a d^3} + \alpha} \right\}$$

(2) Non-Circular Flat Plates

$$t = d \sqrt{\frac{ZCP}{100\sigma_a} + \frac{6Wh_G}{\sigma_a L d^2} + \alpha} \quad \left\{ t = d \sqrt{\frac{ZCP}{\sigma_a} + \frac{6Wh_G}{\sigma_a L d^2} + \alpha} \right\}$$

where W : load applied to bolt used in calculation of flange,

(a) load applied to bolt in working condition W_0

(b) load applied to bolt when fastening gasket $W_g = \frac{A_m + A_b}{2} \sigma_a$

W_0 : load applied to bolt in working condition (kgf) {N}

W_g : load applied to bolt when fastening gasket (kgff) {N}

A_m : total cross-section area to be used for bolts (mm²)

A_b : total cross-section area of bolts to be actually used (mm²)

σ_a : allowable tensile stress of material (kgf/mm²)

h_G : moment arm due to gasket, which is 1/2 of the difference of the pitch circle and d (mm)

L : circumference length measured along the centers of the bolt holes (mm)

C : 0.3 as constant

t, P, d, Z, σ_a and α shall be as defined in 6.8.1.

6.8.3 When the flat plate is machined for a gasket groove as shown in Fig. 6.2 (j), the net thickness deducted by the groove depth shall be not less than the value calculated by the following formulae.

(1) For Circular Flat Plates

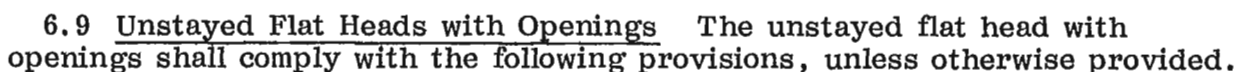
$$t_n = \sqrt{\frac{1.9Wh_G}{\sigma_a d}}$$

(2) For Non-Circular Flat Plates

$$t_n = \sqrt{\frac{6Wh_G}{\sigma_a L}}$$

W , h_G , σ_a , d , and L in (1) and (2) shall be as defined in 6.8.1 and 6.8.2.

Fig. 6.2 Mounting of Flat Plates



- (1) When the diameter of an opening does not exceed 50 % of d in Fig. 6.2, the reinforcement of the opening shall conform to the provisions in 11. In this case, the minimum thickness of the head shall conform to 6.8.

- (2) When the diameter of an opening exceeds 50 % of d in Fig. 6.2, the minimum thickness of the flat head may be calculated assuming it as the bolted flange or by the formula of 6.8.1 in which C is taken as $2.25 C$, or by the formula of 6.8.2 in which the square root sign is taken as 2.25 times.

7. Tube Sheets

7.1 Minimum Thickness of Tube Sheet Where Tubes are Rolled The tube sheet where tubes are rolled shall have a thickness not less than 10 mm at the contact surface which forms a perfect circle.

7.2 Minimum Thickness of Tube Sheets of Fire-Tube Boilers The minimum thickness of a tube sheet of a fire-tube boiler shall be not less than the value given in Table 7.1 and also shall be not less than the value determined by the following formula, when the outside diameter of the fire tubes is from 38 mm to 102 mm.

$$t = 5 + \frac{d}{10}$$

where t : minimum thickness of the tube sheet (mm)
 d : diameter of the tube hole (mm)

Table 7.1

Unit: mm	
Outside diameter of tube sheet	Minimum thickness of tube sheet
1350 or under	10
Over 1350 to 1850 incl.	12
Over 1850	14

7.3 Minimum Thickness of Flat Tube Sheets of Fire-Tube Boilers The minimum thickness of a flat tube sheet of a fire-tube boiler shall conform to the formula for the stayed plates given in 9.3.

- (1) **Portions of Tube Nests** The stays in this case shall be of screwed stay tubes and the values of p and C in the formula of 8.3 shall be as given in Table 7.2.