CHAPTER IV

REGULATIONS FOR DETERMINING THE WORKING PRESSURE TO BE ALLOWED ON VARIOUS PARTS OF BOILERS OTHER THAN FUSION WELDED AND SEAMLESS FORGED DRUMS

175. Maximum pressure.—The maximum pressure at which a boiler may be used shall be determined in accordance with the provisions of this Chapter. The Regulations in this Chapter refer to material subjected to steam temperature not exceeding 500° F.

SHELLS

176. Formula for Working Pressure of Shell—(*a*) For cylindrical shells, barrels, steam and water drums, and domes of boilers the maximum working pressure per square inch to be allowed shall be calculated from the following formula:—

[NOTE.—Where parts of drums of water tube boilers are perforated for tubes, the working pressure shall be calculated by equation (53) under 'Tube Plates'].

$$W.P. = \frac{(t-2)\times S\times J}{C\times D} \quad \ldots\ \ldots\ \ldots\ \ldots\ \ldots\ \ldots \quad \text{Eqn. (1)}$$

where W.P. = the working pressure in lbs. per square inch;

t = the thickness of shell plates in 32nds of an inch;

S = the minimum tensile breaking strength of the shell plates in tons per square inch or whatever strength is allowed under Regulation 5;

J = the percentage of strength of the longitudinal seams of shell or of a line of holes in the shell for stays, or rivets, or of an opening in the shell not fully compensated, whichever is least calculated by the methods hereafter described;

C is a co-efficient as follows:—

2·75 when the longitudinal seams are made with double butt straps and when small shells are formed from solid rolled sections;

2·83 when the longitudinal seams are made with lap joints and are treble riveted;

2·9 when the longitudinal seams are made with lap joints and are double riveted;

3·0 when the longitudinal seams are welded and are fitted with a single butt strap;

3·3 when the longitudinal seams are made with lap joints and are single riveted;

D = the inside diameter of the outer strake of plating of the cylindrical shell measured in inches.

(*b*) The factor of Safety shall in no case be less than 4.

The actual factor of Safety in each case may be found from the equation:

$$F = 1.4\times C\times \frac{t}{t-2}$$

With the best form of joint and least co-efficient (*c*) the Factor of Safety for shell plates, $\frac{7}{16}$ inch to $1\frac{3}{8}$ inches in thickness, varies from 5.13 to 3.99.

(*c*) An addition of 10 per cent. shall be made to the appropriate co-efficient for shells of boilers in which the longitudinal seams are lap jointed and are not accessible to close visual inspection and for shell plates of externally fired boilers exposed to the direct impact of furnace flame; provided that this addition shall not apply to the steam and water drums of water tube boilers where the drums are not close to the fire-grate and there are tubes between the fire-grate and the drum.

(*d*) The above co-efficient are standards and shall be used only for boiler open to inspection by an Inspecting Officer during the whole period of construction and which are certified by him as having been constructed in accordance with the standard conditions laid down in these Regulations.

177. Methods of calculating the strength of riveted joints.—(*a*) The percentage of strength of a riveted joint (J) shall be found from the following formulae (i), (ii), (iii): (i) and (ii) are applicable to any ordinary type of joint, (iii) is applicable only to that type of joint in which the number of rivets in the inner rows is double that of the outer row. The lowest value given by the application of these formulae is to be taken as the percentage of strength of the joint compared with the solid plate.

(*i*) $\frac{100(P-D)}{P}$ = Plate percentage .. .. .. Eqn. (2)

(*ii*) $\frac{100\times A\times N\times C\times S_1}{P\times T\times S}$ = Rivet percentage .. .. Eqn. (3)

(*iii*) $\frac{100(P-2D)}{P}+\frac{100\times A\times C\times S_1}{P\times T\times S}$ = Combined plate and rivet percentage Eqn. (4)

Where P is the pitch of rivets at outer row in inches,

D is the diameter of rivet holes in inches,

A is the sectional area of one rivet hole in square inches,

N is the number of rivets per pitch (P),

T is the thickness of plate in inches,

C = 1 for rivets in single shear as in lap joints, and 1.875 for rivets in double shear as in double butt strapped joints,

S_1 is the shearing strength of rivets, which shall be taken to be 23 tons per square inch for steel and 18 tons per square inch for iron,

S is the minimum tensile breaking strength of shell plates in tons per square inch, or whatever strength is allowed under Regulation 5 of Chapter I.

In the first formula (*l*) D is the diameter of the rivet holes in the outer rows and in the third formula D is the diameter of the rivet holes in the next rows. In the last formula A is the area of one rivet hole in the outer row.

(*b*) When the sectional area of the rivet holes is not the same in all rows' and when some of the rivets are in double shear and others in single shear the rivet sections per pitch of each size in shear shall be computed separately and added together to form the total rivet section.

178. When Pitch exceeds maximum allowed.—Should the pitch of the rivets exceed the maximum pitch allowed, the permissible pitch shall be used in place of the actual pitch in determining the percentage of plate section. No greater percentage than 85 shall be allowed for any type of riveted joint.

179. Butt Straps and spacing of rivets below requirements.—Should the spacing of the rows of rivets or the distance between edge of plat and rivet hole or the thickness of butt straps be less than that specified in Regulations 182 and 184 the percentage representing the strength of joint shall be modified as prescribed in those regulations.

180. Percentage of Welded and Strapped Seams.—In determining the percentage of strength of a welded seam covered by a strap or straps the formulae and allowances in Regulations 177, 178 and 179 shall be applied, but 50 per cent shall be added to the rivet percentage for the weld.

181. Percentage to be allowed for Solid Rolled Shells.—When small shells are rolled from the solid, J. in equation (1) shall be taken as 100 per cent.

182. Thickness of Butt Straps.—The minimum thickness of butt straps for the longitudinal seams of cylindrical shells shall be determined by the following formulae but all straps should be of sufficient thickness to permit of efficient caulking and in any case shall not be less than 3/8 inch in thickness.

Single butt straps having ordinary riveting:—

$1.125T = T_1$ .. .. Eqn. (5)

Single butt straps having every alternate rivet in the outer rows omitted:—

$$1.125T \times \frac{(P-D)}{(P-2D)} = T_1 \quad .. \quad .. \quad .. \quad .. \quad \text{Eqn. (6)}$$

Double butt straps of equal width having ordinary riveting:—

$.625T = T_1$ .. .. Eqn. (7)

Double butt straps of equal width having every alternate rivet in the outer rows omitted:—

$$.625T \times \frac{(P-D)}{(P-2D)} = T_1 \quad .. \quad .. \quad .. \quad .. \quad .. \quad \text{Eqn. (8)}$$

Double butt straps of unequal width either having ordinary riveting, or having every alternate riveting the outer rows omitted:—

$.75T = T_1$ (wide strap) .. .. Eqn. (9)

$.625T = T_1$ (narrow strap) .. .. Eqn. (10)

Where T_1=the thickness of the butt straps in inches. The other symbols have the same significance as in Regulation 177.

Single and wide butt straps shall, wherever practicable, be on the inside of the shell.

Should the thickness of butt straps be less than that above described, the least percentage of joint as determined under Regulation 177 shall be reduced in the proportion of the actual thickness to the prescribed thickness.

183. Maximum Pitch of Rivets in longitudinal joints.—The maximum pitch of the rivets in the longitudinal joints of boiler shells shall be:—

$C \times T + 1.625$ = maximum pitch in inches .. .. .. Eqn. (11)

where T=the thickness o fthe shell plate in inches,

C is a co-efficient as given in the following table:—

Number of Rivets per pitch	Co-efficients for Lap joints	Co-efficients for single Butt-strapped joints	Co-efficients for double Butt-strapped. joints
1			
2	1·31	1·53	1·75
3	2·62	3·06	3·50
4	3·47	4·05	4·63
5	4·14	—	5·52
	—	—	6·00

184. Spacing of rows of rivets.—(*a*) In joints, whether lapped or fitted with butt straps, in which there are more than one row of rivets and in which there is an equal number of rivets in each row, the distance between the rows of rivets shall be not less than—

Zig-zag riveting:—

.33P+.67 D=distance between centre lines of rows (R)..Eqn. (12)

Chain riveting:—

2D=distance between centre lines of rows (R) .. .. Eqn. (13)

(*b*) In joints in which the number of rivets in the outer rows is one-half of the number in each of the inner rows, and in which the inner rows are chain rivets the distance between the outer rows and the next rows shall be not less than as required by equations (12) and (13) whichever is the greater, and the distance between the rows in which there are the full number of rivets shall be not less than $2D(R_1)$.

(*c*) In joints in which the number of rivets in the outer rows is one-half of the number in each of the inner rows and in which the inner rows are zig-zag, the distance between the outer rows and the next rows shall be not less than—

.2P+1.15D=distance between centre lines of outer and next rows (R) .. .. Eqn. (14)

The distance between the rows in which there are the full number of rivets shall be not less than—

.165P+.67D=distance between centre lines of inner rows (R_1)..Eqn. (15)

where P is the pitch of the rivet in the outer rows,

D is the diameter of the rivet holes in inches or the mean of the diameter of rivet holes when the distance to be determined is between two rows of rivets of different diameters.

(*d*) Should the distance between rows of rivets be less than as prescribed above the plate percentage determined by equation (2) shall be modified thus—

$$\frac{100\left[P-\left(2-\frac{\text{actual distance}}{\text{prescribed distance}}\right)D\right]}{P}=\text{modified plate percentage Eqn. (16)}$$

(*e*) In all cases the clear space between a rivet hole and the edge of a plate shall not be less than the diameter of the rivet holes, *i.e.* the centre of the rivet hole shall be at least 1½ diameters distant from the edge of the plate (E):

Provided that, if this condition be not observed, the strength value of the rivet affected shall be reduced in the proportion of the actual distance between the outer edge of the rivets and the edge of the plate to the prescribed distance.

185. Circumferential and End Seams of Water Tube Boilers—The suitability of circumferential seams including the seams joining ends to shells shall be verified by the following formula:—

$$\frac{K\times J\times(t-2)}{D\times C}$$ is equal to or greater than W.P. .. Eqn. (17)

where K=150 for 26/30 tons tensile plates,

K=157 for 28/32 tons tensile plates,
Due to higher stresses, *see* Reg. 271 and 340,

WP=The working pressure in lbs. per sq. in.,

D=The diameter of shell in inches, measured inside the outer ring of plates,

J=Circumferential Joint efficiency calculated by Eqn. 2 or 3.

C=8·24 where the seams are made with lap joints and are treble riveted,
=8.44 where the seams are made with lap joints and are double riveted,
=9.60 where the seams are made with lap joints and are single riveted,

t=thickness of plate in 32nd of an inch.

186. Compensation for Manholes and other openings.—The percentage of compensating section shall be determined by the following formulae:—

$$\frac{200(W-D)\times Tr.}{(L+2D)\times Ts}$$=Percentage strength of compensating section .. .. Eqn. (18)

$$\frac{80\times A\times N}{(L+2D)\times Ts.}$$=Percentage strength of rivet section .. Eqn. (19)

where W is the width of compensation ring in inches measured in the direction of the longitudinal axis of the boiler,

L is the length of opening in shell in inches measured in the direction of the longitudinal axis of the boiler,

D is the diameter of rivet holes in inches,

Tr is the thickness of compensation ring in inches,

Ts is the thickness of shell plate in inches,

A is the area of one rivet hole in inches,

N is the number of rivets on one side of the longitudinal line. When the rivets are in double shear 1.875 times the single rivet section shall be allowed.

Parts of raised manhole mouthpieces within four inches of the shell shall, in addition to the ring, be included in the compensating section.

187. Uncompensated Holes in Water Tube Boilers.—The maximum diameter of any uncompensated opening in a shell shall be determined, subject to the condition that the minimum thickness at the hole in the shell or end plate shall be not less than the thickness required for the maximum permissible working pressure, considering the plate as being unpierced, as follows:—

$$d=\tfrac{1}{2}\times\sqrt{(D+T)T}+N \quad .. \quad .. \quad .. \quad .. \quad .. \quad \text{Eqn. (20)}$$

where d=Maximum mean effective diameter of uncompensated hole in inches,

T=Thickness of drum shell in inches,

D=Internal diameter of drum in inches, but not exceeding 60,

N=3 where E does not exceed 0·50,

$$=3\times\frac{\sqrt{1-E}}{0.50}$$—In other cases .. .. Eqn. (21)

The required thickness of a seamless unpierced shell

where $E=\frac{\quad}{T}$ .. Eqn. (22)

DISHED END PLATES

188. Complete hemisphere without stays or other support made of one or more plates and subject to internal pressure.—The maximum working pressure shall be determined by the following formula:—

$$W.P.=\frac{(t-2)\times S\times J}{C\times R} \quad .. \quad .. \quad .. \quad .. \quad .. \quad \text{Eqn. (23)}$$

where W.P. is the working pressure in lbs. per square inch,

t is the thicknesss of the end plate in 32nds of an inch,

S is the minimum tensile breaking strength of the end plates in tons per square inch, or whatever strength is allowed for them,

J is the least percentage of strength of the riveted joints of the plates forming the hemisphere or securing it to the cylindrical shell,

R is the inner radius of curvature in inches,

C for single riveting is 3.3,

C for double riveting is 2.9,

C for treble riveting is 2.83.

189. Dished ends subject to internal pressure.—(*a*) For unstayed ends of steam and water drums, tops of vertical boilers, etc., when dished to partial

spherical form the maximum working pressure shall be determined by the following formula:—

$$W.P. = \frac{15 \times S \times (t-1)}{R} \quad .. \quad .. \quad .. \quad \text{Eqn. (24)}$$

where W.P. is the working pressure in lbs. per square inch,

t is the thickness of end plates in 32nds of an inch,

R is the inner radius of curvature of the end in inches, which shall not exceed the external diameter of the shell to which it is attached,

S is the minimum tensile breaking strength of plate in tons per square inch, or whatever is allowed for it.

(*b*) The inside radius of curvature at the flange shall be not less than 4 times the thickness of the end plate, and in no case less than 2-1/2 inches.

(*c*) When the end has a manhole in it (t - 5), shall be substituted for (t--1) in the formula.

(*d*) The total depth of flange of manhole from the outer surface in inches measured on the minor axis shall be at least equal to—

$\sqrt{T \times W}$ = depth of flange in inches .. .. Eqn. (25)

where T is the thickness of the plate in inches, and

W is the minor axis of the hole in inches.

NOTE.—The foregoing provisions shall not preclude the use of dished ends in compliance with Regs. 275 to 278, where not fitted with an up-take.

190. Dished ends subject to external pressure.—In the case of unstayed dished ends, for the co-efficient 15 in equation (24) the co-efficient 12 shall be substituted and R shall be the outer radius of curvature of plate which shall not exceed the external diameter of the shell to which it is attached. For plates exposed to furnace flame the co-efficient shall be 10.5. In no case shall $\frac{R}{t}$ exceed 2.75.

191. Dished ends of Lancashire and Cornish Type Boilers.—(*a*) For dished ends of Lancashire and Cornish boilers formed in one piece, without stays and subject to internal pressure the maximum working pressure shall be determined by the following formula:—

$$W.P. = \frac{(t-8) \times 30 \times S}{R} \quad .. \quad .. \quad .. \quad \text{Eqn. (26)}$$

where W.P. is the working pressure in lbs. per square inch,

t is the thickness of the end plate in 32nds of an inch,

R is the inner radius of curvature of the end in inches which shall not exceed one and a half times the external diameter of the shell to which it is attached,

S is the minimum tensile breaking strength of the plate in tons per square inch or whatever is allowed for it.

(*b*) The inside radius of curvature at the flange shall be not less than 4 times the thickness of the plate and in no case less than 3½ inches.

192. Dished shell and firebox crowns.—(*a*) In determining the working pressure in accordance with Regulations 189 and 190 no account shall be taken of the influence of the up-take tube in vertical boilers. If dished crown plates having uptakes are fit for higher pressures, when considered as flat plates, under Reg. 197 such higher pressure shall be allowed.

(*b*) The radius R of the dished part may be found as follows:—

$$R = \frac{C^2 + H^2}{2H} \quad .. \quad .. \quad .. \quad .. \quad .. \quad \text{Eqn. (27)}$$

C and H are the lengths in inches of half the base line or chord on which H measured and the height of the dish or camber at the middle of the chord respectively.

FLAT PLATES

193. Flat plates supported by solid screwed stays, marginal seams or flanges.—(*a*) For plain flat plates supported by solid screwed stays or riveted marginal seams or flanges, the maximum working pressure shall be as follows:—

$$W.P. = \frac{C(t-1)^2}{A^2 + B^2} \quad .. \quad .. \quad .. \quad .. \quad .. \quad \text{Eqn. (28)}$$

In this formula and in those following in the succeeding regulations relating to "Flat Plates" unless otherwise specified—

W.P. is the working pressure in lbs. per square inch,

t is the thickness of the flat plate in 32nds of an inch,

t_1 is the thickness of the washers, strip, or doublings employed in 32nds of an inch,

A is the horizontal pitch of stays in inches,

B is the vertical pitch of the stays in inches,

C is a co-efficient which varies in value with the method of fixing the stays and nature of the support.

Where the plates are exposed to the direct impact of the flame the following of C shall be reduced 12½ per cent.—

C=60 for stays screwed into the plate with their ends riveted over,

C=90 for stays screwed into the plate and fitted with nuts on the outside,

C=100 for stays passed through the plate and fitted with nuts inside and outside,

C=110 for a riveted seam or flange, in the flat plate securing it to the shell side plate, end plate, furnaced or uptake.

Where portions of plate are supported by stays or riveted seams or flanges having various values of support, the value of C, shall be taken as the mean of the points of support concerned.

The support of a riveted seam shall be assumed to be at the line through the centres of rivets in the nearest row and of a flange at the commencement of curvature. In the latter case, if the inner radius of curvature of the flange exceeds $2\frac{1}{2}$ times the thickness of the plate, the support shall be assumed to be at a distance of $2\frac{1}{4}$ times the thickness of the plate from the inner side of the flange.

(*b*) For portions of plate where the stays are irregularly pitched D^2 shall be used instead of A^2+B^2, D being the diameter in inches of the largest circle which can be drawn passing through not less than three points of support, *viz.*, the centres of stays, or rivets or the commencement of the curvature of flanging whichever is applicable.

(*c*) For the tops and sides of combustion chambers and fireboxes the distance between the rows of stays nearest to the back tube plate, or the back or firehole plate respectively, and the commencement of curvature of these plates at their flanges shall not be greater than the maximum pitch of the stays.

(*d*) For the tops of combustion chambers and fireboxes where they are joined to the sides by curved portions, if the outer radius of the curved portion is less than half the allowable distance between the girders, the distance between the first girder and the inner surface of the side plates shall not exceed the allowable distance between the girders. If the radius of curvature is greater than half the allowable distance between the girders, the width of the flat portion measured from the centre of the girder shall not be more than half the allowable distance between the girders.

(*e*) Where stay tubes are not fitted in nest of tubes, as in tube plates of locotype boilers, and parts of plate outside the space occupied by tubes are supported, in accordance with Regulation 212 (b), by screwed stays each stay in the row nearest the tube shall be of sufficient strength to support the plate up to the edges of the tube holes in addition to its share of the plate on the opposite side of the line of stays.

The working pressure for the plate between tubes and stays shall be determined by Eqn. (28), A being the horizontal pitch of the stays in the nearest row, B twice the distance between the centre line of stays and a line touching the tubes opposite them and C the co-efficient appropriate to the kind of stay.

194. Flat plates supported by stays and nuts and large washers or strips or doublings.—(*a*) Where the plates are supported by stays passing through them and are fitted with nuts inside and washers and nuts outside, the diameter of the washers being at least $3\frac{1}{2}$ times that of the stay, and their thickness at least two-thirds that of the plate, but not greater than that of the plate, the maximum working pressure shall be :—

$$\text{W.P.} = \frac{100}{A^2+B^2}[(t-1)^2+\cdot 15t_1^2] \quad .. \quad .. \quad .. \quad \text{Eqn.} \quad (29)$$

(*b*) where the washers have a diameter of at least two-thirds of the pitch of the stays and a thickness of at least two-thirds of the thickness of the plate, but not greater than that of the plate, and are riveted to the plate in an efficient manner, the maximum working pressure shall be:—

$$\text{W.P.} = \frac{100}{A^2+B^2}[(t-1)^2+\cdot 35t_1^2] \quad .. \quad .. \quad \text{Eqn.} \quad (30)$$

(*c*) Where the plate is stiffened by strips at least two-thirds of the pitch of the stays in breadth which have a thickness of at least two-thirds of that of the plate but not greater than that of the plate, and are riveted to the plate in an efficient manner, the maximum working pressure shall be :—

$$\text{W. P.} = \frac{100}{A^2+B^2}[(t-1)^2+\cdot 55t_1^2] \quad .. \quad .. \quad .. \quad \text{Eqn.} \quad (31)$$

(*d*) Where the plates are fitted with doubling plates having a thickness of at least two-thirds of that of the plate but not greater than that of the plate, and are riveted to them in an efficient manner, the maximum working pressure shall be:—

$$\text{W. P.} = \frac{100}{A^2+B^2}[(t-1)^2+\cdot 85t_1^2] \quad .. \quad .. \quad .. \quad \text{Eqn.} \quad (32)$$

195. Flat tube plates.—(*a*) For the portions of tube plates in the nests of tubes where stay tubes are required and where the minimum thickness and cross section of tube plate are not less than as prescribed in Regulation 211 the maximum working pressure shall be:—

$$\text{W.P.} = \frac{C(t-1)^2}{P^2} \quad .. \quad .. \quad .. \quad .. \quad .. \quad \text{Eqn.} \quad (33)$$

where P is the mean pitch of the stay tubes supporting any portion of the plate (being the sum of the four sides of the quadrilateral divided by four).

C=70 for stay tubes screwed and expanded into the plate and no nuts fitted and for those attached by welding in accordance with regulation 147(b).

C=85 for stay tubes screwed and expanded into the plate and fitted with nuts.

(*b*) No nuts shall be fitted to stay tubes at the combustion chamber or fire box end.

(*c*) Where the plates are exposed to the direct impact of flame the co-efficient C shall be reduced by $12\frac{1}{2}$ per cent, and where the thickness or cross section of tube plate between tubes is less than as prescribed in Regulation 211 the appropriate co-officient shall be reduced in proportion to the deficit.

(*d*) For the wide water spaces of tube plates between the nests of tubes and between the wing rows of tubes and the shell, the maximum working pressure shall be :—

$$\text{W.P.} = \frac{C}{A^2+B^2}[(t-1)^2+\cdot 55t_1^2] \quad .. \quad .. \quad .. \quad \text{Eqn.} \quad (34)$$

where A = the horizontal pitch of stay tubes in inches measured across the wide water space from centre to centre,

B = the vertical pitch of stay tubes in the bounding rows in inches measured from centre to centre,

C=60 for stay tubes screwed and expanded into the tube plates and no nuts are fitted, and for those attached by welding in accordance with regulation 147(b).

C=80 for stay tubes screwed and expanded into the tube plates and fitted with nuts.

C=70 for stay tubes screwed and expanded into the tube plates and nuts are fitted only to alternate stay tube.

t is the thickness of the flat plate in 32nds of an inch,

t_1 is the thickness of the washers, strips or doublings employed in 32nds of an inch.

(*e*) Where the plates are exposed to the direct impact of flame, the co-efficient shall be reduced 12½ per cent.

196. Plates supported by gusset stays.—(*a*) For the end plates of Lancashire, Cornish, Vertical and Locotype boilers, and other flat surfaces supported by irregularly picthed gusset stays, the maximum working pressure shall be :—

$$\text{W.P.} = \frac{C(t-1)^2}{D^2} \quad \text{Eqn. (35)}$$

where D = the diameter in inches of the largest circle which can be drawn passing through not less than three points of support, *viz*:, the centre lines of rivets or the commencement of the curvature of flanging, whichever is applicable,

C=100 for plates not exposed to flame,

C=88 for plates exposed to flame.

(*b*) Where such plates are stiffened by suitable tee or angle bars securely riveted to the plates within the circle D, the appropriate co-efficient may be increased thirty per cent. Such stiffening bars shall be placed so as to transmit their load in a direct manner to the gusset stays or shell plate.

(*c*) For the part of the end plate containing the manhole in Lancashire boiler the maximum working pressure shall be:—

$$\text{W.P.} = \frac{C}{D^2}[(t-1)^2+(t_1-1)^2] \quad \text{Eqn. (36)}$$

where D is the diameter in inches of the largest circle which can be drawn enclosing the manhole and passing through the centres of the rivets in end plates connecting the shell and gusset angles and furnaces or to the commencement of curvature of flanging, whichever is applicable where the circle passes through only three of the possible five points of support mentioned the remaining two shall be embraced within the circle;

t is the thickness of the end plates in 32nds of an inch;

t_1 is the thickness of the base of the mouthpiece of flat ring in 32nds of an inch;

C=90 where the manhole mouthpiece is either of mild or cast steel, and has a turned-in flange of a depth, measured from inside of end plate, of not less than 4 times the thickness of the end plate, and thickness not less than the thickness of the end plate;

C=70 where only a flat steel compensating ring is fitted;

C is to be taken as the mean of the points of support through which circle passes in accordance with Regulation 193 where there is no mouthpiece or flat ring and the end plate is flanged around the manhole to the depth required in Regulation 201.

197. Flat Crown plates of Vertical Boilers.—(*a*) For the flat crown plates of vertical boilers either with or without bolt stays, Equation (35) shall be used in determining the working pressure with C=80, when the plates are not exposed to flame, and 70 when they are exposed to flame. In this case D is the diameter of the largest circle in inches that can be drawn passing through the centres of the rivets or bolt stays when fitted, or the commencement of the curvature of the flanging, whichever is applicable. Where bolt stays are fitted with washers of the same thickness as the plate securely riveted thereto, the circle shall pass through the centres of the washer rivets but where the washers are not riveted or where none are fitted the circle shall pass through the centre of the stays.

(*b*) Where the crown plate is flanged the inside radius of curvature at the flange shall not be less than 4 times the thickness of the end plate, but in no case less than 2½".

(*c*) The thickness of flat crown plates shall in no case be less than the thickness of the cylindrical portion to which it is attached.

198. Circular flat ends of drums, etc., supported only at edges.—(*a*) For these ends C in Equation (35) shall be taken as 140 when the plates are not exposed to flame, and 122·5 when they are exposed to flame. In this case the circle D shall pass through the centres of rivets or bolt securing the end to the shell or, where the end is flanged, through the commencement of curvature.

(*b*) Where flanged the inside radius of curvature at the flange shall not be less than 4 times, the thickness of the end plate but in no case less than 2½".

199. Bar or bulb stiffened end plates and smokebox tube plates of Locotype Boilers.—Where such plates instead of being supported by stays are stiffened in the steam space by substantial tee or angle bars securely riveted to the plate and extending across the plate to within the margin allowed by Equation (37) or where such plates are formed with a deep bulb extending across the plate to well within the margin allowed, for the support thus given.

C shall be taken as equal to 80 and 70 for plates not exposed, and exposed, to flame respectively. The margin or pitch for such stiffening shall be measured from the centre line of rivets or commencement of curvature of bulb provided it is not more than 2 inches from the centre line of bulb.

For the flat plate above the stiffener or bulb, C shall be taken as the mean of the values appropriate for the points of support.

200. Flat plate margins.—The amount of support in relief of stays which may be credited to the sides of shells, furnaces, uptakes, fireholes and foundation rings to which flat plates are attached shall not exceed that found by the following formula:—

$$\text{Width of margin in inches} = \frac{C(t-1)}{\sqrt{\text{W.P.}}} \quad \text{Eqn. (37)}$$

where t=thickness is 32nds of an inch.

W.P. =Working pressure in lb. per sq. inch,

C=3·47 for plates exposed to flame.

C=3·70 for plates not exposed to flame.

Where the plates are flanged the margin shall be measured from the commencement of curvature or from a line 2½ times the thickness of the plate distant from the side of the flange next to the inner radius of the corner whichever is the less. In other cases, the margin shall be measured from the centre line of rivets in the nearest row of the seam by which the flat plate is attached.

Doubling plates shall cover the area supported between the stays and extend beyond the stays so that the centre of the rivets securing the doubling plate to the end plate shall be at least half the distance from the outermost stays to the nearest substantial point of support.

Where flat end plates are flanged for connection to the shell the inside radius of flanging shall be not less than 1·75 times the plate thickness with a minimum of 1½ inches.

201. Manholes and Mudholes in Flat Plates.—Where a flat plate is flanged to stiffen it at a manhole or sighthole, to permit same working pressure as would be allowed upon an unpierced plate, the depth of the flange measured from the outer surface shall be at least equal to—

$\sqrt{T \times W}$=depth of flange in inches .. .. Eqn. (38)

where T=the thickness of the plate in inches, and

W=the minor axis of the hole in inches.

STAYS

202. Solid screwed stays.—For screw stays to combustion chambers and fireboxes and for longitudinal and cross stays the maximum working pressure for the stays is to be calculated from the appropriate one of the following two formulae:—

$$W.P.= \frac{C}{A}\left(D - \frac{1 \cdot 28}{N}\right)^2 \quad .. \quad .. \quad .. \quad .. \quad \text{Eqn. (39)}$$

$$W.P.= \frac{C \times D_1^2}{A} \quad .. \quad .. \quad .. \quad .. \quad .. \quad \text{Eqn. (40)}$$

where W.P. =the working pressure in lbs. per square inch,

D=the diameter of stays over threads in inches,

D_1=the diameter of body of stay at its smallest part in inches,

N=the number of threads of stay per inch,

A=the area in square inches supported by one stay [for area to be supported by stays near tubes in firebox tube platesof locotype boilers, *see* Regulation 193(e)],

C=7100 for steel or special wrought iron screw stays to combustion chamber or fireboxes,

C=8640 for steel longitudinal or cross stays fitted with nuts,

C=4700 for copper screw stays to fireboxes.

Where stays are made with enlarged ends and the body of the stay is smaller in diameter than at the bottom of the thread the working pressure shall be calculated from the second formula.

203. Stresses in steel jointed stays.—(*a*) The section of least strength whether of stay, rivets, shackle or pin shall be used in calculating the working pressure for the stay. For parts in tension a stress of 9,000 lbs. per square inch of net section shall be allowed, and for parts in shear stress of 8,000 lbs. per square inch of net section.

(*b*) Parts in double shear shall be allowed a section of 1·875 times the single section.

204. Stay Tubes.—For stay tubes, whether of wrought iron or steel, seamless or electric resistance welded or lap-welded the maximum working pressure shall be calculated from the following formula :—

$$W.P.= \frac{5900}{A}\left[\left(D - \frac{1 \cdot 28}{N}\right)^2 - D_1^2\right] \quad .. \quad .. \quad \text{Eqn. (41)}$$

where D=the diameter of the tube over threads in inches.

D_1=the internal diameter of the tube under the threads in inches,

N=the number of threads of stay per inch.

A is the area in square inches supported by one stay tube, measured from centre to centre of stay tubes. When the area contains tubes or parts of tubes their aggregate area, calculated from their smallest external diameter of body when in tension and smallest internal diameter when in compression, shall be deducted from the area of the containing figure and the remainder used as A in the formula.

205. Stays in tension and compression.—(*a*) The same stress shall be allowed in compression as in tension. The strength of short stays in compression and not liable to bending shall be calculated on the net section of the stay at bottom of thread or in body, whichever is less.

(*b*) The stress to be allowed on any stay or part of a stay not provided for in foregoing shall be the same as that allowed for stays or parts of stays of approximately like kind in similar conditions.

206. Measurements of stayed areas in the end plates of Locotype and Vertical Boilers.—When the areas supported by stays are semi-circular as in the upper parts of the end plates and smokebox tube plates of locotype boilers, or annular as in the crown plates of vertical type boilers, the area to be supported by stays A in Eqns, 39 and 40 shall, in the first case, be the area of the plate contained within the margins credited to casing or barrel sides, screw stays, fire door ring or tube stays as the case may be, and in the second case be the area of the annulus between the margins credited to uptake and shell. When bolt staying is necessary the stays shall be properly distributed; the aggregate stay section shall then be used in the formula for calculating the working pressure.

207. Gusset Stays.—The maximum working pressure for gusset stays shall be calculated by the following formula:—

$$W.P.= \frac{9000 \times C}{A} \quad .. \quad .. \quad .. \quad .. \quad .. \quad \text{Eqn. (42)}$$

C, the co-efficient, is the number representing the least of the following:—

(1) $N_1 \times A_1$.

(2) $N_2 \times A_2 \times 1{\cdot}875$.

(3) $N_3 \times A_3 \times 1{\cdot}875$.

(4) $N_4 \times A_4$.

(5) $(G - N_2D_2) \times (t-2) \times {\cdot}037$.

(6) $(G_1 - D_3) \times (t-2) \times {\cdot}037$.

N_1, N_2, N_3, N_4, D_1, D_2, D_3, D_4, and A_1, A_2, A_3, A_4, are respectively the numbers, diameters and sectional areas of the rivets in the joints of each gusset stay, only rivets in the supported area, to be considered effective, the order of the joints being, (1) angles to end plate, (2) end plate angles to gusset, (3) shell angles to gusset, and (4) angles to shell,

G is the depth in inches of gusset plate measured through the line of rivet attaching it to the end plate angles.

G_1 is the depth in inches of gusset plate measured normal to the slant edge of plate through the rivet nearest to the end plate in the joint attaching gusset plate to shell angles,

t is the thickness of the gusset plate in 32nds of an inch,

A is the area in square inches of flat plate supported by the gusset stay which in the case of Lancashire and Cornish boilers, shall be determined as follows:—

(*a*) The margins allowed under flat plate regulations for shell and furnace shall be marked on end plates and the lengths of the centre lines of gussets between them measured, also the distance between each pair of gusset lines from the middle of the smaller in a direction normal to the greater. If L and L_1, be the lengths of two adjacent gusset lines and if the distance between them be W, the area contained by the gusset lines and the shell and furnace margin lines may be apportioned between the stays thus:

$\frac{W(3L+L_1)}{8}$ = Portion of area in square inches, apportioned to L line gusset .. .. Eqn. (43)

$\frac{W(3L_1+L)}{8}$ = Portion of area in square inches, apportioned to L_1, line gusset .. .. Eqn. (44)

(*b*) The portion of the area on the other side of each gusset line shall except when of triangular form, be found in like manner and its amount added to that already found to form the total.

(*c*) For the triangular portions in the wing spaces the area shall be taken as half the product of the length of gusset line into the perpendicular distance between it and the intersecting point where the marginal curves meet.

208. Bolts and Studs.—(*a*) Bolts and studs connecting parts of boilers such as shell, end plates, tube plates, furnaces, uptakes, externally fitted manhole covers, mountings, etc., may be made either of steel or good quality wrought iron.

(*b*) The maximum working pressure for the bolts or studs shall be calculated by the following formula:—

$$W.P. = \frac{N \times C}{A}\left(D - \frac{1{\cdot}28}{n}\right)^2 \quad .. \quad .. \quad \text{Eqn. (45)}$$

where D is the diameter of bolt or stud over threads in inches,

N is the number of bolts or studs securing the part,

n is the number of threads of screws per inch,

C=4,700 for steel bolts or studs of 28 tons/sq. in. minimum ultimate tensile stress where the diameter over thread is less than $\frac{3}{4}$ inch,

C=5,100 for steel bolts or studs of 30 tons/sq. in. minimum ultimate tensile stress where the diameter over thread is less than $\frac{3}{4}$ inch,

C=5,600 for steel bolts or studs of 35 tons/sq. in. minimum ultimate tensile stress where the diameter over thread is less than $\frac{3}{4}$ inch,

C=5,600 for steel bolts or studs of 28 tons/sq. in. minimum ultimate tensile stress where the diameter over thread is not less than $\frac{3}{4}$ inch and not greater than 7/8 inch.

C=7,000 for steel bolts for studs of 28 tons/sq. in. minimum ultimate tensile stress where the diameter over thread is greater than 7/8 inch.

When the material is iron, a reduction, of 15 per cent shall be made in the working pressure as calculated by the formula.

A is the area in square inches of the surface supported by the bolts or studs. For jointed flanges the area shall be taken to extend to midway between the pitch line of the bolts and the inner edge of the flange by which the part is secured.

TUBE PLATES

209. Compression of tube plates.—(*a*) For fire-box or combustion chamber tube plates which are subject to compression due to the pressure on the roof plate, the maximum working pressure shall be:—

$$W.P. = \frac{C \times (P-D)t}{L \times P} \quad .. \quad .. \quad .. \quad .. \quad \text{Eqn. (46)}$$

where t is the thickness of the tube plate in 32nds of an inch,

P is the pitch of the tubes in inches, measured horizontally where the tubes are chain pitched, and diagonally where the tubes are zig-zag pitched and the diagonal pitch is less than the horizontal,

D is the internal diameter of the plain tubes in inches,

L is the internal length of the firebox or combustion chamber in inches measured at top between tube plate and firehole plate or back plate, or between tube plates in double ended boilers with combustion chambers common to two opposite furnaces,

C=875 for steel and 437·5 for copper :

134/2/M. of Industry/69-70-8

Provided that the above formula shall not apply in the case of fireboxes where the girders do not rest on the tube plate, or where the roof plate is stayed direct to the outer shell or to girders supported by the shell.

(*b*) Where girders rest on the side plates or the roof plate is so formed that the load is carried both by side and end plates, in no case shall the compressive stress on the plates exceed 14,000 lbs. per square inch for steel or 7,000 square inch for copper.

210. Parts to be stayed.—(*a*) The stiffness of tube plates and pitch of stays within the nests of tubes where stay tubes are required and where marginal stay tubes are required in support of blank spaces adjacent to or between the nests shall be determined by flat plate rules under Regulation 195.

(*b*) Tubes plates within the nests of tubes whether fitted with stay tubes or not shall comply with the requirements of Regulation 211 in regard to thickness and cross section between tubes.

211. Minimum thickness and cross-section.—To provide a secure attachment for plain tubes in the tube plates the thickness and cross-section of the plate between the tube holes shall not be less than:—

Steel tube plate

$\cdot 125D + \cdot 2$ = minimum thickness in inches .. .. Eqn. (47)

$\cdot 17D + \cdot 025$ = minimum cross section in square inches Eqn. (48)

Copper tube plate,

$\cdot 2D + \cdot 4$ = minimum thickness in inches .. .. Eqn. (49)

$\cdot 527D - \cdot 263$ = minimum cross section in square inches Eqn. (50)

D is the diameter in inches of the tube at the part of attachment to tube plate.

Where the thickness and cross-section of the tube plates are less than the minimum the appropriate co-efficient in Eqn. (51) shall be reduced in proportion to the deficit.

212. Holding power of plain tubes.—(*a*) Where tube plates are not specially stayed in nests of tubes the working pressure, based on the holding power of the tubes shall not exceed that found by the following formula:—

$$\text{W.P.} = \frac{C \times D}{A} \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \text{ Eqn. (51)}$$

where D = the diameter of tube at the part of attachment to tube plate in inches.

A = the area in square inches of the tube plate supported by each tube which generally may be taken as the product of the horizontal and vertical pitches of the tube less the area of the tube itself,

C = 470 for tubes expanded into parallel holes in steel or iron tube plates,

C = 530 for tubes expanded into taper holes in steel or iron tube plates.

For copper tube plates or copper or brass tubes the appropriate co-efficient should be deducted 20 per cent.

(*b*) In the unstayed tube plates of locotype boilers and in other tube plates in which stay tubes are not required the support afforded by the plain tubes shall not be taken to extend beyond the lines enclosing the outer edges of the tubes. Parts of flat plate outside this line shall either lie in the plate margin or be separately supported. No account need be taken of the stiffness of tube plate in the nests of tubes when the above conditions are fulfilled.

Ordinarily the requirements of this clause are applicable only to expanded smoke and water tubes in flat continuous tube plates containing more than one row of tubes.

(*See* Reg. 152 for attachment of tubes in Water Tube Boiler.)

213. Tube plates, other than ends of vertical boilers forming parts of outer shell.—(*a*) When vertical boilers have a nest or nests of horizontal tubes so that there is direct tension on the tube plates due to the vertical load on the boiler ends, or to their acting as horizontal ties across the shell the thickness of the tube plates and the spacing of the tubes shall be such that the section of metal taking the load is sufficient to keep the stress within that allowed on the shell plates.

(*b*) Each alternate tube in the outer vertical rows of tubes shall be a stay tube. The tube plates between the stay tubes shall be of accordance with the rules for tube plates and in addition, considered as part shell, the maximum working pressure.

$$\text{W.P.} = \frac{17 \cdot 24(t-2) \times (P-D) \times S}{R \times P} \quad .. \quad .. \quad .. \quad \text{Eqn. (52}$$

where t is the thickness of the tube plate in 32nds of an inch,

P is the vertical pitch of the tubes in inches,

D is the diameter of the tube holes in inches,

S is the minimum tensile breaking strength of the tube plates in tons per square inch, or whatever is allowed for them,

R is the radial distance of the centre of the outer row of tube hole from the axis of the shell in inches.

214. Curved tube plates of water-tube boilers.—For tube plates forming part of cylindrical drums the maximum working pressure shall be:—

$$\text{W.P.} = \frac{33 \cdot 3(t-4) \times E \times S}{D} \quad .. \quad .. \quad .. \quad .. \quad \text{Eqn. (53)}$$

where t = thickness of tube plate in 32nds of an inch,

E = Efficiency of the longitudinal joint or the ligament between the tube holes, whichever is less,

S = Minimum Tensile Stress of the tube plate in tons per sq. in. or whatever is allowed for it,

D = Inside diameter of the drum in inches,

215. Efficiency of Ligament.—(*a*) When a shell or drum is drilled for tubes in a line parallel to the axis of the shell or drum, the efficiency of the ligament between the tube holes shall be determined as follows:—

(*a*) When a pitch of the tube holes on every row is equal (as in Fig. 10), the formula is:—

$$\frac{p-d}{p} = \text{efficiency of ligament} \quad .. \quad .. \quad \text{Eqn. (54)}$$

where p=pitch of tube holes, inches,

d=diameter of tube holes, inches.

The pitch of tube holes shall be measured either on the flat plate before rolling or on the median line after rolling.

Example.—Pitch of tube holes in the drum as shown in Fig. 10=5¼ in. diameter of tube=3¼". Diameter of tube holes=3-9/32".

$$\frac{p-d}{p} = \frac{5{\cdot}25-3{\cdot}281}{5{\cdot}25} = 0{\cdot}375, \text{ efficiency of ligament.}$$

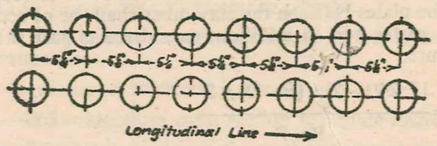


Fig. 10. Example of Tube Spacing with Pitch of Holes equal in every Row.

(*b*) When the pitch of tube holes on any one row is unequal (as in Figs. 11 & 12), the formula is:—

$$\frac{p-nd}{p} = \text{efficiency of ligament} \quad .. \quad .. \quad \text{Eqn. (55)}$$

where p=unit length of ligament, inches,

n=number of tube holes in length p,

d=diameter of tube holes, inches.

Example.—Spacing shown in Fig. 11. Diameter of tube holes=3-9/32".

$$\frac{p-nd}{p} = \frac{12 \div 2 \times 3{\cdot}281}{12} = 0{\cdot}453, \text{ efficiency of ligament.}$$

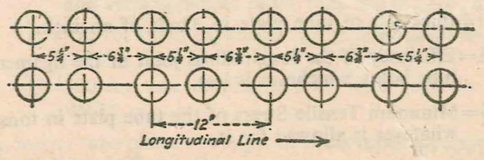


Fig. 11. Example of Tube Spacing with Pitch of Holes unequal in every Second Row.

Example.—Spacing shown in Fig. 12. Diameter of tube hole=3-9/32".

$$\frac{p-nd}{p} = \frac{29{\cdot}25-5\times3{\cdot}281}{29{\cdot}25} = 0{\cdot}439, \text{ efficiency of ligament.}$$

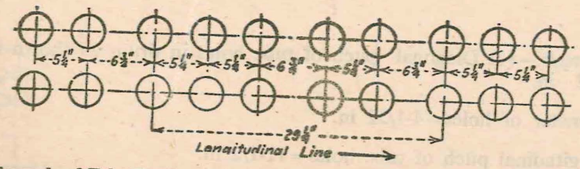


Fig. 12. Example of Tube Spacing with pitch of Holes varying in every Second and Third Row.

(*c*) The strength of those ligaments between the tube holes which are subjected to a longitudinal stress shall be at least one-half the required strength of those ligaments which come between the tube holes which are subjected to a circumferential stress.

(*d*) When a shell or drum is drilled for tube hole so as to form diagonal ligaments as shown in Fig. 13, the efficiency of these ligaments shall be that given by the diagram in Fig. 14.

In this diagram the abscissas are $\frac{p}{d}$ and the ordinates $\frac{p^1}{p}$

where p=longitudinal pitch of tube holes, or distance between centres of tubes in a longitudinal row, inches,

p^1=diagonal pitch of tube holes, inches,

d=diameter of tube holes, inches.

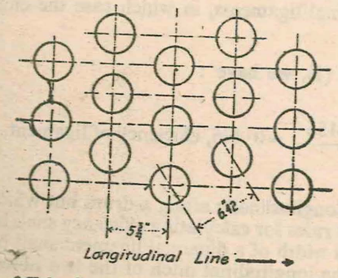


Fig. 13. Example of Tube Spacing with Tube Holes on Diagonal Lines.

To use the diagram in Fig. 14, the values of $\frac{p}{d}$ and $\frac{p}{p^1}$ are computed and the efficiency for the corresponding points is read off from the diagram. Should the point fall above the curve of equal efficiency for the diagoanl and

longitudinal ligaments, the longitudinal ligaments will be the weaker in which case the efficiency is computed from the following formula :—

$$\frac{p-d}{P}$$

Example.—(1) Diagonal pitch of tube holes in drum as shown in Fig. 13=6·42 in.

Diameter of holes=4-1/32 in.

Longitudinal pitch of tube holes=11-1/2 in.

$$\frac{p}{d}=\frac{11\cdot5}{4\cdot031}=2\cdot853,\ \frac{p^1}{p}=\frac{6\cdot42}{11\cdot5}=0\cdot558$$

The point corresponding to these values is shown at A on the diagram in Fig. 14 and the corresponding efficiency is 35·3 per cent. As the point falls below the curve of equal efficiency for the diagonal and longitudinal ligaments, the diagonal ligament is the weaker.

(2) Diagonal pitch of tube holes in drum .. .. .. =6–35/64 in.

Diameter of tube holes .. .. =4–1/64 in.

Longitudinal pitch of tube holes .. .. .. =7 in.

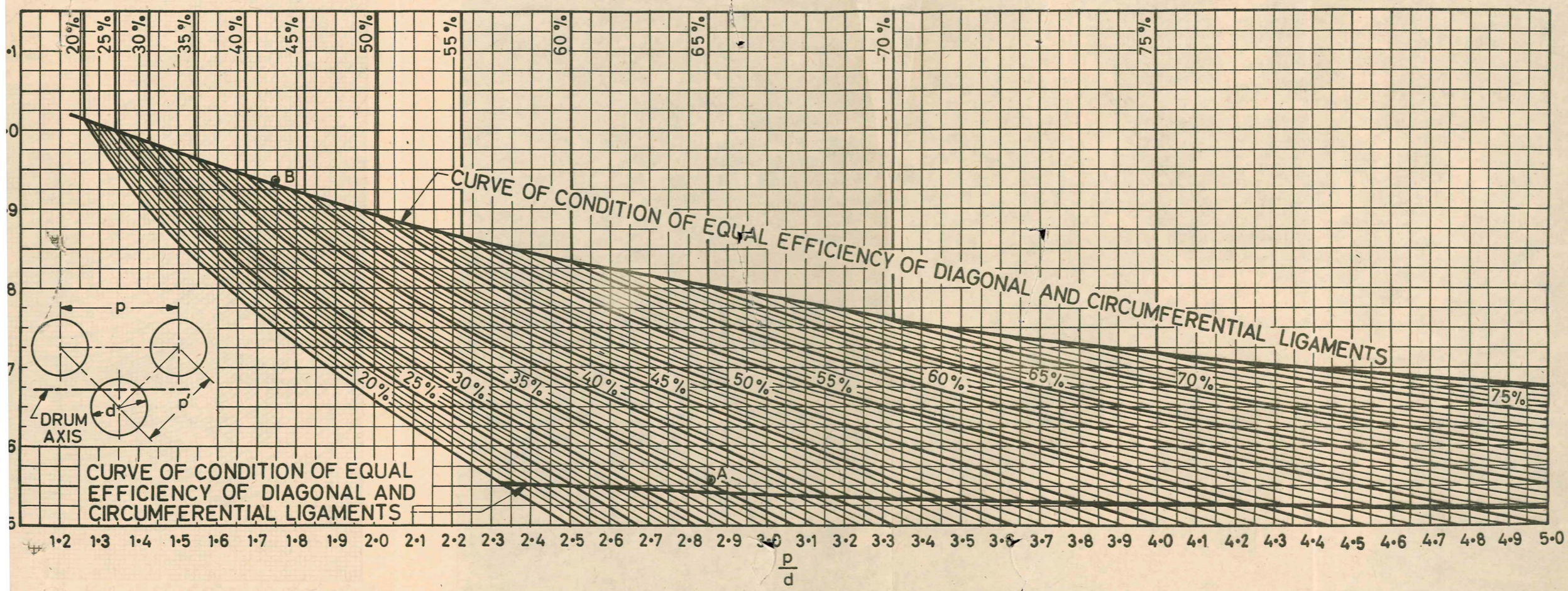
$$\frac{p}{d}=\frac{7}{4\cdot0156}=1\cdot743,\ \frac{p^1}{p}=\frac{6\cdot547}{7}=0\cdot935.$$

The point corresponding to these values is shown at B on the diagram in Fig. 14 and it will be seen that it falls above the line of equal efficiency for the diagonal and longitudinal ligaments, in which case the efficiency is computed from formula (1)

Applying formula (1), we have :

$$\frac{7-4\cdot0156}{7}=0\cdot426,$$ efficiency of ligament, or 42·6 per cent.

For holes placed longitudinally along a drum but which do not come in a straight line, the above rules for calculating efficiency shall hold, except that the equivalent longitudinal width of a diagonal ligament shall be used. To obtain the equivalent width the longitudinal pitch of the two holes having a diagonal ligament shall be multiplied by the efficiency of the diagonal ligament. The efficiency to be used for the diagonal ligaments is given in Fig. 15.


20%
25%
30%
35%
40%
45%
50%
55%
60%
65%
70%
75%
B
A
CURVE OF CONDITION OF EQUAL EFFICIENCY OF DIAGONAL AND CIRCUMFERENTIAL LIGAMENTS
p
d
p'
DRUM AXIS
CURVE OF CONDITION OF EQUAL EFFICIENCY OF DIAGONAL AND CIRCUMFERENTIAL LIGAMENTS
1·2 1·3 1·4 1·5 1·6 1·7 1·8 1·9 2·0 2·1 2·2 2·3 2·4 2·5 2·6 2·7 2·8 2·9 3·0 3·1 3·2 3·3 3·4 3·5 3·6 3·7 3·8 3·9 4·0 4·1 4·2 4·3 4·4 4·5 4·6 4·7 4·8 4·9 5·0
p/d

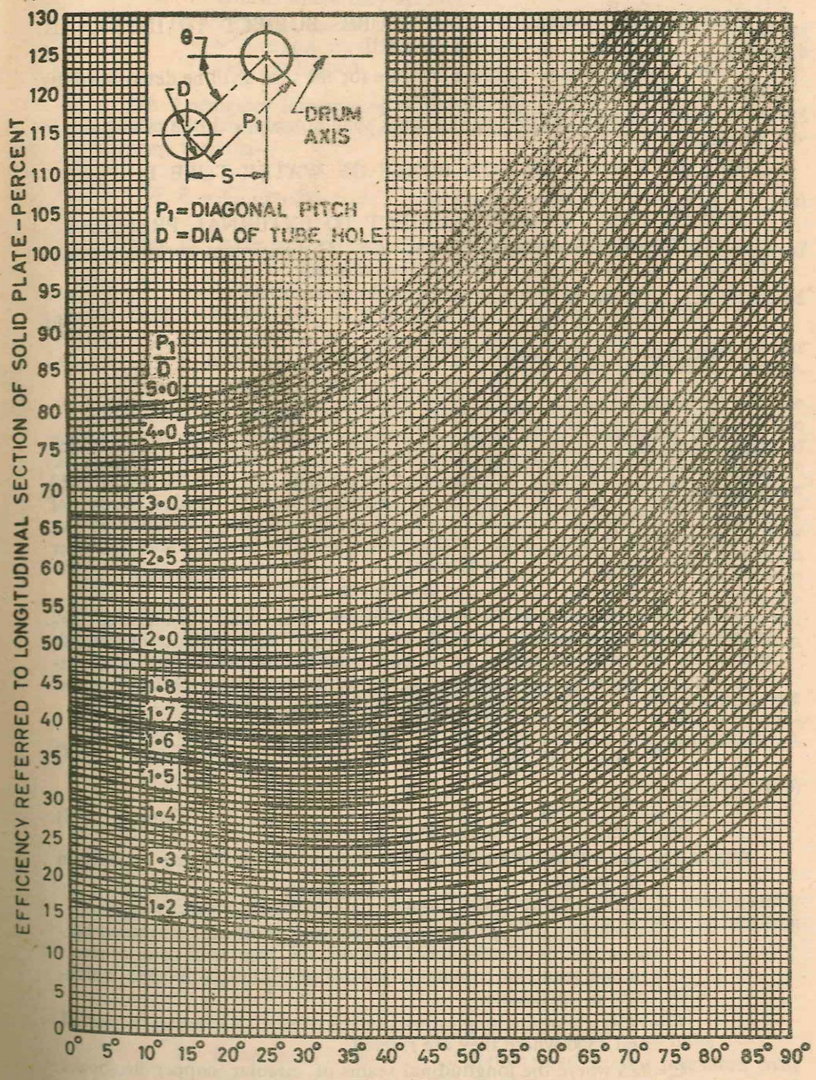


FIG. 15 DIAGRAM FOR DETERMINING EFFICIENCY OF DIAGONAL LIGAMENTS IN ORDER TO OBTAIN EQUIVALENT LONGITUDINAL EFFICIENCY

BOILER AND SUPERHEATER TUBES SUBJECT TO INTERNAL PRESSURE

216. The maximum working pressure for the tube shall be determined by equation No. 87 (*see* Regulation 338).

The minimum thickness of the tubes shall comply with the table given in Regulation 338 (b).

HEADERS AND SECTION BOXES OF WATER TUBE BOILERS

217. *See* Eqn. (88), Reg. (340).

BOILER TUBES (SMOKE) SUBJECT TO EXTERNAL PRESSURE

218. Steel and Wrought Iron Tubes.—(*a*) The maximum working pressure for the tubes shall be:—

$$W.P. = \frac{100\ (t-6)}{D} \quad .. \quad .. \quad .. \quad .. \quad .. \quad \text{Eqn. (56)}$$

Where t = the thickness of the tubes in 100ths of an inch.

D = the external diameter of the tubes in inches,

(*b*) No tube shall be less than 12 S.W.G. (·104″) thick.

219. Brass and Copper Tubes.—The thickness of tapered brass and copper smoke tubes for locomotive boilers shall, in the case of tubes of an external diameter of 1½ to 1-7/8 inches inclusive, be not less than 12 S.W.G. (·104 inch) at the smoke-box end and 10 S.W.G. (·128 inch) at the other and in the case of tubes of an external diameter of 2 to 2-3/8 inches inclusive, the thickness, at the smoke-box end shall not be less than 11 S.W.G. (·116 inch) and at the other end not less than 9 S.W.G. (·144 inch).

FURNACES

220. Plain Furnaces of Horizontal Boilers.—For plain furnaces or furnaces strengthened by Adamson or other joints or stiffeners of sufficient strength and for the semi-cylindrical tops of fire-boxes and bottom of combustion chambers where the sides are securely stayed, the working pressure shall not exceed the smaller of the values obtained from the following formulae :—

$$W.P. = \frac{C}{D} \times \frac{(t-1)^2}{(L+24)} \quad .. \quad .. \quad .. \quad .. \quad \text{Eqn. (57)}$$

$$W.P. = \frac{C_1}{D} \times [10(t-1)-L] \quad .. \quad .. \quad .. \quad .. \quad \text{Eqn. (58)}$$

Where D = the external diameter of the furnace or chamber top or bottom in inches,

t = the thickness of the furnace plate in 32nds of an inch,

L = the length of the furnace or other part in inches measured between points of substantial support, *i.e.*, centres of rows of rivets in end seams or commencement of curvature of flange, whichever is applicable,

C = 1450 where the longitudinal seams of steel furnaces are welded and 1300 where they are riveted,

C = 725 where the longitudinal seams of circular copper fire-boxes or furnaces are fitted with double butt straps and 650 where they are lapped,

C_1 = 50 where the longitudinal seams of steel furnaces are welded and 45 where they are riveted,

C_1 = 25 where the longitudinal seams of circular copper fire-boxes or furnaces are fitted with double butt straps and 22·5 where they are lapped.

221. Corrugated Furnaces of Horizontal Boilers.—The maximum working pressure to be allowed on corrugated furnaces shall be determined by the following formula—

$$W.P. = \frac{C}{D}(t-1) \quad .. \quad .. \quad .. \quad .. \quad .. \quad \text{Eqn. (59)}$$

Where D is the least external diameter in inches measured at the bottom of the corrugations on the water side,

t is the thickness of the furnace plate in 32nds of an inch measured at the bottom of the corrugation or chamber,

C = 480 for the Fox, Morrison, Deighton, Purves, and other similar furnaces and 510 for the leeds Forge Bulb Suspension Furnace.

222. Plain Furnaces of Vertical Boilers.—The same formulae as for the plain furnaces of horizontal boilers shall be used, but where the furnaces are tapered the diameter to be taken for calculation purposes shall be the mean of that at the top and of that at the bottom where it meets the substantial support from flange or ring. The length for the same purpose shall be the distance from the centre of the row of rivets connecting the crown and the body of the furnace to the substantial support at the bottom of the furnace, or to a row of screwed stays connecting the furnace to the shell, provided that the pitch of stays at the furnace does not exceed 14 times the thickness of the furnace plate when the stays are riveted at their ends or 16 times when the stays are fitted with nuts. Such screwed stays shall be in diameter over the threads not less than twice the thickness of the furnace plate and in no case less than ¾″ diameter [(*see* Reg. 135(d)].

223. Hemispherical Furnaces of Vertical Boilers.—When furnaces are hemispherical in form and subject to pressure on the convex side and are without support from stays of any kind, the maximum working pressure shall be:—

$$W.P. = \frac{275\ (t-1)}{R} \quad .. \quad .. \quad .. \quad .. \quad .. \quad \text{Eqn. (60)}$$

Where t is the thickness of the top plate in 32nds of an inch,

R is the outer radius of curvature of the furnace in inches.

224. Corrugated Fireboxes of Vertical Boilers.—For the semi-spirally corrugated fireboxes of "Sentinel" standard motor wagon boilers the working pressure shall be determined by the following formula :—

$$W.P. = \frac{C(t-1)}{D} \quad .. \quad .. \quad .. \quad .. \quad .. \quad \text{Eqn. (61)}$$

where t is the thickness of the firebox plate in 32nds of an inch,

D is the mean of the external diameters of firebox measured over the plain part at each end at commencement of curvature of flange,

C = 390.

225. Foundations of Vertical Boiler Furnaces.—Where circular furnaces, or fireboxes of vertical boilers are not connected to the shell crown by uptake tube, smoke tube or bolt stays and the whole load on the firebox vertically is borne by the bottom part of the firebox where it is connected to the shell the working pressure for the part, if firebox is joggled out to meet the shell or if an ogee ring is fitted, shall not exceed that found by the following formula:—

$$W.P. = \frac{140\,(t-1)^2}{D\,(D-D_1)} \quad .. \quad .. \quad .. \quad .. \quad .. \qquad \text{Eqn. (62)}$$

Where t is the thickness of the joggled firebox plate or ogee ring in 32nds of an inch,

D is the inside diameter of the boiler shell in inches,

D_1 is the outside diameter of the joggled firebox at the commencement of curvature above joggled part or the outside diameter of the firebox where it joins the ogee ring.

226. Foundations of Loco-type Boiler Fireboxes.—Where the firebox roof in loco-type boilers is not stayed direct to the external casing crown or to girders carried by the casing or is not connected to the casing, by slings in accordance with Regulation 229(c) and the whole load on the firebox vertically is borne by the bottom parts of the firebox where connected to the external casing, the working pressure for the parts, if plats are joggled out to meet the casing or if an ogee ring if fitted, shall not exceed that found by the following formula :—

$$W.P. = \frac{70(t-1)^2 \times (L+W)}{L \times W(W-W_1)} \quad .. \quad .. \quad .. \quad .. \qquad \text{Eqn. (63)}$$

where t is the thickness of the joggled firebox side plates or fire hole plate (whichever is less), or ogee ring in 32nds of an inch,

L is the length of firebox casing in inches measured between the water sides of front end plate and saddle plate at the foundation seam,

W is the width of firebox casing in inches measured between the water sides of casing side plates at the foundation seam,

W_1 is the width of firebox in inches measured between the water sides of fire-box side plates at the commencement of curvature above joggled part of where it joins the ogee ring.

Where only a comparatively narrow strip of the firebox roof is stayed directly to the casing crown the area so stayed shall be deducted from the area represented by $L \times W$ in the bottom line of the formula thus : $(L \times W - A)$ $(W - W_1)$ and so used in Equation (63) in determining the working pressure for the parts, "A" being the area in square inches of the part of roof supported by the casing crown.

227. Cross Tubes.—The working pressure of the tubes shall be determined by the following formula :—

$$W.P. = \frac{200\,(t-7)}{D} \quad .. \quad .. \quad .. \quad .. \quad .. \qquad \text{Eqn. (64)}$$

where W.P. = working pressure in lbs. per sq. inch,

t = minimum thickness in 32nds of an inch,

D = the internal diameter in inches of the cross tube.

228. Uptakes of Vertical Boilers.—The working pressure for uptake tube of vertical boilers shall be determined by Eqns. 57 and 58 but only half the least pressure so found is to be allowed for uptake tubes.

SUPPORTS FOR COMBUSTION CHAMBER AND FIREBOX CROWN

229. Girder stays for firebox crowns.—(*a*) For girders supporting crown plates of rectangular fireboxes, where the ends of the girders are supported by the vertical end or sideplates, their proportions shall be calculated from the following formula:—

$$W.P. = \frac{C\,S\,T\,D^2}{L^2 Y} \quad .. \quad .. \quad .. \quad .. \quad .. \qquad \text{Eqn. (65)}$$

where W.P. = Working pressure in lb. per sq. inch,

S = Minimum tensile stress of the material in tons per sq. inch,

T = Total thickness of the stay in thirty-seconds of an inch,

D = Depth of the girder stay in inches,

L = Length of girder stay in inches measured between the inside of the tube plate and the firehole plate, or between the inside of the side plates, according to the method of support,

Y = Pitch of girder stays in inches,

C = 22 for steel plates or steel forgings, 19 for steel castings.

(*b*) Where girders are supported in any other way than by the end or side plates of the firebox or combustion chamber the calculations for determining the working pressure shall be made in accordance with the actual conditions of support.

In such cases the length of the strip of firebox or combustion chamber top plate to be supported by the girder shall, subject to the limit imposed on the distance of the nearest stay, be taken as equal to the product of the number of bolts carried by the girder into the pitch of the bolts. A maximum nominal stress of 14,000 lbs. per square inch on girder section shall be allowed for steel.

(*c*) Slings, links pins, rivets, and connections to shell of slung girders shall be sufficient to carry the whole load that would otherwise be carried by the girder, and each girder must be equally slung or supported. For stresses allowed on the sections, *see* Regulation 203.

(*d*) In the case of girders supported at the ends only by angle bars riveted to the casing crown, the length L may, when the girder extends over the full breadth of the angle face, be taken as the distance between the centres of the angle faces. When this distance does not exceed that of L in the formula, the pressure shall be determined in the ordinary way. The supporting angles and rivets shall be of sufficient section for the intended purpose. For stresses allowed on the sections, *see* Regulation 203.

225. Foundations of Vertical Boiler Furnaces.—Where circular furnaces, or fireboxes of vertical boilers are not connected to the shell crown by uptake tube, smoke tube or bolt stays and the whole load on the firebox vertically is borne by the bottom part of the firebox where it is connected to the shell the working pressure for the part, if firebox is joggled out to meet the shell or if an ogee ring is fitted, shall not exceed that found by the following formula:—

$$W.P. = \frac{140\,(t-1)^2}{D\,(D-D_1)} \quad .. \quad .. \quad .. \quad .. \quad .. \qquad \text{Eqn. (62)}$$

Where t is the thickness of the joggled firebox plate or ogee ring in 32nds of an inch,

D is the inside diameter of the boiler shell in inches,

D_1 is the outside diameter of the joggled firebox at the commencement of curvature above joggled part or the outside diameter of the firebox where it joins the ogee ring.

226. Foundations of Loco-type Boiler Fireboxes.—Where the firebox roof in loco-type boilers is not stayed direct to the external casing crown or to girders carried by the casing or is not connected to the casing, by slings in accordance with Regulation 229(c) and the whole load on the firebox vertically is borne by the bottom parts of the firebox where connected to the external casing, the working pressure for the parts, if plats are joggled out to meet the casing or if an ogee ring if fitted, shall not exceed that found by the following formula :—

$$W.P. = \frac{70(t-1)^2 \times (L+W)}{L \times W(W-W_1)} \quad .. \quad .. \quad .. \quad .. \qquad \text{Eqn. (63)}$$

where t is the thickness of the joggled firebox side plates or fire hole plate (whichever is less), or ogee ring in 32nds of an inch,

L is the length of firebox casing in inches measured between the water sides of front end plate and saddle plate at the foundation seam,

W is the width of firebox casing in inches measured between the water sides of casing side plates at the foundation seam,

W_1 is the width of firebox in inches measured between the water sides of fire-box side plates at the commencement of curvature above joggled part of where it joins the ogee ring.

Where only a comparatively narrow strip of the firebox roof is stayed directly to the casing crown the area so stayed shall be deducted from the area represented by L×W in the bottom line of the formula thus : $(L \times W - A)$ $(W-W_1)$ and so used in Equation (63) in determining the working pressure for the parts, "A" being the area in square inches of the part of roof supported by the casing crown.

227. Cross Tubes.—The working pressure of the tubes shall be determined by the following formula :—

$$W.P. = \frac{200\,(t-7)}{D} \quad .. \quad .. \quad .. \quad .. \quad .. \qquad \text{Eqn. (64)}$$

where W.P. = working pressure in lbs. per sq. inch,

t = minimum thickness in 32nds of an inch,

D = the internal diameter in inches of the cross tube.

228. Uptakes of Vertical Boilers.—The working pressure for uptake tube of vertical boilers shall be determined by Eqns. 57 and 58 but only half the least pressure so found is to be allowed for uptake tubes.

SUPPORTS FOR COMBUSTION CHAMBER AND FIREBOX CROWN

229. Girder stays for firebox crowns.—(*a*) For girders supporting crown plates of rectangular fireboxes, where the ends of the girders are supported by the vertical end or sideplates, their proportions shall be calculated from the following formula:—

$$W.P. = \frac{C\,S\,T\,D^2}{L^2 Y} \quad .. \quad .. \quad .. \quad .. \quad .. \qquad \text{Eqn. (65)}$$

where W.P. = Working pressure in lb. per sq. inch,

S = Minimum tensile stress of the material in tons per sq. inch,

T = Total thickness of the stay in thirty-seconds of an inch,

D = Depth of the girder stay in inches,

L = Length of girder stay in inches measured between the inside of the tube plate and the firehole plate, or between the inside of the side plates, according to the method of support,

Y = Pitch of girder stays in inches,

C = 22 for steel plates or steel forgings, 19 for steel castings.

(*b*) Where girders are supported in any other way than by the end or side plates of the firebox or combustion chamber the calculations for determining the working pressure shall be made in accordance with the actual conditions of support.

In such cases the length of the strip of firebox or combustion chamber top plate to be supported by the girder shall, subject to the limit imposed on the distance of the nearest stay, be taken as equal to the product of the number of bolts carried by the girder into the pitch of the bolts. A maximum nominal stress of 14,000 lbs. per square inch on girder section shall be allowed for steel.

(*c*) Slings, links pins, rivets, and connections to shell of slung girders shall be sufficient to carry the whole load that would otherwise be carried by the girder, and each girder must be equally slung or supported. For stresses allowed on the sections, *see* Regulation 203.

(*d*) In the case of girders supported at the ends only by angle bars riveted to the casing crown, the length L may, when the girder extends over the full breadth of the angle face, be aken as the distance between the centres of the angle faces. When this distance does not exceed that of L in the formula, the pressure shall be determined in the ordinary way. The supporting angles and rivets shall be of sufficient section for the intended purpose. For stresses allowed on the sections, *see* Regulation 203.

PATENT FIREBOX ROOFS OF LOCOTYPE BOILERS

230. Marshall Type.—For Messrs. Marshall Sons and Company's patent stayless roof for fireboxes of locotype boilers made of steel in which the centre lines of the corrugations meet the centre lines of the end riveted seams at points not farther distance from the side plates than one-half the inner radius of curvature of the corner formed by the roof and side plate, in order to ensure that the thickness and height of the pressed diagonal corrugations of the chamber are satisfactory, the working pressure shall not exceed the smaller of the values obtained from the following formulae :—

$$\text{W.P.} = \frac{25000\,(t-1)\times H^2}{W\times L\times\sqrt{W^2+L^2}} \quad \text{Eqn. (66)}$$

$$\text{W.P.} = \frac{55(t-1)^2\times(W+\sqrt{W^2\times L^2})^2}{W^2\times L^2} \quad \text{Eqn. (67)}$$

where t is the thickness of the roof plate in 32nds of an inch,

H is the height of the corrugation at its highest part measured perpendicularly on one side of the plate in inches,

W is the width of the roof plate between the flat of side plates at top less the inner radius of curvature of corner of roof and side plate in inches, *i.e.*, W+radius=internal width of firebox at top,

L is the length of the roof plate between centre lines of rivets in inches.

231. Garrett Type.—For Messrs. Richard Garrett and Son's corrugated stayless roof for fireboxes of locotype boilers made of steel in which the side corrugations are parts of true circles and the radius of the middle corrugation is not more than about $\frac{1}{4}$th of the radius of the outer corrugations and the corrugations are cambered longitudinally, the working pressure shall not exceed the smaller of the values obtained from the following formulae :—

$$\text{W.P.} = \frac{C}{R}\times\frac{(t-1)^2}{(L+24)} \quad \text{Eqn. (68)}$$

$$\text{W.P.} = \frac{C_1}{R}\,[10(t-1)-L] \quad \text{Eqn. (69)}$$

where t is the thickness of the corrugated plate in 32nds of an inch,

L is the length of the roof plate between centre lines if rivets in inches,

R is the external radius of the side corrugations at the middle of the length in inches,

C=363 where the roof and side plates are in one piece and 325 when they are riveted,

C_1=12·5 where the roof and side plates are in one piece and 11·25 where they are riveted.

232. Fowler Type.—(*a*) For Messrs. John Fowler and Company's (Leeds) corrugated roof for fireboxes of locotype boilers made of steel in which the

crown of the roof is transversely curved and corrugated in the style of Fox's corrugated furnace and the roof plate, if not solid with the side plates of the firebox, is securely riveted thereto and to the flanges of the tube plate and firehole plate and there is a row of suitably sized and spaced screw stays below the commencement of corrugations on each side attaching the roof plate to the external casing, when the conditions hereunder are complied with, the working pressure shall not exceed the smaller of the values obtained from the following formulae:—

$$\text{W.P.} = \frac{C(t-3)}{R} \quad \text{Eqn. (70)}$$

$$\text{W.P.} = \frac{C_1(t_1-1)}{W} \quad \text{Eqn. (71)}$$

where t is the thickness of roof plate before corrugations are formed, in 32nds of an inch,

t_1 is the thickness of side plates of firebox to which roof plate is attached, in 32nds of an inch,

R=the radius of transverse curvature or camber of middle part of corrugation measured from the bottom of corrugation on water side in inches,

W=the width of firebox in inches measured over water sides of side plates at the seams attaching them to roof plate,

C=240,

C_1= 875

(*b*) The corrugations measured from top to bottom on one side, shall not be less than three times the thickness of the finished plate in depth and not more than 12 times the thickness of the finished plate apart.

(*c*) The inner radius of corner at sides where corrugations merge into the flat sides shall be not less than 4 times the thickness of the finished plate.

(*d*) The length of the plain parts at ends of roof between the centre lines of riveted seams and commencement of curvature of corrugations shall not exceed that allowed for flat plate margins under Regulation 200.