SECTION III.

THE CONSTRUCTION OF MACHINE ELEMENTS.

INTRODUCTORY.

Under the title of "Machine Elements" we may consider those single or grouped parts which are employed to a greater or less extent in all forms of machinery. It is not practicable to determine their number, nor, indeed, is that matter of importance, since the selection of groups and details is not based upon any positive or generally accepted system. The following selection of the constructive elements of machinery may be found useful and convenient, which is the principal end to be achieved.

In the previous sections a number of general formulae have been given, while in the cases which follow detailed examples are selected. The dimensions and weights of the parts expressed in inches and pounds, except where otherwise distinctly stated; velocities in feet per second; and rotations in turns per minute. The measure of force is the pound; that of work in foot pounds; and of power, or for larger quantities in horse-power (33,000 foot pounds).\(^*\)

CHAPTER I.

RIVETING.

§ 54.

RIVETS.

Rivets are principally used for joining sheet metals or other flat shapes together for the construction of a variety of sheet and framed structures. They may be considered as a fundamental machine element acting to transform detailed parts into combinations.

In the illustrations various forms of rivets are shown. The common wrought-iron rivet is shown in Fig. 132, with the button head, while Fig. 133 shows the conical head generally formed by hand riveting. The length of body required to form the head varies from 1 1/2 to 1 7/8 times the diameter; according to the completeness with which the rivet fills the hole. When the head is formed by dies instead of the hand hammer, the shape is usually conical or spherical, as in Figs. 134-135.

The slight bevel given to each end of the rivet, as shown in Fig. 136, adds materially to its strength. The double conical hole shown in Fig. 137 assists in uniting the plates, and this shape may be produced by using in the punching machine a die slightly larger than the diameter of the punch. This difference has been experimentally determined for wrought-iron plates, and is secured by making the hole in the die equal to the diameter of the punch plus 1/4 the thickness of the plate.

In Fig. 138 a rivet is shown a form of countersunk rivet used in shipbuilding.

For bridge construction great care should be taken in the choice of proportions. Figs. 137-139 show the proportions adopted for the Dirscharner Bridge after the careful researches of the engineer Krüger. Fig. 137 shows the normal rivet head, and Figs. 138 and 139 the half and full countersunk heads. Rivets up to 1 1/2 inches in diameter may readily be closed with hammers of 8 to 10 pounds weight; but if the head is to be formed in a swage or die, a heavier hammer, say 25 pounds weight, is necessary.

The rate at which this work can be done by skillful riveters per day, according to Molinari and Premoli, is as follows:

<table>
<thead>
<tr>
<th>Diameter of rivet</th>
<th>No. per Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/16&quot;</td>
<td>200 to 250</td>
</tr>
<tr>
<td>1/4&quot;</td>
<td>120 to 200</td>
</tr>
<tr>
<td>5/32&quot;</td>
<td>100 to 125</td>
</tr>
<tr>
<td>3/32&quot;</td>
<td>90 to 120</td>
</tr>
</tbody>
</table>

These figures are for horizontal bridge work; on vertical members about three-fourths these numbers may be taken.

In cylindrical shells of more than three feet diameter these rivets may be increased ten per cent., while for awkward or difficult work ten per cent. reduction should be made. Each man had the assistance of two strikers, one holder and one boy, sizes less than 3/32" requiring but one striker.

Hand riveting is now being largely superseded by machine work. These machines possess the advantage of performing the work much more rapidly, thus insuring a stronger joint, besides which they are much more economical. Since their first introduction at the time of the building of the Conwy Bridge, they have been extensively used for bridge work, and with the improvements which have been successively made they are rapidly displacing hand riveting for boiler work.\(^*\)

Among modern riveting machines the hydraulic riveter of Bredikhoff holds the first place. For a description the following references may serve: Poly Blum, Zentralblatt, 1879, p. 141; Engler's Engineering, Jan. 24th, 1879, p. 76; Scherer's Improved Bredikhoff's Machine, Jour. of, 1878, 1879, p. 289; Tweddle's Machine, Am. Machin., 1879, p. 293; Small Tweddle Machine, Revue Industr., 1879, p. 95.

Other forms of steam and hydraulic riveters well suited for boiler work are:

E. Garforth's Machine, Economist's, 1873, Johnson's Imp. Age, Pl. 49; the excellent steam riveter of Ginn, see Molinez & Premoli, Firms, Metalurgica, p. 175; also the hydraulic riveter at Crewe (giving a pressure of 19 tons per square inch) and closing 325 heads per minute. Neve Enders, 1875, p. 230; also the very heavy machines of Ely & S. George (giving a pressure of 1 ton per square inch) and riveting 273 rivets per minute. These machines are very ingenious and are in use in various parts of the country. At the Philadelphia Centennial Exhibition this machine closed three or more rivets per minute.

\(^*\) These quantities are all given in metric units in the original, but have been transformed in the text into English units. It must be remembered that the metric horsepower (12.7 kw) is slightly smaller than the English horse-power. — Trans.


\[ \frac{d}{\delta} = \frac{\pi}{2} \left( \frac{d}{\delta} \right) \left( \frac{d}{\delta} \right) \]

which gives:

\[ \varphi = \frac{1}{2} \frac{d}{\delta} \]

or for butt joint riveting:

\[ \frac{d}{\delta} = \frac{\pi}{2} \left( \frac{d}{\delta} \right) \left( \frac{d}{\delta} \right) \]

which gives:

\[ \varphi = \frac{1}{2} \frac{d}{\delta} \]

The overlap of the plate is subjected both to shearing and bending. For the former conditions, call the lap \( b' \), and for the latter \( b'' \), measuring in both cases from the centre of the rivets to the edge of the joint. To obtain the same resistance in the lap as in the perforated portion of the plate we have:

For lap joint riveting:

\[ \frac{b'}{\delta} = \frac{\pi}{8} \frac{a-d}{\delta} = \frac{\pi}{8} \left( \frac{d}{\delta} \right)^2 \]

\[ \frac{b''}{\delta} = \frac{0.5 + 0.60}{ \delta } \sqrt{ \frac{d}{\delta} } \]

For butt joint riveting:

\[ \frac{b'}{\delta} = \frac{\pi}{8} \frac{a-d}{\delta} = \frac{\pi}{8} \left( \frac{d}{\delta} \right)^2 \]

\[ \frac{b''}{\delta} = \frac{0.5 + 0.79}{ \delta } \sqrt{ \frac{d}{\delta} } \]
If now we assume that the force $P$, upon each strip between the dotted lines, is equally divided among the rivets, we have for the efficiency of the first row:

\[
\frac{a}{d} = m \pi \left( \frac{d}{d} \right)^n + \frac{1}{m} \frac{d}{d} \]

or

\[
\frac{a}{d} = m \pi \left( \frac{d}{d} \right)^n + \frac{1}{m}
\]

If the stress in the punched plate in the lines I, II, III, IV, etc., Fig. 146, be called $S_{II}$, $S_{III}$, $S_{IV}$, etc., we have:

\[
P = S_{II} \left( m a - \frac{a}{d} \right) \delta
\]

\[
= S_{II} \left( m a - \frac{a}{d} \right) \frac{m^2}{m^2 - 1} \delta
\]

\[
= S_{III} \left( m a - \frac{a}{d} \right) \frac{m^2}{m^2 - 3} \delta
\]

\[
= S_{IV} \left( m a - \frac{a}{d} \right) \frac{m^2}{m^2 - 6} \delta
\]

and from this when $S_{II} = S_{III}$ we have:

\[
\frac{a}{d} = m^2 + 1
\]

And upon the same supposition:

\[
S_{III} = m a - \frac{a}{d}
\]

\[
S_{IV} = m a - \frac{a}{d}
\]

that is, the stresses at the lines III, IV, V, are smaller than $S_{II} = S_{III}$. The useful application of this fact may be readily seen.

Let us introduce in (50):

\[
\frac{d}{a} = \frac{a}{m} = 1.5915, \text{ or say 1.6}
\]

that is, we make the ratio of $d$ of constant and = 1.6. For the modulus of the efficiency of the joint $\phi$, when the stress in the solid plate is $S_{II}$, we have:

\[
\phi = \frac{S_{II}}{S_{II}} = 1: \frac{a}{m a} = \frac{a}{m a} + 1
\]

We also have for the pressure $P$, on the rivets:

\[
P = \frac{m^2 \delta}{m a}
\]

Tabulating the results of the applications of these equations to various groups we have:

<table>
<thead>
<tr>
<th>$m$</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\frac{d}{a}$</td>
<td>1.6</td>
<td>1.6</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>$\frac{a}{d}$</td>
<td>2.50</td>
<td>3.33</td>
<td>4.25</td>
<td>5.20</td>
</tr>
<tr>
<td>$\frac{a}{\delta}$</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>$\phi$</td>
<td>0.90</td>
<td>0.90</td>
<td>0.94</td>
<td>0.96</td>
</tr>
</tbody>
</table>

For joining narrow plates the rivets may often be disposed in double groups, while for the union of several plates, as in the construction of plate girders, a number of groups may be em-
The following table contains the collected results of the preceding formulæ for the more commonly occurring proportions:

<table>
<thead>
<tr>
<th>Modulus of Efficiency, $\phi'$, $\phi''$, $\phi'''$</th>
<th>Weight of Plate, $W$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\phi'$</td>
<td>$\phi''$</td>
</tr>
<tr>
<td>$\phi'''$</td>
<td></td>
</tr>
</tbody>
</table>

### Section 58.

**Steam Boiler Riveting.**

For the joints of steam boilers parallel riveting is generally used. In this case the question of the tightness of the joint prevents a wide spacing of the rivets. For the same reason the thinner plates require proportionally larger rivets than the heavier plates, and the lap of the plates, and also of the rivet heads, must be greater. The method of caulking is also to be considered. The older method consisted in driving the caulking chisel into the perpendicular edge of the plate and forcing the lower edge of the groove thus made down upon the lower plate, as shown in Fig. 149 A. The modern method, shown in Fig. 150, requires the plate to be planed on the edge to an angle, which can then be caulked without grooving. The angle of bevel should be about $15^\circ$, or about $1$ in $3$.

The method of the American, Conner, consists in the use of a round nosed caulked tool, Fig. 151, which is much less liable to injure the lower plate than the sharp chisel of the previous methods; the action extends farther into the plate also.

The consideration of the tightness of the joint compels a modification of the theoretical treatment of the proportions of boiler seams, based upon practical experience.

According to Lemoître the following proportions are suitable for single riveted joints:

\[
a = 3.5d + 0.167 \\
b = 1.5d
\]

Double riveted joints are also much used for steam boilers, especially for the longitudinal seams, while single riveting is used for the circumferential joints, since the stress upon the longitudinal joints is much greater than upon the circumferential joints.

For double riveted joints, that is, for riveting in two parallel rows, we have for the pitch $a'$ of the rivets in each row:

\[
a' = 3.5d + 0.187
\]

while the space between the two rows may be taken as equal to the previous value of $a$, or $2d + 0.34d$.

In some cases this value is used for the pitch of both rows (see Fig. 153).

We have previously taken the modulus of efficiency $\phi$, so that the rivets and the perforated plate have not the same degree of security. The values of $\phi'$ for the rivets and for the plate should therefore be determined separately, and the smaller value taken for that of the completed joint. Let:

\[
\phi' = \text{modulus for the perforated plate} \\
\phi'' = \text{that of the rivets}
\]

then according to the previous formulæ we have:

\[
\phi' = \frac{a - b}{a} \\
\phi'' = \frac{\phi' a'^2}{5}
\]

For the pressure $p$ upon the body of the rivet we have finally, both for single and double joints,

\[
P_S = \frac{p}{5} \left( 4 \left( 1 + 0.6 \right) \right)
\]

The stress $S_S$ in the perforated plates of boiler shells is not generally permitted to exceed 5000 pounds per square inch of cross section.
THE CONSTRUCTOR.

The rivet length is \( = \pi + 1.74\pi \), upon the assumption that both plates are of the thickness \( b \), and this length gives an ample allowance for the full clearance of the rivet holes (see \( \pm 54 \)). The last column is of service in making estimates of weight.

Fig. 153 is a graphical presentation of the principal results of the preceding formula. It will be noticed that for single riveting the modulus \( \phi'' \) for the rivets, is always less than the modulus \( \phi' \) for the perforated plate, and that nearly always less than \( \frac{1}{2} \). It follows that for single riveted joints of steam boilers we should never assume a greater strength than one-half that of the solid plate. By the adoption of double riveting, while retaining the same pitch, \( a = 2a + 0.4\pi \), we ought to obtain, according to the formula of \( \pm 55 \), a value of \( \phi'' \), twice as great, which in the case of very light plates would be more surely, and in case of very light plates would be more surely. In that case, however, the value of \( \phi'' \) is the lesser, and it determines the efficiency of the joint, so that the only gain due to the double riveting in that case is the increase in the value of \( \phi'' \). If, however, we choose for double riveting the pitch \( \phi'' \), as given from equation (57), both \( \phi' \) and \( \phi'' \) will be increased in value. The lesser of the two moduli is that for the rivets, and its value is obtained from

\[
\phi'' = \frac{3}{2a} \left( \frac{d}{3a} \right) \quad (66)
\]

Its value lies between 0.75 and 0.55, and is shown in the table and diagram. The pressure \( \phi' \) in all cases remains within practicable limits.

![Fig. 153](image1.png)

![Fig. 154](image2.png)

![Fig. 155](image3.png)

Three rows of rivets are used in this form of joint, and the outside rows of wide pitch make this method more troubleless of execution than the group riveting shown in Fig. 144, which has a modulus of 0.60. This is a point which should be borne in mind.

The joints of gussets exhibit but little variety in plates or rivets. The rivets are usually about \( \frac{1}{3} \) to \( \frac{1}{6} \) in diameter and \( \frac{1}{6} \) pitch, with a lap at the joint of about \( \frac{1}{6} \), the rivets being clinched cold and the joints combed with red lead.

### TABLE OF THE WEIGHT OF SHEET METAL

<table>
<thead>
<tr>
<th>Thickness in</th>
<th>Weight in Pounds per Square Foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inch</td>
<td>Wro. Iron</td>
</tr>
<tr>
<td>( \frac{1}{16} )</td>
<td>2.53</td>
</tr>
<tr>
<td>( \frac{1}{8} )</td>
<td>4.05</td>
</tr>
<tr>
<td>( \frac{1}{4} )</td>
<td>7.58</td>
</tr>
<tr>
<td>( \frac{3}{16} )</td>
<td>10.10</td>
</tr>
<tr>
<td>( \frac{5}{16} )</td>
<td>12.65</td>
</tr>
<tr>
<td>( \frac{3}{8} )</td>
<td>17.76</td>
</tr>
<tr>
<td>( \frac{1}{2} )</td>
<td>22.78</td>
</tr>
<tr>
<td>( \frac{5}{16} )</td>
<td>27.75</td>
</tr>
<tr>
<td>( \frac{3}{8} )</td>
<td>32.76</td>
</tr>
<tr>
<td>( \frac{1}{2} )</td>
<td>37.79</td>
</tr>
<tr>
<td>( \frac{5}{16} )</td>
<td>42.81</td>
</tr>
</tbody>
</table>

### SPECIAL FORMS OF RIVETED JOINTS

#### Junction of Several Plates

In Fig. 156 is shown the junction of three plates. In this case the corner of sheet No. 2 is beveled off and No. 1 worked down over the lap.

![Fig. 156](image4.png)

In Fig. 157 the junction of four plates is shown. Here the angles of sheets Nos. 2 and 3 are beveled and Nos. 1 and 4 are left unaltered. In the construction of steam boilers the shell may be formed either in cylindrical sections, as shown in Fig. 158, or in sections of a conical shape, the taper of all the sections bearing the same relation to the direction of the flame as shown in Fig. 159. This latter method requires that a slight curvature should be given to the sheets in order to secure the required taper. The determination of the taper and curvature of the sheets and lines for the rivet holes may be made in the following manner:

![Fig. 157](image5.png)

![Fig. 158](image6.png)

![Fig. 159](image7.png)
LET—

\[ D = \text{the diameter of the shell, as in Fig. 159,} \]

\[ b = \text{the breadth of the sheet, Fig. 160, on a circumferential seam,} \]

\[ L = \text{the length of the sheet between pitch lines of rivets,} \]

\[ f = \text{the versed sine of the arc } \theta; \text{ we then have:} \]

\[ f = \frac{\theta}{2} \theta \frac{D}{L} \]

(51)

**Fig. 156.**

EXAMPLES. In a riveted tube where each section is made of an entire sheet we have \( b = \frac{nD}{2} \). If the breadth \( b \) is twice the length \( L \), we have

\[ \frac{L}{b} = \frac{1}{2} \times \frac{1}{2} = \frac{1}{4} \]

so that \( f \) will be a little greater than \( \frac{1}{2} \) times the thickness of the plate.

In arranging the junction of sheets when the flange joint is employed, care must be taken to avoid complicated intersections. This is best accomplished by making the flaps on the longitudinal and circumferential seams come on opposite sides of the plates. Where the flaps are both on the same side, they are sometimes let into each other.

**Reinforcement of Plates.**—This may often be done very readily by the use of angle and \( T \) iron. In Fig. 161 is shown an internal angle iron, and in Fig. 162 an external, and in Fig. 163 a simple \( T \) iron. The proportions for angle iron given by Reitenbacher are as follows:

\[ h = \text{height of angle arm,} \]

\[ \delta = \text{thickness.} \]

\[ h = 4 \delta + 1' \]

For \( T \) iron \( h_i = \text{the base } = 8 \delta + 2', \) and the height of the rib = \( \frac{1}{2} h_i \). In practice a great variety of proportions are made to suit all possible cases, examples of which may be found in the illustrated catalogues of the mills where they are rolled.

**Fig. 167.**

**Fig. 168.**

**Fig. 169.**

**Construction of Angles** (Figs. 167-173).—Angle junctions in riveted work are made either by flanging the plate or by the use of angle iron. In Fig. 167 the flange is turned inward, and in Fig. 168 it is turned outward. In these cases \( b \) is made the same as for angle iron of the same thickness. Figs. 169 and 170 show the use of internal and external angle iron.

**Fig. 171.**

**Fig. 172.**

**Construction of Solid Angles.**—These are the most difficult forms of riveted work, and may be made in several manners, the most important being shown in the illustrations. In Fig. 171 the vertical angle is made as in Fig. 167, and the horizontal angles as in Fig. 169, sheet No. 2 being beveled under the angle iron. In Fig. 172 all three angles are made as in Fig. 169, the vertical angle iron being cut and bent over the horizontal. In Fig. 173 the angles are all made as in Fig. 169, but the angle irons are welded together at their junction. This makes an excellent piece of work, but is difficult and expensive, and requires firm support for the work, and is only applicable for important constructions. In Fig. 174 the vertical angle is made like Fig. 169, while the lower joint is made as in Fig. 170, making simple and substantial corner.