Measurement of rivet-head wastage using height

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1 Introduction

Rivet heads in certain locations of a riveted boiler are subject to loss of volume through corrosion caused by interaction between moisture and deposited products of combustion over time. The loss is called "wastage" and rivet heads affected by it are characterized as "wasted". The visual appearance of a wasted rivet is a reduction in the size of its head and an irregular surface. The material around the rivet head – that which is being fastened by the rivet – may also suffer wastage.

The amount of wastage can be approximated by measuring the height of a wasted rivet and comparing it to the factory height of a rivet with the same diameter. Section 3 shows how to determine the volume mathematically and provides tabulated calculations for volumes of rivets with incrementally reduced height. Section 4 restates the allowable wastage according to NBIC and compares the techniques of interpolation and direct calculation when interpreting measurement results.

Section 5 describes the procedure for accurate measurement of rivet heights in the field.

2 Summary of procedure

Use these steps to provide a report on rivet wastage.

1. Establish a numbering scheme for the rivets in question.
2. Select a control rivet and add it to the numbering scheme. A control rivet is one that most resembles the originally installed rivets and shows no deterioration.
3. Establish whether the rivets to be measured are under tension, shear or both.
4. Measure and record the height of each rivet in the numbering scheme using the technique of Section 5.
5. Lookup and record the remaining volume of each measured rivet from Table 2. or Table 3..
6. Used the remaining volume and the allowance in Table 3 to determine which rivets pass or fail.

3 Change of Volume Through Deterioration

This section explains how deterioration affects volume. Even though the height of a deteriorated rivet decreases linearly, the resulting change in volume scales with the cube of that reduction. Numerical examples illustrate the magnitude of this effect

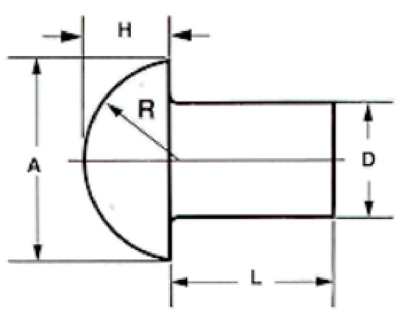


Fig. 1 Button-Head Rivet[1]: $A_{B(D)} \to 1.750D$, $H_{B(D)} \to 0.750D$, $R_{B(D)} \to 0.885D$

Button-head rivets have the shape of a truncated hemisphere, also known as a spherical cap. The volume of a spherical cap is given by

$$V(H,R) = \frac{1}{3} \cdot \pi H^2 (3R - H)$$

Steeple-head rivets have a conical shape with a right angle at the peak, a height equal to the diameter of the shank, and a base twice the height.

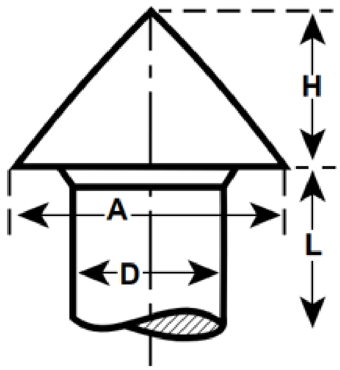


Fig. 2 Steeple-Head rivet: $A_{S(D)} \to 2D$, $H_{S(D)} \to 1D$

The volume of a steeple-head rivet is given by

$$V_{(A,H)} \to \frac{\pi\left(\frac{A}{2}\right)^2 H}{3}$$

but with $A = 2H$, this becomes

$$V_{(H)} \to \frac{\pi H^3}{3}$$

For commonly used rivets with $\frac{11}{16}$ in and $\frac{3}{4}$ in diameters, application of these formulae, along with the dimensions for rivet heads given in Fig. 1 and Fig. 2, yields dimensions shown in Table 1..

Table 1. Rivet Dimensions

	Button Head			**Steeple Head**	
D	Width	Height	Radius	Width	Height
	$A_B(D)$	$H_B(D)$	$R_B(D)$	$A_S(D)$	$H_S(D)$
$D = \frac{11}{16}$	1.203	0.516	0.608	1.375	0.688
$D = \frac{3}{4}$	1.313	0.563	0.664	1.500	0.750

3.1 Button-head rivets

The volume of a button-head rivet after deterioration can be approximated by treating the head as a spherical cap whose height and radius have both been reduced by the same amount. This assumes that material loss occurs uniformly over the exposed surface. Because the shank diameter remains unchanged, the center of curvature of the spherical head stays fixed, and only the cap’s height and effective radius decrease. That is,

$$V_{B(D,\Delta)} \to \frac{1}{3} \cdot \pi H(D,\Delta)^2 (3R(D,\Delta) - H(D,\Delta)) \text{ where } \begin{cases} H_{(D,\Delta_H)} \to 0.750D + \Delta_H \\ R_{(D,\Delta_R)} \to 0.885D + \Delta_R \end{cases}$$

where $\Delta = \Delta_H = \Delta_R$ and $\Delta \leq 0$ indicates a reduction in head height.

Given this, the affect on volume of a reduction in height is given by

$Rem_B(D, \Delta) = \frac{V(D,-\Delta)}{V(D,0)}$

Table 2. Calculated effect of change in height on button-head volume

11/16 in			3/4 in		
Δ Height	Volume	Remaining	Δ Height	Volume	Remaining
0	0.365	1	0	0.473	1
−0.025	0.318	0.871	−0.025	0.417	0.881
−0.050	0.275	0.753	−0.050	0.365	0.772
−0.075	0.236	0.647	−0.075	0.318	0.672
−0.100	0.201	0.551	−0.100	0.275	0.581
−0.125	0.169	0.464	−0.125	0.236	0.499
−0.150	0.141	0.388	−0.150	0.201	0.425
−0.175	0.117	0.320	−0.175	0.170	0.358
−0.200	0.095	0.260	−0.200	0.142	0.299
−0.225	0.076	0.209	−0.225	0.117	0.247
−0.250	0.060	0.164	−0.250	0.095	0.201
−0.275	0.046	0.126	−0.275	0.076	0.161
−0.300	0.035	0.095	−0.300	0.060	0.126

Table 2. presents the remaining volume after the rivet head height is reduced in increments of 0.025 in for two different rivet sizes. The values show how successive linear reductions in height translate into progressively larger changes in volume.

For example, after a height loss of 0.1 in, the remaining volumes are 55.1% and 58.1% for the two rivet sizes. This highlights how a modest linear reduction in height produces a substantial nonlinear reduction in volume.

3.2 Steeple-head Rivets

The formula for volume loss for steeple-head rivets is given by

$$V_{S(D,\Delta)} \to \frac{1}{3} \cdot \pi H(D, \Delta)^3 \text{ where } H_{(D,\Delta_H)} \to H_S(D) + \Delta_H$$

Table 3. Calculated effect of change in height on steeple-head volume

$$
\begin{bmatrix}
 & 11/16\text{ in} & & & 3/4\text{ in} & \\
\Delta\text{ Height} & \text{Volume} & \text{Remaining} & \Delta\text{ Height} & \text{Volume} & \text{Remaining} \\
0 & 0.340 & 1 & 0 & 0.442 & 1 \\
-0.025 & 0.304 & 0.895 & -0.025 & 0.399 & 0.903 \\
-0.050 & 0.271 & 0.797 & -0.050 & 0.359 & 0.813 \\
-0.075 & 0.241 & 0.707 & -0.075 & 0.322 & 0.729 \\
-0.100 & 0.212 & 0.624 & -0.100 & 0.288 & 0.651 \\
-0.125 & 0.186 & 0.548 & -0.125 & 0.256 & 0.579 \\
-0.150 & 0.163 & 0.478 & -0.150 & 0.226 & 0.512 \\
-0.175 & 0.141 & 0.414 & -0.175 & 0.199 & 0.451 \\
-0.200 & 0.121 & 0.357 & -0.200 & 0.174 & 0.394 \\
-0.225 & 0.104 & 0.304 & -0.225 & 0.152 & 0.343 \\
-0.250 & 0.088 & 0.258 & -0.250 & 0.131 & 0.296 \\
-0.275 & 0.074 & 0.216 & -0.275 & 0.112 & 0.254 \\
-0.300 & 0.061 & 0.179 & -0.300 & 0.095 & 0.216 \\
-0.325 & 0.050 & 0.147 & -0.325 & 0.080 & 0.182
\end{bmatrix}
$$

4 Allowable wastage

NBIC S2.10.2.2 specifies allowable deterioration limits, summarized in Table 4. The permitted deterioration for each load type determines the minimum required remaining volume of the rivet head.

Table 4. Allowances for Deterioration

Load Type	**Shear**	**Tension**	**Combined Shear and Tension**
Permitted deterioration	80%	35%	60%
Required Volume	20%	65%	40%

Rivet Type	**Δ Height (Shear)**	**Δ Height (Tension)**	**Δ Height (Combined)**
11/16 button	-0.231	-0.074	-0.146
3/4 button	-0.251	-0.081	-0.159
11/16 steeple	-0.286	-0.092	-0.181
3/4 steeple	-0.312	-0.100	-0.197

The maximum allowable reductions in height shown in Table 4. are obtained by linear interpolation of the volume-loss data in Table 2. and Table 3. While interpolation offers a practical estimate, it only approximates the true volume–height relationship and may not always meet the precision required for design limits. A more reliable value comes from computing the permissible height loss directly from the specified remaining volume.

For example, if a remaining volume of 20% is required, it is nessary to produce the value of $\varDelta$ that satisfies

$$Rem_B(D, \varDelta) = 0.200$$

with $D = 0.750$. This can be done by finding the root of

$$Rem_B(D, \varDelta) - 0.200 = 0.$$

To solve for the height decrease $\mathit{\Delta}$ that gives a specified remaining volume, Newton's method updates an estimate using

$$x_{n+1} = x_n - \frac{f(x)}{f\prime(x)}$$

by increasing n until the difference between two successive estimates fall below some threshhold.

Here, $f(x)$ represents the remaining-volume function given as

$$Rem_{B(D,\mathit{\Delta})} \to \frac{V_B(D,\mathit{\Delta})}{V_B(D,0)}$$

and the required derivate

$$Rem\prime_B(D,\mathit{\Delta}) = \frac{\partial}{\partial\mathit{\Delta}} Rem_B(D,\mathit{\Delta}) \text{ for } f\prime(x).$$

These are then transformed to functions of one variable by partial application of parameter D with the rivet-shank diameter.

$$Rem_B^{0.75}{}_{(\mathit{\Delta})} \to \frac{V_B(0.750,\mathit{\Delta})}{V_B(0.750,0)}$$

The resulting derivative is quite complicated but reduces to

$$Rem\prime_B^{0.75}{}_{(\mathit{\Delta})} \to 13.272\mathit{\Delta}^2 + 16.275\mathit{\Delta} + 4.955$$

Similarly for $D = \frac{11}{16}$,

$$Rem\prime_B^{0.6875}(\mathit{\Delta}) = Rem\prime_B(0.688, \mathit{\Delta}).$$

$$Rem\prime_B^{0.6875}{}_{(\mathit{\Delta})} \to 17.231\mathit{\Delta}^2 + 19.369\mathit{\Delta} + 5.406$$

Table 5. Allowances for Deterioration using root finding

Load Type	**Shear**	**Tension**	**Combined Shear and Tension**
Permitted deterioration	80%	35%	60%
Required Volume	20%	65%	40%
11$/16 button	-0.230	-0.074	-0.146
3/4 button	-0.250	-0.081	-0.159

The values in Table 5. differ from those in Table 4. by at most 0.001. This confirms that the interpolated values are sufficient for practical use, even though establishing this required the direct computation.

5 Measurement of rivet head height

The height of a rivet head can be estimated by placing a flat bar across the rivet and measuring the distance from the underside of the bar to the surrounding surface on diametrically opposite sides. The bar must be parallel to the surface, so the two measurements should agree. In practice, this method is sensitive to small errors in bar placement and to variations in how the bar is held during measurement.

The bar technique can be improved by using a simple gauge plate that reduces sensitivity to placement error. As shown in Fig. 3, the gauge plate is made from a triangular metal plate roughly

2 in on each side. Three holes are drilled and tapped at the vertices of an equilateral triangle with 1.25 in centre-to-centre spacing. This spacing is large enough to clear the rivet head being measured[2]. The plate should be thick enough to provide at least three full threads of engagement for the chosen screw size, and the screw tips should be ground to a blunt taper. More precision can be obtained using fine-thread screws.

To use the gauge plate, place the plate over the rivet. Extend each screw until it just contacts the surface around the rivet head, ensuring that the underside of the plate lightly touches the top of the rivet head. Remove the plate and measure the projection of each screw from the plate using a depth gauge or caliper. Adjust the screws so that all three have the same projection, then repeat the placement and measurement until no further adjustment is required and the plate again contacts the rivet head. The common screw projection is the measured height of the rivet head.

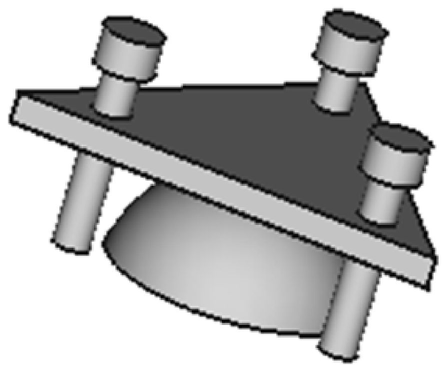


Fig. 3 Rivet-head height gauge

A control rivet should be measured in the same general area as the wasted rivets but located where deterioration has not occurred. Its measured head height serves as a reference for validating the expected head height described above and should be cross-checked against rivet specifications obtained from direct measurement[3], blueprints, ASME standards, or other authoritative sources. Establishing this reference height is essential before assessing the degree of wastage in nearby rivets.

A quick way to assess a group of rivets is to begin with the rivet showing the most obvious wastage. Measure this rivet first and set the gauge screws accordingly. Without altering the screw settings, place the gauge on the heads of the other rivets:

- If the gauge rocks, at least one screw is not touching the surrounding plate, meaning the rivet under the gauge is taller than the measured rivet.
- If the gauge does not rock, the rivet is either the same height or shorter.

In the latter case, measure that rivet directly and treat it as the new measured rivet. If the measured rivet is within specification and all other candidates cause the gauge to rock, then those rivets must also be within specification. This approach allows rapid elimination of acceptable rivets without individually measuring each one.

Another technique is to measure the control rivet and adjust the gauge screws until they are equal in length and the gauge plate does not touch the rivet head. Lock the screws in place with three locknuts, ensuring the nuts do not interfere with the rivet head. With the screws fixed, use feeler gauges to determine the gap between the underside of the gauge plate and the head of the control rivet. Then move to the most wasted rivet and repeat the feeler-gauge measurement. The combination of screw length and measured gap provides an accurate determination of the wasted rivet's head height.

6 Interpretive Remarks

The computations in Sections 3 and 4 highlight geometric and mechanical differences between the two rivet types that are worth noting.

6.1 Head geometry and remaining volume

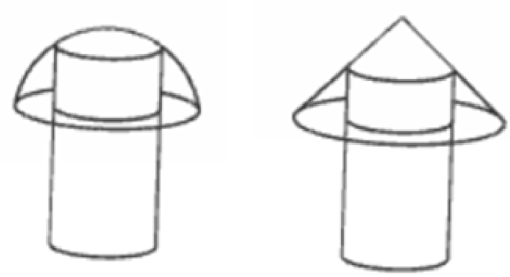
A steeple-head rivet begins with a taller, more tapered profile. For any given loss of head height:

- The remaining volume of a steeple head is larger than that of a button head, simply because it starts taller.
- However, the rate at which volume is lost per unit of height is not constant.
- At the tip, the cross-sectional area is small, so a small loss of height removes relatively little volume.
- As the head wears down toward the broader region, the area increases, and the same loss of height removes more volume.

This creates the possibility that a steeple head may lose height more rapidly—in the sense of approaching a "button-like" profile—before its remaining volume becomes comparable to that of a worn button head. The early taper accelerates the transition from a pointed head to a truncated shape with degraded sides.

6.2 Shear area and tensile failure

Tensile failure of a rivet is governed by the shear area of the internal cylindrical surface that must tear for the rivet to pull through the hole. This area depends on the shank diameter and the head shape. The head shape determines how much material participates in resisting pull-through.



a) button head b) steeple head

Fig. 4 Shear area

Visualizing the rivet after it has been pulled through the plate:

- The sheared surface is a cylinder whose height is the thickness of material that resisted the pull.
- The projection of the shank where it intersects with the surface of the head determines the height of the cylinder.
- The height of the cylinder is greater for a button-head rivet than for a steeple-head rivet.

This means that, for equal shank sizes, a button-head rivet has a higher tensile pull-through capacity than a steeple-head rivet.

6.3 Shear failure

- Rivets under pure shear fail by shearing across the shank, and in that mode the head geometry is irrelevant; only shank diameter and material strength matter.
- Riveted joints—especially in boilers, tanks, and pressure vessels—are often designed with substantial excess strength because the joint must also seal, not merely carry load.
- This over-strength means that allowable head-height loss is often governed more by inspection standards and sealing reliability than by approaching an actual mechanical limit.

6.4 Bringing the two effects together

The combination of:

- greater initial height but faster early height loss for steeple heads, and
- smaller shear area for tensile resistance,

explains why allowable height-loss limits differ between the two types. A steeple head can tolerate more absolute volume loss before reaching a critical remaining volume, but it may reach that point at a smaller remaining height. Meanwhile, its lower shear area means that its structural margin under tension is inherently smaller.

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1. https://rivetsinstock.com/rivets/solid-rivets/large-solid-rivets-1-2-1-3-4-dia.html

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2. The 1.25 in accommodates $\frac{11}{16}$ in rivets, but not modern $\frac{3}{4}$ in rivets. The latter require a triangle 1.375 in on a side.

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3. It should be noted that a popular size for Case boilers until 1911 was 11/16 in and for Gaar Scott boilers was 15/16. Direct measurement of new unused rivets with these sizes is not possible due to the lack of new-old stock.

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