13 Stayed Surfaces

13.1 Stayed Surfaces

Round surfaces want to be round. Flat surfaces want to be round.

A cylindrical boiler shell naturally resists internal pressure because its curved shape allows the load to be carried as tension in the shell. The pressure tries to make the shell larger, but not flatter.

A flat plate behaves differently. Internal pressure causes a flat surface to bulge outward, attempting to transform it into a curved surface. Unless the plate is made very thick, the resulting bending stresses quickly become excessive.

Boiler designers therefore support flat surfaces with stays. The stays transfer the pressure load into tension members and prevent the plate from deflecting excessively.

Analysis of stayed surfaces therefore requires three separate calculations:

1. The load applied to the plate by pressure.
2. The strength of the connection between the stay and the plate.
3. The strength of the stay itself.

The allowable load is governed by the weakest of these three conditions.

The construction of the stay attachment significantly affects strength. For this reason the ASME Code assigns different construction factors to different stay arrangements.

Riveted-joint analysis showed that the strength of a structure is often governed by its connection details rather than by the strength of the metal itself.

The same principle applies to stayed surfaces. A stay may be made from excellent material, but the allowable pressure is often determined by the manner in which the stay is attached to the plate.

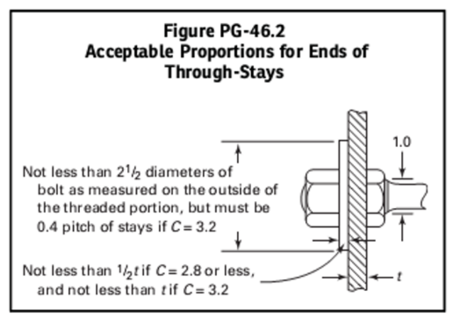

Fig. 2 Through-stay attachment details

13.1.1 Through Stays

The equations used for stayed surfaces vary between references because different codes incorporate the factor of safety in different ways.

Older ASME boiler formulas often express the allowable pressure using the ultimate tensile strength and an explicit factor of safety. Modern NBIC calculations typically use an allowable stress value that already includes the required safety factor.

Although the equations may appear different, they generally produce equivalent results when the same assumptions are used.

Before looking at the formula, consider what must happen.

- A thicker plate should resist pressure better than a thinner plate.
- Stays placed closer together should support the plate better than stays placed farther apart.

The ASME equation reflects both of these observations.

$P_{through} = \frac{t^2 \cdot S \cdot C}{p^2}$

where

Symbol	Meaning
t	Thickness of the stayed surface
p	Stay spacing (centre-to-centre distance between stays)
S	Allowable stress for the stayed surface. In NBIC this value already includes the required factor of safety.
C	Construction factor based on stay attachment details:
	2.1 for welded stays or stays screwed through plates not over 7/16 in. thick and riveted over
	2.2 for welded stays or stays screwed through plates over 7/16 in. thick and riveted over
	2.5 for stays fitted with nuts but without washers
	2.8 for headed or taper-fit stays having true bearing on the plate
	3.2 for stays fitted with inside and outside nuts and outside washers meeting Code requirements

For example,

$$\begin{aligned} P_{through} &= \frac{t^2 \cdot S \cdot C}{p^2} \text{ where } \begin{cases} t \to 2 \cdot 0.375 \\ S \to \frac{55000}{4} \\ C \to 3.200 \\ p \to 6.500 \end{cases} \\ &= 585.799 \end{aligned}$$

The values chosen reflect a boiler having widely spaced through stays connecting double-plated heads fitted with nuts and washers.

13.1.2 Regular Staybolt Patterns.

Where flat surfaces are supported by staybolts, the stays are often arranged in a regular square pattern.

Each staybolt supports the pressure acting on the surrounding area of plate, often called the tributary area of the stay. For uniformly spaced staybolts, the area supported by one stay is approximately the square of the stay pitch.

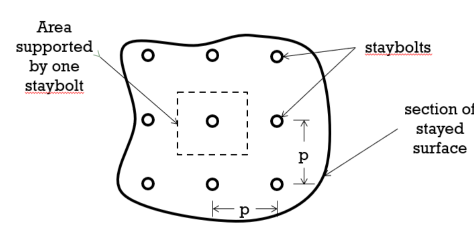

Fig. 2 Area supported by a staybolt

The ASME Code treats regularly spaced staybolts threaded into plate less than 1/2 inch thick and riveted over in the same manner as through stays. The allowable working pressure is given by

$P_{regular} = \frac{t^2 \cdot S \cdot C}{p^2}$

For example,

$$
\begin{aligned}
P_{regular} &= \frac{t^2 \cdot S \cdot C}{p^2} \text{ where } \begin{cases} t \to 0.300 \\ S \to \frac{55000}{4} \\ C \to 3.200 \\ p \to 4.500 \end{cases} \\
&= 195.556
\end{aligned}
$$

Notice that stay spacing appears in the denominator as the square of the pitch.

If the spacing is increased, each stay must support a larger area of plate and the allowable pressure decreases rapidly.

As a boiler deteriorates through corrosion, the stay spacing and construction factor remain unchanged. The principal change is a reduction in plate thickness.

Because plate thickness appears squared in the equation, small losses of material can result in a surprisingly large reduction in allowable working pressure.

- A useful rule of thumb is that pressure falls approximately with the square of the remaining thickness.
- A plate thinned to 90% of its original thickness has only about 81% of its original pressure-carrying capacity.

This equation evaluates the strength of the stayed surface.

The staybolt itself must also be capable of carrying the load imposed by the supported area. The strength of the staybolt is considered separately.

13.1.3 Maximum Allowable Load for Staybolts

The previous section considered the strength of the stayed plate.

A stayed surface can fail either because the plate is too weak for the spacing of the stays, or because the staybolts themselves are too weak to carry the imposed load.

The strength of the staybolt must therefore be evaluated separately.

Each staybolt supports the pressure acting on its tributary area. For a regular pattern of staybolts, the tributary area is approximately equal to the square of the stay pitch.

$$P_{load} = \frac{\pi\left(\frac{d}{2}\right)^2 S}{1.100p^2}$$

where

Symbol	Meaning
P	Maximum allowable working pressure
d	Diameter of the staybolt
p	Staybolt pitch (centre-to-centre spacing)
S	Maximum allowable stress value (11,300 psi in NBIC)

Notice that staybolt strength varies with the square of the diameter.

A small increase in staybolt diameter produces a significant increase in load-carrying capacity.

Conversely, staybolt spacing also appears squared in the equation. Increasing the spacing between staybolts increases the area supported by each stay and reduces the allowable pressure.

For a stayed surface, both the plate-strength equation and the staybolt-strength equation must be evaluated.

The allowable working pressure of a stayed surface is therefore determined by the weakest element in the load path. The plate between the stays, the attachment of the stay to the plate, and the stay itself must all be capable of resisting the imposed load. The allowable pressure is the smallest value produced by the applicable calculations.