

BOILER CODE OF  
PRACTICE (BCOP)



## GUIDANCE NOTE

### BOILER STAYS

#### Purpose

This document describes good practice in relation to its subject to be followed by Heritage Railways, Tramways and similar bodies to whom this document applies.

#### Development

This document has been developed by boiler experts in consultation with His Majesty's Railway Inspectorate (HMRI) a directorate of the Office of Rail and Road (ORR). The document HGR B9000 sets out the background to setting up the Boiler Code of Practice Committee (BCOP).

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## 1. Introduction

Railway locomotive boilers are designed to create, store and distribute steam at high pressure. The working life of such a boiler can be considerably shortened if due care is not taken at all stages of inspection, repair, running maintenance and day-to-day running.

In the past there have been a series of accidents and explosions due to work being undertaken without having due regard to the inherent risks involved. It is with that in mind that HMRI and HRA set up the series of meetings of boiler practitioners to discuss the issues; distil good practice and codify it into this series of Guidance Notes.

This guidance is written for the assistance of people competent to perform these tasks. In places the terminology used may be specific to such practitioners.

This guidance will also be useful to those in a supervisory or more general role. However, no work should be undertaken unless the people concerned are deemed competent to do so.

Where managements decide to take actions that are not in agreement with these recommendations, following appropriate risk assessments or for other reasons, it is recommended that those decisions are reviewed by the senior management body of the organisation and a formal minute is recorded of both the reasons for and the decision reached.

## 2. Units

The dimensions in this document are variously described in a mixture of imperial and metric units. Where practical equivalent dimensions have been shown but in some cases the dimensions do not easily equate and so the units in force at the time the original designs were documented have been used.

The term "psi." is used to indicate pressures in pounds per square inch.

## 3. Personal Protective Equipment

Before undertaking any work, a risk assessment must be conducted.

Protective equipment is to be supplied and used at work wherever there are risks to health and safety that cannot be adequately controlled in other ways.

The equipment must be:

- In accordance with the latest Personal Protective Equipment (PPE) regulations;
- Properly assessed before use to ensure it is suitable;
- Maintained and stored properly;
- Provided with instructions on how to use it safely; and
- Used correctly by those undertaking the work.

## 4. Inspection

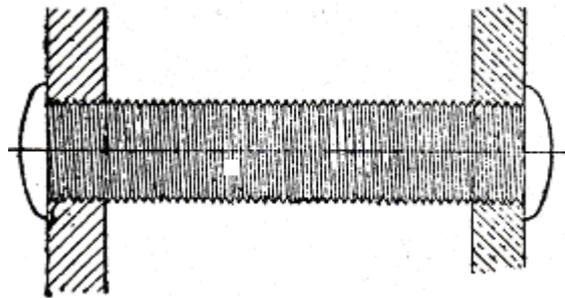
In the event of finding any suspect stays; seek guidance from the Boiler Competent Person before proceeding with any renewal.

Where there is doubt, the golden rule is, "stop work and consult with a more experienced or a competent person" before proceeding.

## 5. Introduction

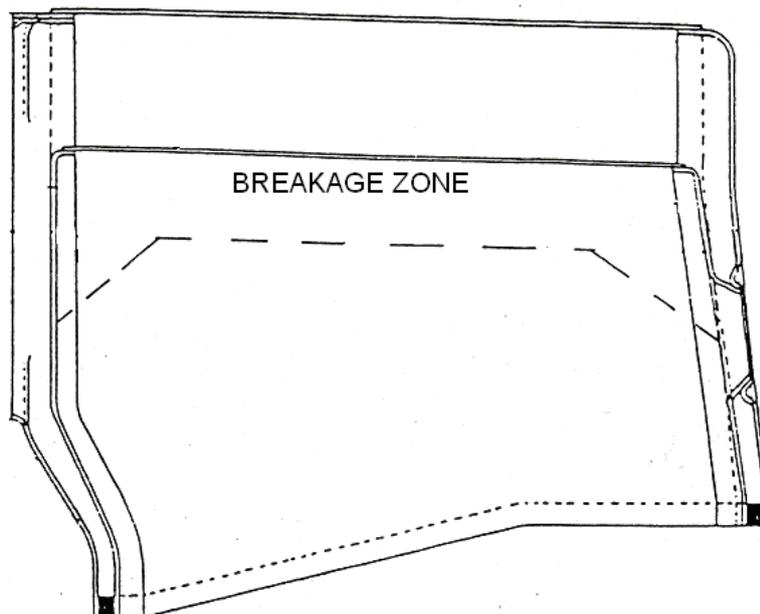
Flat surfaces that are subjected to the influence of rising pressure will start to bulge and eventually rupture when the material can no longer resist the imposed stresses. The earliest stationary shell boilers worked at very low pressures and it was possible to employ unsupported flat surfaces in their design. However, as working pressures increased, it became necessary to tie the flat plates together, usually with screwed rods fixed at frequent intervals to help them to withstand the loads. These screwed rods are called "stays" and are essential components in all tank type and locomotive boilers. Stays are not always used in the form of screwed rods (Fig 1); they can be made of plates, forgings with articulated ends, plain round or tubular bars welded into position, all depending on their intended duty. Several designs of boilers employ so called flexible stays which are intended to have some self aligning capability where bending loads are prevalent.

Cylindrical surfaces, such as the boiler barrel and curved plate work are self supporting under pressure and are not fitted with stays.



**Fig 1 Early type of screwed firebox side stay**

Locomotive boilers with water spaces between the outer casings and inner firebox are good steam producers; however, they suffer from adverse differential expansion effects. The firebox gets very hot and the casing much less so. This promotes convection currents in the water which helps with circulation, but the plates expand at uneven rates, particularly if the inner firebox is of copper and the loads that the stays have to resist give rise to bending stresses, as well as taking the principal tensile loads. This tendency is more pronounced in specific areas which are often termed “breakage zones” (Fig 2). This is simply because under cyclic stressing, due to alternate heating and cooling, and working the boiler under varying rates of evaporation, the stays are repeatedly bent backwards and forwards and eventually fail. More often than not, the majority of side stay failures occur at the end nearest the outer firebox casing. This characteristic with locomotive boilers necessitates continuous maintenance attention throughout their working lives and is perhaps the single most expensive and safety critical area which thus has to be managed with great care and attention.



**Fig 2 Firebox side stay  
“Breakage Zones”**

Leaking stays are also a source of hazard, since screwed fittings are likely to suffer corrosion, erosion and consequent loss of strength. Burned away stay heads and nuts are also likely to lead to problems if rectification is not applied.

This Section of the Code of Practice for Locomotive Boiler Maintenance sets out a framework for the management of boiler stays and also gives a brief introduction to the design principles involved. As such it cannot be regarded as a full treatise on the subject and the reader is encouraged to take further guidance from other published sources of information.

## 6. Materials and Specifications

Boiler stays are produced from wrought metals and their derived products. Table 1 lists the different materials commonly used. The material grades and specifications are those which are generally recognised in the metal supply trade. However, where the exact grade cannot be obtained commercially, the nearest equivalent will suffice, provided its properties are similar. Where there is doubt, the competent person should be consulted for a final decision.

## 7. Records

It is essential to make and retain accurate and auditable records of any work that is carried out on boilers, no less for any attention given to stays. This provides:

- a means of reference to previous work completed when it is necessary to implement repair activities at later dates;
- the means of traceability of all materials used;
- when the work was carried out;
- the details of persons undertaking and checking the work;
- the extent and results of tests carried out;
- confirmation of an effective maintenance regime to the competent person;
- proof of maintenance to a prospective purchaser or independent auditor; and
- evidence in the case of an enquiry.

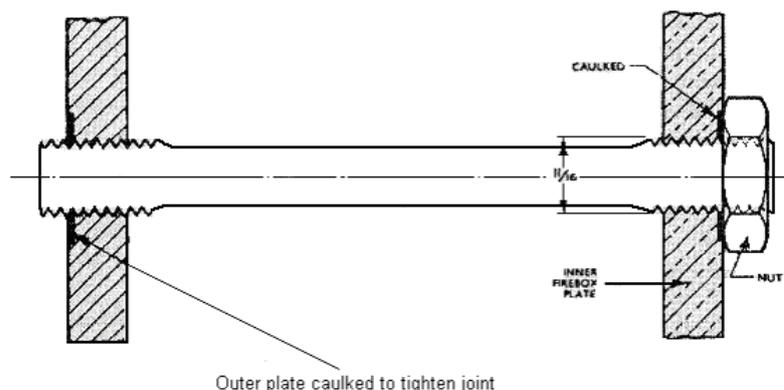
It is essential to have in place a stay location system and diagram by which any defective or suspect stay and subsequent actions taken can readily be identified. A recognised system is described in Section B, of the "BR Red Book" (Diagram DD 3745).

## 8. Stay types and varieties

In the Introduction, reference was made to the different types of stays employed in the construction of a locomotive boiler. The design of locomotive boilers has evolved over the years when their commercial use was commonplace. The basic principles have seen little change. However, much of the development that has taken place has been due to increases in working pressures and the steam outputs required to provide greater haulage power and improved efficiency. This has necessitated significant changes to the methods of construction and to the materials used for stays. The age range of preserved steam locomotives span the whole period of their use and thus the design of the stays found in preserved locomotives varies considerably, as do the techniques for their maintenance and renewal. Boilers that have survived generally represent the more satisfactory or successful designs but all boilers are now much older and so new and different problems will occur and must be anticipated.

### Rigid Stays

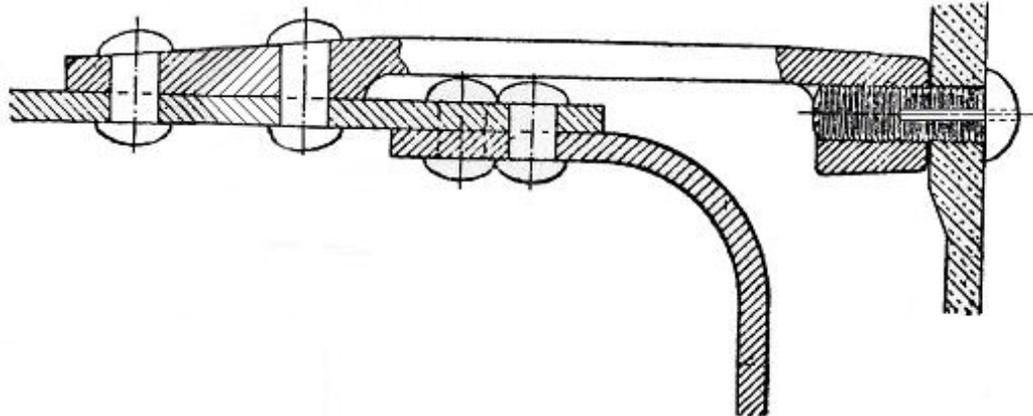
This type of stay, Fig 3, is secured rigidly to the boiler plates concerned and includes the stays that support the firebox sides, ends, and crown sheets.



**Fig 3 Typical "Rigid" side stay**

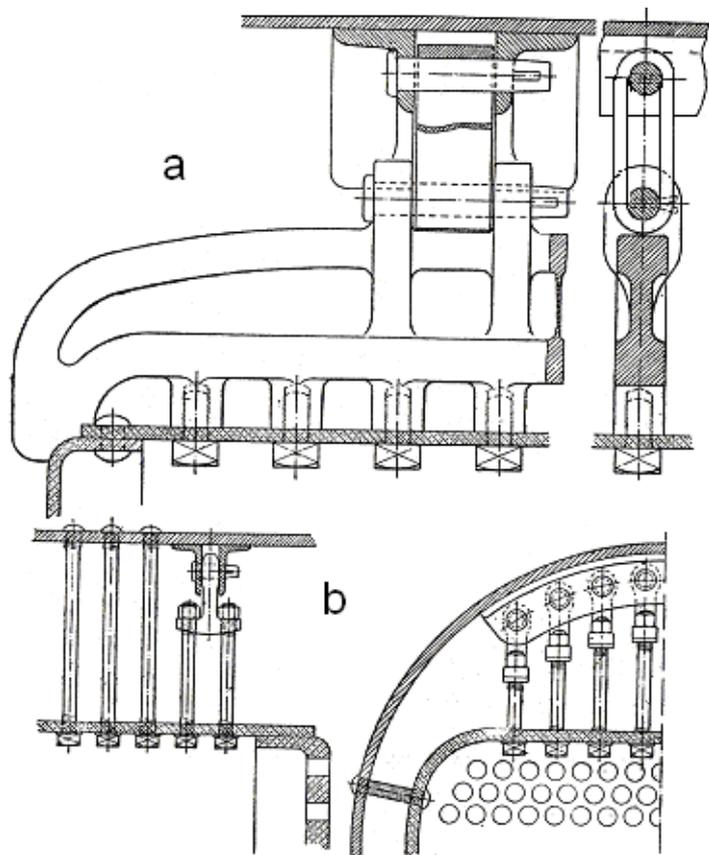
The design of many boilers employs longitudinal stays of circular cross section for the whole length of the boiler to support the flat ends of the back head and front tube plate. Large round top and Belpaire fireboxes use a similar type of stay to brace the transverse sides of the outer wrapper plates. In Belpaire fireboxes, it is usual to fit one or more stays over the length of the firebox to support the flat ends of the throatplate, these in turn being secured to the back head. Another type of rigid support is the palm stay which anchors the firebox tubeplate to the boiler shell (See Fig 4).

**Fig 4 Typical "Palm" stay**



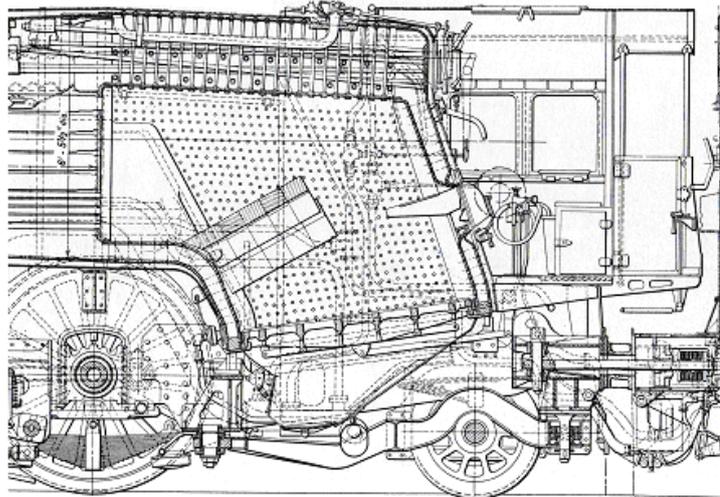
**Girder and Sling Stays**

In most locomotives produced before the 1920s, it was normal to use a type of flexible stay that could accommodate a degree of vertical movement in the firebox, particularly when the boiler was cold and a fire was first lit. This was believed to be the worst condition when the front of the firebox expanded more quickly than the rest and a degree of flexibility was needed to eliminate undue stresses in the crown sheet and its stays. To support this type of stay, T iron brackets or forgings were fitted to the outer shell and extended typically via looped steel sling links to a number of heavy cast steel girders that ran the whole length of the firebox crown sheet (see Fig 5a). The girders are secured to the crown sheet either with set screws or studded fasteners. Variations of this were for the first two to four rows of crown stays, which are special forgings, to be suspended on palm forgings slung from brackets fitted to the boiler shell (Fig 5b) and these are termed sling stays which have the freedom to move upwards to afford a degree of flexibility whilst steam raising. Practice in the USA proved that such stays were not necessary and plain crown stays became the norm in the United Kingdom in the second quarter of the 20th Century (Fig 6).

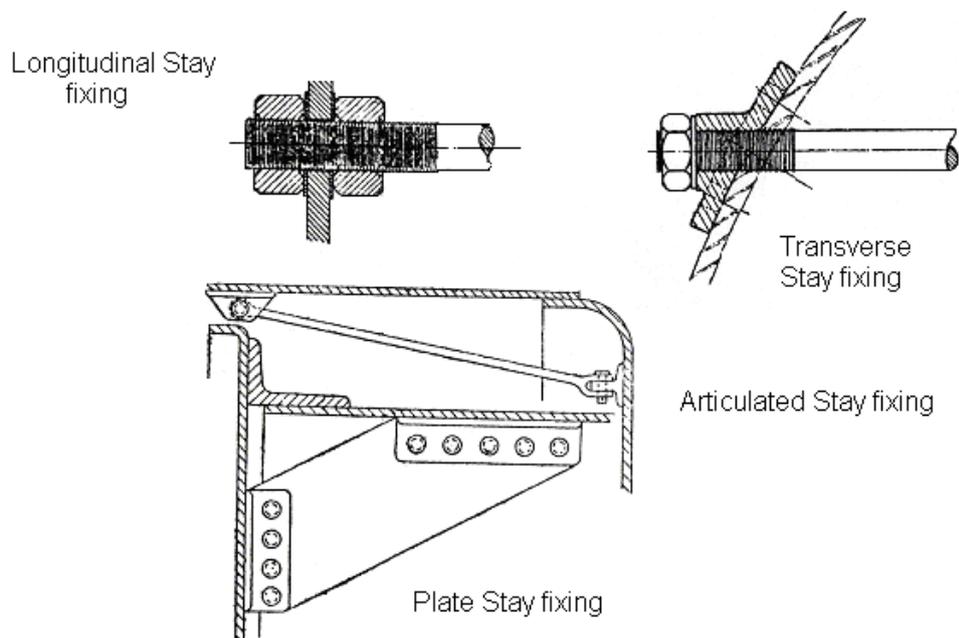


**Fig 5: a Cast steel "Girder" type crown sheet stay      b Sling stay arrangement**

**Fig 6: Typical post 1930s Crown Stay arrangement**



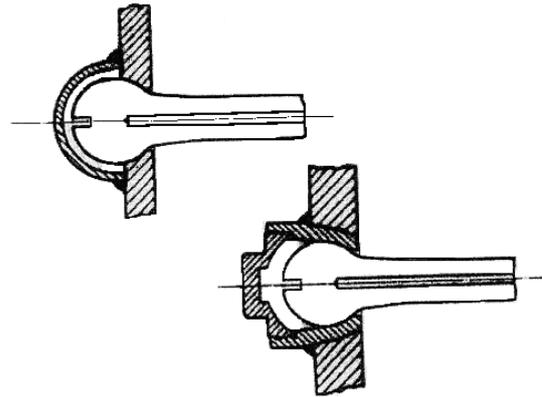
Other types of stay are depicted in Fig 7, illustrating the use of doubler plates or steel castings to compensate for the obliquity of the boiler plates or to spread the load more evenly.



**Fig 7: Other forms of rigid stay**

### **Flexible Stays**

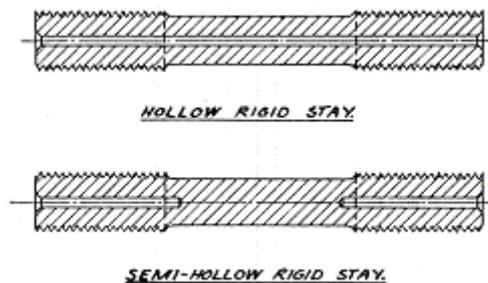
To alleviate the tendency of fatigue cracking of rigid type stays, particularly in the breakage zones and for the support of combustion chambers, the flexible stay was developed. This arrangement was widely used on the continent and in the USA, being utilised in some British designed boilers with good effect to provide longer periods between the need for renewals. This type of stay has a spherical outer end which is supported by a cup or matching counter bore machined in the boiler shell. A slot is provided in the ball end to enable it to be screwed into the inner firebox where it is secured in a conventional manner. Either a screwed cap or domed pressing, welded to the boiler shell, is used to seal the outer end. Fig 8 shows two specimens and it will be apparent that the ball end provides a degree of flexibility to accommodate the bending strains due to differential expansion. Effective boiler water treatment is essential with this type of stay to prolong the self aligning properties, since any scale build-up is likely to adversely affect it.



**Fig 8** *Examples of ball ended "Flexible" stay*

### Tell-tale stays

It is normally only possible to detect broken stays by hammer testing where they are fractured right through. It is possible nowadays to detect partially cracked stays by non destructive tests using ultrasonic devices, although volumetric testing in this manner is not a practical technique. To aid the detection of partially cracked stays, hollow or drilled stays are often used (See Fig 9). Such stays were almost universally employed on the continent and in the USA (by law). It can be seen that where a crack has propagated into the hollow or drilled portion, water will issue, indicating the presence of a fault and the need for renewal.



**Fig 9:** *Examples of "Tell-Tale" stays*

### Monel Metal Stays

The use of Monel metal became widespread in Great Britain following the introduction of the larger locomotives of the LMSR, SR and for the British Railways Standard boilers. This material is much stronger at elevated temperatures than steel, possesses low notch sensitivity and higher fatigue and corrosion resistance. Because of its much-improved strength, it is possible to employ thinner sections which afford greater flexibility and ability to accommodate bending stresses. The stay pitch using Monel metal is usually set slightly less than with conventional materials.

### Steam Tight Stays

Stays of this description, sometimes called blind stays, are normal screwed stays which are inserted using a special procedure. They are fitted in places where it is not readily possible to gain access to the outside of the boiler. Typically, this could be in the case of narrow fireboxes below the level of the frames or where the cladding cannot be removed such as adjacent to the cab structure.

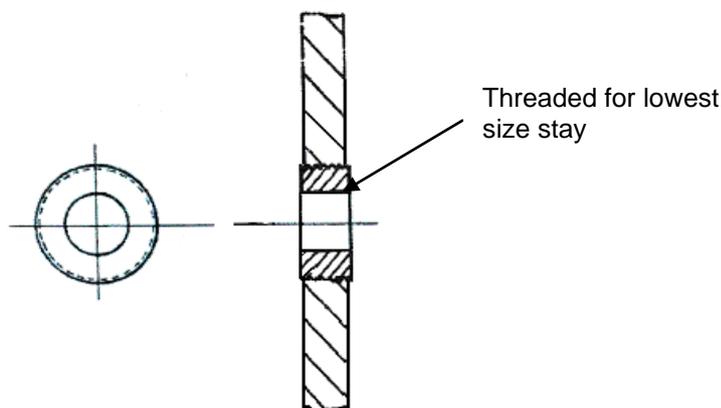
### Related details

The inner ends of stays that are screwed into the firebox are either riveted over in the case of copper stays or fitted with hexagonal nuts in the case of steel or Monel metal stays. Nuts fitted to steel side stays are normally of less thickness (1/2") than standard and are intended primarily to prevent the stay ends from burning. For crown stays, full thickness nuts are employed which also contribute to spreading the load into the plates over a larger area. It is important to obtain good metal to metal contact to ensure that stay nuts of any type do not overheat.

## 9. Stay Renewal

### Rigid Fireside Stays

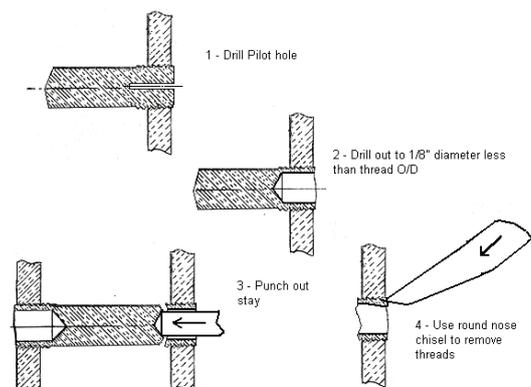
Most firebox waterspace stays are threaded 11 threads per inch. Tables 2A and 2B illustrate the range of tapped holes and stay thread sizes with the tolerances that apply for each increment of diameter. These dimensions were used by the LMSR and adopted for the BR Standard locomotives. The table is included as a guide, rather than forming a definitive practice since locomotives from different origins may specify different tolerances. Usually, the diameter of a stay needs to increase when failed items have to be replaced. This is to make certain that any thread damage or corrosion damage is removed and to ensure a full thread form is created to mate correctly with the new stay. There is a very definite upper limit of diameter which is permissible, dictated by the need to limit the increase in rigidity of larger diameter stays. For copper stays, the maximum outside diameter is 1¼" whilst for steel and Monel metal 13/16". It is necessary to ensure that any stays to be replaced do not exceed this limit (Ref: the BR Red Book, Section 9). Where the maximum diameter stay size has been reached, it is possible, when renewing a firebox, to employ a screwed bush to return the tapped stay holes in the boiler casings to original (see Fig 10). Details of Standard Stay Bushes for steel firebox plates can be found in the "BR Red Book" (DD3760).



**Fig 10 - Typical outer firebox stay bush**

Before commencing work to replace stays, it is vital to ensure that the boiler is properly prepared and washed out. Have all tools available and in good working order. Stay taps should not be used if they are worn, damaged or the cutting edges are not sharp. All driving squares or tangs must be full and in good order.

The first operation is to remove the stay that requires renewing. This can be accomplished using a number of techniques. The most usual method is to commence by cutting off the heads of the stays on both sides of the firebox using a suitable cold chisel (grease may be applied to aid cutting) taking care not to damage the surrounding platework. The centre of each stay is marked out and centre punched, following which a pilot hole is drilled to a depth of about 1 ½ times the plate thickness. Next, the pilot hole is opened out by a drill, 1/8" diameter less than the outside diameter of the stay as shown in Fig 11. With the use of a punch, the body of the stay is broken off and the remains of the stay threads picked out of the holes on both sides using a round nosed chisel. The body of the broken stay should be retrieved by extracting it through the nearest mud hole. Other methods involve grinding off the heads and on steel stays, use of oxy-acetylene cutting techniques but care has to be exercised when cutting out stays in copper plate work to ensure the copper is kept cool. This can be achieved by using maximum permitted oxygen pressure.



**Fig 11 – How to remove a stay**

The second operation is to tap out the new hole for the replacement stay. This will normally be 1/16" larger diameter than previous and it is necessary that the tapping size of the hole and correct hole alignment is achieved. The first operation is to use a suitable length stay hole reamer to size the hole ready for tapping. A suitable stay tap of the correct length is used. Stay taps (Fig.12) have their initial length parallel and unthreaded so that this portion can be fitted right through from the casing side into the corresponding hole in the firebox. The next portion of the tap is gradually tapered from its core diameter to full thread profile for about 1/3 of the tap length, with the last part parallel and to standard Whitworth form. Care must be taken to cut the threads cleanly and at right angles to the casing. A proprietary cutting lubricant should be used and the tap flutes regularly brushed clean to avoid torn threads.

**Fig 12 Typical Stay Tap**

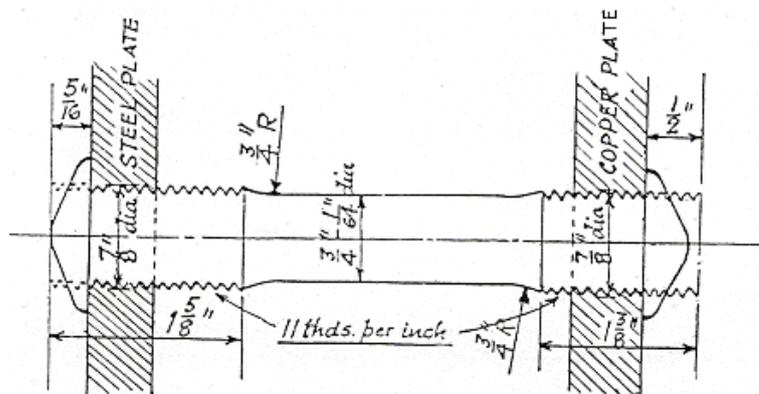


It will be seen from Table 2A that the Major Diameter of the replacement stay has a tolerance generally between -0.0005" to +0.002" to the nominal diameter of the threaded hole, the objective being that the fit has a slight interference. When ordering new stays, it is a good policy to provide the supplier with a sample piece of plate with a tapped hole using the tap that will be employed for the work. The supplier or machinist can then use this to size the new stays and obtain the best fit. New stays must be produced using a method that will ensure a continuous thread. The waisted portion of a stay having 11 threads per inch is 9/64" less on diameter than nominal. The waisted portion should be of such length that allows full engagement in the outer plate before entering the firebox side so as to avoid cross threads and ensure a good fit.

Stays are screwed in from the outer side using either a stud box or alternatively, the end of the stay may have a square machined on it to facilitate assembly and is cut off afterwards.

Copper stays are measured, cut to length and screwed in such that their ends project around 5/16" from the outside of each plate (See BR Red Book Section 9). The stay heads are then closed either by hand or with pneumatic tools using a flat headed tool. The opposite end of the stay should be "held-up" to provide support and minimise the tendency to strain the surrounding plates. The technique is to start in the middle of the stay and gradually work around to produce a head as shown in Fig 13. Alternatively, a profiled snap tool can be used. Another method used to close a copper stay head is to employ a butterfly shaped snap tool. To facilitate this, a centre hole is first drilled in the middle of the stay after which the guide pin of the butterfly snap is located in this and the snap is revolved slowly whilst the hammering action is applied. Using this method, a full snap head profile can be produced with comparative ease. For steel stays, a lobed tubular caulking punch may be used to seal the copper firebox plate immediately surrounding stay ends prior to fitting the stay nuts. In general, care must be taken not to over-work the caulking and stay heading of the copper in the firebox. This is to avoid possible local distortion of the plate or loosening of the threads.

**Fig 13 Copper stay head closures**



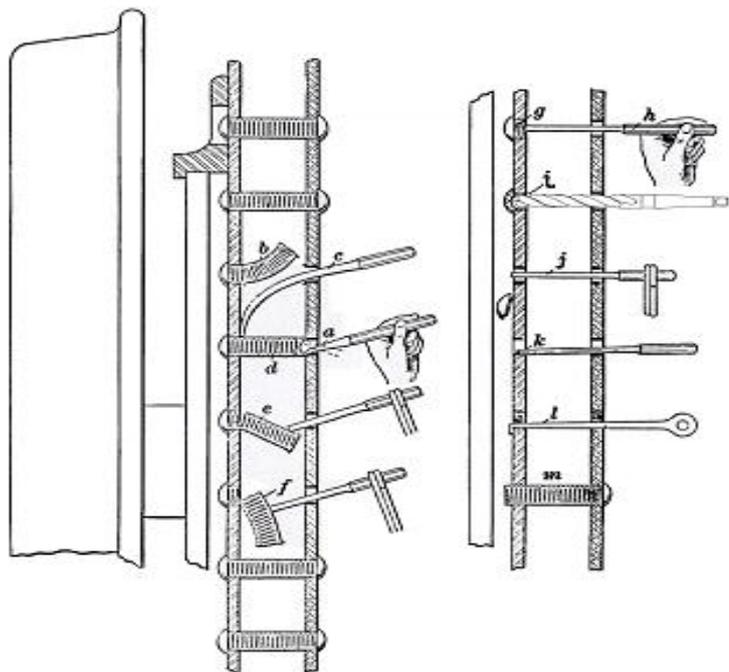
Some designs of stay ends make use of a hole approximately 5/16" diameter into both ends of the stays about 1 1/4" deep so that the ends can be expanded into the plates by use of hardened steel drifts. In some stays using this fixing method, the holes are preformed or drilled right through and a steel sealing cup is fixed to stop off the outer ends.

Steel and Monel stays are similarly screwed in. However, they are not normally riveted over but project from the firebox side by about 9/16" and, after caulking, are fitted with 1/2" thickness steel nuts. The outsides are left about 5/16" proud, caulked and the projecting ends left plain.

### Steam Tight Stays

In narrow fireboxes below frame level, or in locations that have restricted external access, a broken stay can be renewed using a "steam tight" or "blind" stay.

To fit a steam tight stay, the head of the defective stay and the one immediately above it is first cut off on the inside of the firebox. Both stays are centre popped, drilled and released using the technique previously described. A specially curved swan neck cold chisel is then inserted through the upper stay hole and the lower stay is heavily nicked and then punched out as shown in Fig 14 (a to f). The outer ends of the stays are removed as shown in Fig 14 (g to k) the drill size being about 1/64" less than the core diameter. A long round nosed chisel is used to chip out the thread coils.



**Fig 14 Fitting Steam Tight Stays**

Once the tapped holes are cleared, the next size, usually 1/16" in diameter larger, has to be tapped. To accomplish this, a set of three special taps are used. None of the taps will be able to pass very far through the outer plate due to the limited clearance between it and the frames. The first or taper tap has very little depth of thread at the end, its purpose being to act as a reamer and take off the tops of the existing threads in the plates. Care must be taken to ensure the tap runs axially true and does not wander, particularly when tapping the firebox plate. The threads at the end of the second tap are about half as deep as the full thread tap and the third, or plug tap, are of full depth but the leading 3/4" is tapered or reduced in diameter from full size by approximately 1/64." The object of this taper is to produce a slightly tapered stay hole in the outer plate so that when the new screwed stay has passed through the firebox plate and entered the casing plate it gradually begins to tighten, i.e. an interference fit. Using the stay gauge, Fig 14 (l) the length of the stay is deduced such that when screwed home the stay should project about 1/8" beyond the outer casing plate. Since greater torque has to be applied to achieve the interference and steam tight fit, the stay has to be longer at the driving end to facilitate screwing it home. The surplus length is sawn off so that 5/16" projects from the firebox plate to facilitate tooling over. The finished stay is shown in Fig 14.

## **Crown Stays**

These are made of steel and generally resemble rigid side stays but are usually larger in diameter. The removal and fitting techniques are practically identical, except that the stays being replaced are tied back and removed from the boiler instead of falling away. However, crown stays are much longer and since the fireboxes of larger locomotives have sloping firebox crowns, the lengths vary, being longer at the back head end. If all the crown stays are to be renewed during overhaul, it is essential to ensure that at least three rows or more, depending on the size of the firebox, should be left in situ. This is to avoid the risk of displacement of the crown sheet and to assist in maintaining the plates at the corresponding fixed distances and to avoid the possibility of crossed threads during the tapping and fitting process. It may also be necessary to have two or more stay taps to cover the varying lengths of stay, the other variable being the different diameters of thread that may be required.

Since the temperatures at the firebox crown sheet are highest, it is essential to dissipate the heat applied to the stay nuts into the copper wrapper to avoid burning them and, thus, good thread engagement and contact between the nut and crown sheet is essential. In cases where the stay projection is not normal to the crown sheet, use of a copper tapered washer between the nut and crown sheet is advisable. It should be borne in mind that if a boiler fitted with a copper firebox suffers low water during heavy steaming conditions, the exposed firebox will rapidly lose its strength and the screwed portion in the crown sheet will also lose its ability to withstand the load. Under these conditions, provided the low water condition is of short duration, properly fitted stay nuts should continue to provide support until the working water level has been restored.

In many boilers, the first three or four rows of crown stays at each end of the firebox are riveted over almost flush instead of using nuts. This is to assist with gaining access to tubes for rolling, to facilitate inspection or attention to lap edges, rivets and lacings. Care has to be taken when tooling-over the stay ends which is normally carried out with the ends locally heated. A flat snap is used and great care must be taken to prevent the snap from slipping off the stay head in order to avoid damage to the copper plate work. Finally, the head is caulked to ensure a leak free closure.

## **Girder and Sling Stays**

Boilers fitted with girder or sling type stays require special attention.

At overhaul, the girders that take the loads applied to the crown sheet must be checked by an appropriate non-destructive testing method to ensure freedom from cracks. The girder feet that are supported on the ends of the tube and door plates must be carefully fitted as the main loads are reacted at these points. It is essential that the mating surfaces are carefully prepared and any wear or corrosion effects are repaired by appropriate methods. The resultant fits must be such that intimate contact is provided over the full surface area of the support legs.

Girder or sling stay bolts are often secured to the firebox crown using square headed steel set screws. These must be regarded as renewable items and be carefully checked for integrity at periodical examinations. Ideally, they should be renewed at each general overhaul. It is likely that the threaded ends of the set screws will corrode and make it impossible to effect removal. For girder stays in such circumstances, the set screws will have to be drilled out and the tapped holes proven or opened out to the next size.

It is very difficult to remove corroded and seized set screws from sling stay bolts, on account of these being free of constraint above the crown sheet. In such circumstances, it is essential to raise the situation with the competent person and agree a recovery procedure. It is a good policy to regularly change out the set screws in order to ensure that they are sound and that the effects of corrosion are controlled. The threaded portion of the set screws should be coated with a graphite or molybdenum disulphide-based corrosion inhibitor prior to fitting. Since they are fitted to blind tapped holes, care must also be taken to ensure that the threaded length of the set screws does not allow them to bottom out and fail to clamp the crown sheet effectively.

Over the years, it may be found that the top portion of an outer firebox casing or boiler shell has tended to sag slightly. Similarly, the sides can tend to bulge. Any tendency to this condition may affect the alignment of the supporting swing pins and their housings. At a heavy overhaul, all pins and palmed supports must be removed and repaired/renewed as required. Where plain cylindrical pins are fitted, it should be borne in mind that they require a small degree of radial freedom. However, worn pins must be renewed and there must be adequate material thickness in their mating housings to ensure that the correct support is provided for the firebox crown sheet. Where sling stay bolts are involved, these are often secured in the working position by lock nuts. The integrity of these must be assured and the correct support maintained.

## Flexible Stays

Since the greatest likelihood for broken stays is at the outer plate interface, a solution developed in the USA and on the continent was the use of spherical headed steel stays which have some degree of flexibility to accommodate the bending and cyclic stresses. Two methods of fixing these were shown in Fig 8. The first method affords the least volume for accumulation of scale and consequent locking. It can be seen that the welded-on cup requires to be ground out or the screwed caps removed to access the stay. The fireside end may be conventionally fitted. To renew the stay, the ball end seats must be cleaned or re-cut and the new stay screwed-in using a ratchet drive and screw driver ended socket via the slotted end. Undue force should be avoided. Where the stays are welded to a steel inner firebox, the stays are held-up at the ball end in close contact with the preformed cup whilst the welding operation is completed.

## Palm Stays

These rarely require attention at the running shed, save that any leakage should be investigated and remedied. Often, heads securing palm stays in the firebox have drilled "tell-tale" holes, which must be maintained clear if they are to indicate properly. At heavy overhauls, the condition of the palm ends and the rivets which secure them to the boiler shell must be checked to confirm they are free from wastage and fit for use until the next overhaul. Riveted projecting ends may suffer damage and depending on the design of fixings, may be recoverable by the use of tapped holes and patch screws. Where there is any doubt, the guidance of a competent person must be sought.

## Longitudinal Stays

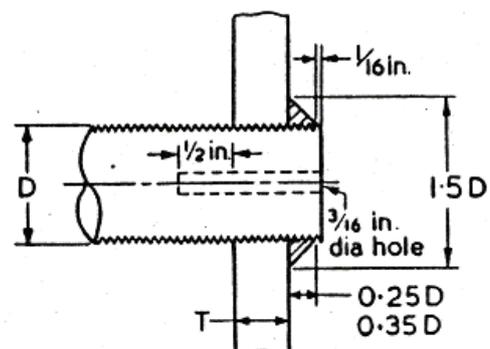
Longitudinal stays which support the flat areas of the front tube and back plates can be of the end to end type or run from brackets secured to the boiler barrel. With end to end stays, the holes in the back plate are tapped large enough to allow the stay to be passed through and be secured to the front tube plate. Usually, this is facilitated by use of running nuts to enable the stays to be tensioned correctly and these are normally fitted with copper washers on either side. When tensioning up such stays, the boiler design should incorporate adequate support to prevent sagging and the tightening procedure must ensure uniform sharing of load by each stay.

## Welded Stays

The design and maintenance of steel fireboxes has been the subject of much technical discussion, particularly in Germany where the initial use of this material in place of copper gave rise to many failures. Readers who are concerned with the design and maintenance of steel fireboxes are recommended to make reference to the many technical papers that have been produced on this subject.

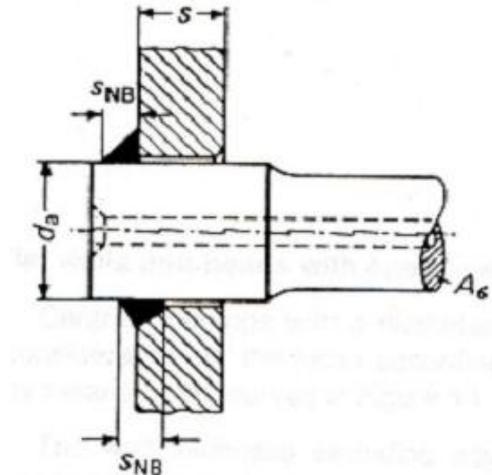
In boilers fitted with steel fireboxes and designed to employ welded stays, the welding must only be carried out by a coded welder. The employment of welding introduces residual stresses which give rise to local straining of the boiler platework. For this reason, the welding sequence must be carefully considered in order to spread the heat input. An approved Weld and Test procedure must be adopted together with specification of the appropriate welder qualifications.

The requirements for a seal weld applied to a conventionally threaded stay are defined in BS 931: 1951, Section 16 (see Fig 15a).



**Fig 15a BS 931 Outer stay end seal welded**

The practice illustrated in the TRD Code (Fig 15 b) is aimed at ensuring a relatively small heat affected zone.



**Fig 15b BS 931 Welded stay ends (TRD)**

In Fig 15 b, the dimension  $S_{NB}$  refers to the thickness of the weld in the direction of loading. The shearing cross section of the fillet weld shall be at least 1.25 times the required cross section of the bolt, e.g.:

$$d_a \cdot \pi \cdot S_{NB} \geq 1.25 A_s \quad \text{Where } A_s \text{ is the required cross section of the stay bolt.}$$

Note that a small clearance of not less than 0.020" (0.5 mm) must be introduced between stay and the boiler plate.

## 10. Inspection and Testing

The risks and consequences of broken stays have been previously discussed and it will thus be apparent that to mitigate the risks, a regular inspection regime is essential.

The Pressure Systems Safety Regulations 2000 require that any user or owner of a pressure system must not operate the system without a "Written Scheme of Examination." A Competent Person or Boiler Inspector is required to carry out periodical examinations in accordance with the Written Scheme at the prescribed intervals (normally less than 14 months) or when especially required in particular circumstances. Notwithstanding this statutory requirement, the owner must regularly implement his own maintenance and inspection scheme which must be properly documented.

The daily disposal, wash out, periodical and overhaul inspection regimes are covered in other documents in this Code.

The four inspection techniques normally used are:

- Visual;
- Hammer Testing;
- Non-Destructive Testing; and
- Hydraulic testing

Testing is required to confirm that the boiler staying system is in a serviceable and safe condition at all times whilst the locomotive is in steam.

In order to carry out inspection of the stays within a firebox, the firebox and brick arch must be cool or cold. The deflector plate must be removed and the interior should be cleaned out of all ash, loose soot and firm standing provided. All health and safety requirements must be adhered to and precautions taken to ensure that anyone entering a firebox is medically fit. The Confined Spaces Regulations may also apply and its requirements must be complied with. Since there are risks in carrying out inspection inside a firebox, such work should never be carried out without the presence of a responsible person who can summon the emergency services in case of need.

It is a good plan to develop a "routine" when inspecting stays and to chalk mark areas that have been examined to ensure that none have been missed. Start, progressively complete and finish in a regular manner so that nothing is missed, paying special attention to the stays in the breakage zones. Where stays are obscured, for example by the brick arch, it will be necessary to inspect internally from another access point. Stays normally obscured by the fire arch must be tested prior to its rebuilding during maintenance.

The scope of a visual examination within the firebox is as follows:

- Check the overall condition of the firebox. It should be "good and black."
- If the box is not good and black, check for indications of overheating, for example, the presence of pink (overheated) copper platework. Stays in the vicinity of overheated surfaces or where there is evidence of quilting, are to be regarded as suspect.
- Examine stay heads and nuts for signs of wastage, looseness, or leakage. White deposits around stays indicate looseness and likely leakage. Mark-up any that require attention.
- If there are any "birds nests" adhering to crown stay nuts, these must be removed and the nuts and stay ends inspected for signs of overheating. Mark-up any that require attention.
- For stays with tell tale holes, these should be proved clear and checked for signs of leakage when the boiler has been filled with cold water.
- The final tests are carried out hot, at full working pressure, when stays are checked for signs of leakage with the dampers shut and a low fire. A mirror is normally clamped to a shovel to view the door plate stays.

The scope of visual examination on the water side of the boiler is as follows:

- With the boiler thoroughly washed out and all wash out plugs removed, use a flare through each hole to examine crown stays and check for wastage (necking due to electrolytic corrosion). This form of corrosion typically results in steel stays necking adjacent to copper plates and shows up particularly at the outer rows of stays. Correspondingly, steel plates tend to waste locally where copper stays are fitted. It is possible that scale build-up may obscure the areas of wastage, in which case the scale should be knocked off using a flat ended brass rod. The amount of wastage may be judged by viewing against varying diameters of rods inserted through the wash out plug holes and set adjacent to the wasted portion of the stay. Alternatively, a horseshoe template made from a steel washer cut open to a "C" shape and welded to the ends of long rods may be used to check the smallest diameter. Whilst there is no strict limit for wastage, it is not considered safe to allow a boiler to re-enter service if the wastage is around 20% or more on diameter, i.e. the reduction from the "as fitted" diameter (see section 11 on Design Principles).
- Side stays should be similarly inspected using a flare or endoscope probe through the mud holes. Since the visual access is limited, articulated mirrors of various shapes may be inserted through mud and washout holes to inspect the stays for cracks and wastage.
- The final tests are carried out hot at full working pressure, when stays are checked for signs of leakage.

## Hammer and NDT Testing

If a hammer test is to be carried out, the boiler must be drained of water. The normal procedure is as follows: Using a light weight hammer (preferably a boiler inspector's hammer) each stay head is struck with a sharp but light blow cleanly in the centre of the projecting stay end. The sound emitted should be a clear "tack" which indicates that the stay is not broken. N.B. it will not indicate if the stay is partially broken. If the sound is different and resembles "tonk" the stay is broken. Mark-up any stays that require attention. Where the technique is new to the examiner, it is a good plan to try it out on a boiler with known defects where the distinctive tones can be readily experienced. Crown stays can be similarly tested.

An alternative method, seldom used on British prototypes, is where the boiler cladding is not applied or has been removed. In this instance, the testing requires two people working as a team, one inside and one outside the firebox. The technique is to place a hammer lightly in contact with the stay on the outside of the boiler and wrap the inside end. If the stay is solid, the hammer will bounce off the other end.

Stays can be tested with an ultrasonic thickness tester, provided it is of the type which can penetrate long distances such as the length of a stay. The technique may be used where suspect stays are involved, particularly on stays in the vicinity of those that have broken and which may themselves be partially broken. Stays in these areas should in any case be renewed. The technique can only work where the stay end has been cleaned and provides sufficient flat area to allow the ultrasound signal to penetrate the length of the stay and bounce back to the receiver. Where no signal has been detected, either the stay is fractured or there is inadequate coupling to facilitate a "clean" signal. In such cases, a visual examination should be attempted from the nearest washout hole with the aid of a flare or endoscope probe.

One broken stay will not generally represent a dangerous situation but it is quite likely that, since the load it supported has thence to be absorbed by its neighbours, the surrounding stays soon become suspect, particularly in the breakage zones. Timely maintenance attention can thus be seen to be vital to avoid sudden catastrophic failure.

## Hydraulic Testing

The use of hydraulic testing involves filling the boiler (minimum temperature 7°C) completely with cold water and with all air removed, pressing it to above the working pressure for a defined period of time to the pressures shown in other documents of this Code. The purpose of the tests is to confirm that the general structure continues to be sound, the absence of bulging or distortion and freedom from leakage. The latter applies particularly to stays, where any leakage has to be followed-up, usually by light caulking. Leaking stays give rise to corrosion of the threads and eventual failure.

Having recorded the location of suspect, broken or leaking stays, remedial attention must be carried out and the details suitably recorded.

## 11. Design Principles

The design of locomotive boilers was carried out by locomotive manufacturers, contractors or by the railway companies themselves. Records of the design activity are rare and it is not clear what criteria were set regarding the working stresses or stay pitches that were employed by these organisations other than that which survive on preserved drawings and rare documents. "Boiler Codes" were developed by Standards bodies both in Great Britain and abroad mainly for land and marine boilers. In particular, the following documents will be found to provide useful guidance:

- B.S. 931:1951, "Loco-Type Multi-tubular Boilers of Riveted Construction"
- B.S. 2790: Parts 1 (Class I welded construction) 1969 and Part 2 (Class II and Class III welded construction) 1973, "Specification for Shell Boilers of Welded Construction (other than water-tube boilers)" For imperial measurements.
- B.S. 2790:1992 is in metric units.
- Other codes include ASME and DIN (TRD), all of which can be consulted when required to prepare a safe design change for a locomotive boiler.

The following indicates the basis for the determination of stay diameters. The detail of the form of a stay, as described previously, can be selected to best suit the particular situation under consideration.

**Staying flat surfaces:**

The design of stays has to address the following **considerations**:

1. **Direct tensile stress due to the maximum working pressure in the boiler.**
2. **Bending stresses due to the differential expansion of the inner firebox plates relative to the outer casing plates.**
3. **Stresses due to vibrations set up during generation and release of steam.**

***For consideration 1 – Direct Stresses***

The following formula may be used to determine the basic minimum diameter of a stay bolt (root diameter of the threaded portion):

$$d = \sqrt{\{P \times A / 0.7854 \times f\}}$$

where:

d = minimum diameter of the stay in inches.

A = Area of plate supported by one stay in square inches.

P = Maximum safe working pressure of the boiler in lb per square inch.

f = Safe working stress in tension in lb per square inch for the stay material.

From the above formula,

$$A = 0.7854 \times d^2 \times f / P \quad \text{or}$$

$$f = A \times P / 0.7854 \times d^2$$

The following safe working stresses may be assumed:

Steel ..... 8,000 to 9,000 lb. per sq. inch.

Copper ..... 4,000 to 5,000 lb. per sq. inch.

Monel ..... 10,000 to 11,000 lb. per sq. inch.

From this, it will be appreciated that a 20% reduction of the diameter of a circular stay will result in an approximate 36% loss of its cross-sectional area. The stress in the bolt will thus have increased by just over 56%. Allowance for this wastage effect should be considered by the designer together with the effect of reduction of safe working stress due to higher operating temperatures. For a stay made from steel having a lower yield strength of 28,000 psi. at room temperature, when raised to typical working temperatures, the reduction in yield point will be to around 25,000 psi. It can thus be seen that that, the stress in the 20% wasted stay bolt could have risen to around 14,000 psi. which would imply a significant reduction in the margin of safety.

The determination of the pitch of stays, particularly of longitudinal and cross stays is a fairly complex design process and requires an in-depth understanding of the variables to be considered. This aspect of the design is not considered appropriate to the scope of this document. However, full details may be found in BS 2790 or TRD 305.

***If modifications to a boiler are being considered, a competent person such as an accredited Notified Body must be consulted and an appropriate boiler code adopted.***

***For consideration 2 – Bending Stresses***

It can be shown that even quite small strains resulting from differential expansion, i.e. the induction of high bending stresses in the outermost surfaces of stay bolts, can reach yield point in the outer fibres of the stay section. Generally speaking, to accommodate the effects of this, it is better to choose a greater number of long small diameter stays, spaced closer together than short large diameter stays, pitched at greater intervals. Monel metal stays having a smaller core diameter are eminently suited to this duty.

***For Consideration 3 – Evaporative Stresses***

Since the stresses induced by this condition are indeterminate and of lower significance these can be ignored in the design process, save that the attrition on the stays will vary with the intensity of the erosive effect of steam bubbles and higher velocity water flows. The choice of material is therefore a factor to be considered.

**12. Conclusion**

Knowledge of what needs to be done, careful attention to detail, good workmanship, the use of high quality materials and tools are essential to keeping stays in good order, safe and free from leakage.

Where there is doubt, the golden rule is, “stop work and consult with a more experienced or a competent person” before proceeding.

\_\_\_\_\_ end of main document \_\_\_\_\_

## Tables used in Firebox Stays

**Table 1 – Commonly used Materials**

Material	Specification	Basic Composition and Properties										
		Fe	C	S	P	Si	Cu	Ni	Mn	As	Yield	UTS
		%	%	%	%	%	%	%	%	%	Tons/in <sup>2</sup>	Tons/in <sup>2</sup>
Mild Steel	BS EN 10025-2 Grade S275JR	Balance	0.13 to 0.18	0.05 max.	0.05 max.	0.10 to 0.40			0.70 to 0.90		16-19	28-30
	BS970 - PD970: 2005 Grade 070M20 (EN 3) 080A15 (EN3B)	Balance	0.16 to 0.24	0.05 max.	0.05 max.	0.10 to 0.40			0.50 to 0.90		16-19	28-30
Copper	BS 2874 (1969) Grade C 107 Supply Condition - Cold worked and annealed				0.013-0.050		99.5			0.3 – 0.5	11-12.1 (0.2% Proof offset)	14.5
Monel	BS 3076:1989 Gde. NA13 Cold worked and stress relieved	<2.5	<0.3	<0.024	----	<0.25	28-34	63-70	<2.0	-----	26 (0.2% Proof offset)	32-38

Table 2A - Firebox Waterspace Stays

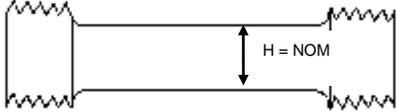
FIREBOX WATERSPACE STAYS										(Source MS11)	LMSR	
NOMINAL DIAMETER OF WAIST TO BE 9/64" LESS THAN NOMINAL DIAMETER OF STAY 		NOMINAL DIAMETER OF STAY		COPPER STAYS				MONEL & STEEL STAYS				
				MAJOR DIA.		EFFECTIVE DIA.		MAJOR DIA.		EFFECTIVE DIA.		
		MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	
11 THREADS PER INCH		5/8	.6250	.6270	.6245	.5688	.5633	.6270	.6250	.5688	.5668	
		11/16	.6875	.6895	.6870	.6313	.6288	.6895	.6875	.6313	.6293	
		3/4	.7500	.7520	.7495	.6938	.6913	.7520	.7500	.6938	.6918	
MAJOR & EFFECTIVE DIAS. LIMITS		13/16	.8125	.8145	.8120	.7563	.7538	.8145	.8125	.7563	.7543	
		7/8	.8750	.8770	.8745	.8188	.8163	.8770	.8750	.8188	.8168	
STAYS	HIGH	15/16	.9375	.9395	.9370	.8813	.8788	.9395	.9375	.8813	.8793	
	LOW	1	1.0000	1.0020	.9995	.9438	.9413	1.0020	1.0000	.9438	.9418	
COPPER	NOM. +.002	NOM. -.0005	1 1/16	1.0625	1.0645	1.0620	1.0063	1.0038	1.0645	1.0625	1.0063	1.0043
			1 1/8	1.1250	1.1270	1.1245	1.0688	1.0663	1.1270	1.1250	1.0688	1.0668
			1 3/16	1.1875	1.1895	1.1870	1.1313	1.1288	1.1895	1.1875	1.1313	1.1293
MONEL	NOM. +.002	NOM.	1 1/4	1.2500	1.2520	1.2495	1.1938	1.1913	1.2520	1.2500	1.1938	1.1918
			1 5/16	1.3125	1.3145	1.3120	1.2563	1.2538	1.3145	1.3125	1.2563	1.2543
STEEL	NOM. +.002	NOM.	1 3/8	1.3750	1.3770	1.3745	1.3188	1.3163	1.3770	1.3750	1.3188	1.3168
			1 7/16	1.4375	1.4395	1.4370	1.3813	1.3788	1.4395	1.4375	1.3813	1.3793
			1 1/2	1.5000	1.5020	1.4995	1.4438	1.4413	1.5020	1.5000	1.4438	1.4418
			1 9/16	1.5625	1.5645	1.5620	1.5063	1.5038	1.5645	1.5625	1.5063	1.5043
			1 5/8	1.6250	1.6270	1.6245	1.5688	1.5663	1.6270	1.6250	1.5688	1.5668
FOR LIMITS ON FIREBOX WATERSPACE STAYHOLES SEE SHEET NO MS11A												

Table 2B - Firebox Waterspace Stays

FIREBOX WATERSPACE STAYHOLES				(Source LMSR MS11A)								
TAPPED HOLES	LIMITS		NOMINAL DIAMETER OF TAPPED HOLES	MAJOR DIAMETER		EFFECTIVE DIAMETER		CORE DIAMETER				
	HIGH NOMINAL +005"	LOW NOMINAL NOMINAL		MAX	MIN	MAX	MIN	Conditions A&C		Condition B		
MAJOR DIA. EFFECTIVE DIA.  CORE DIA. CONDITIONS	HIGH NOMINAL +005"	LOW NOMINAL NOMINAL						MAX	MIN	MAX	MIN	
A FOR NEW HOLES B FOR HOLES WHICH CAN BE RE-TAPPED 1/16" ABOVE Previous Diameter C FOR HOLES WHICH REQUIRE RE-TAPPING 1/8" ABOVE Previous Diameter	NOMINAL +005"	NOMINAL	5/8	.6250	.6300	.6250	.5718	.5668	.5186	.5086		
			11/16	.6875	.6925	.6875	.6364	.6293	.5811	.5711	.5681	.5711
			3/4	.7500	.7550	.7500	.6968	.6918	.6436	.6336	.6486	.6336
			13/16	.8125	.8175	.8125	.7593	.7543	.7061	.6961	.7111	.6961
	NOMINAL +010"	NOMINAL	15/16	.9375	.9425	.9375	.8843	.8793	.8311	.8211	.8361	.8211
			1	1.0000	1.0050	1.0000	.9468	.9418	.8936	.8836	.8986	.8836
			1 1/16	1.0625	1.0675	1.0625	1.0093	1.0043	.9561	.9461	.9611	.9461
			1 1/8	1.1250	1.1300	1.1250	1.0718	1.0668	1.0186	1.0086	1.0236	1.0086
	NOMINAL +015"	NOMINAL	1 3/16	1.1875	1.1925	1.1875	1.1343	1.1293	1.0811	1.0711	1.0861	1.0711
			1 1/4	1.2500	1.2550	1.2500	1.1968	1.1918	1.1436	1.1336	1.1486	1.1336
			1 5/11	1.3125	1.3175	1.3125	1.2593	1.2543	1.2061	1.1961	1.2111	1.1961
			1 3/8	1.3750	1.3800	1.3750	1.3218	1.3168	1.2686	1.2586	1.2736	1.2586
	NOMINAL +.010"	NOMINAL	1 7/16	1.4375	1.4425	1.4375	1.3843	1.3793	1.3311	1.3211	1.3366	1.3211
			1 1/2	1.5000	1.5050	1.5000	1.4468	1.4418	1.3936	1.3836	1.3986	1.3836
			1 9/16	1.5625	1.5675	1.5625	1.5093	1.5043	1.4561	1.4461	1.4611	1.4461
			1 5/8	1.6250	1.6300	1.6250	1.5718	1.5668	1.5186	1.5086	1.5236	1.5086
11 THREADS PER INCH	FOR LIMITS ON FIREBOX WATERSPACE STAYS SEE SHEET NO MS11											

end of tables