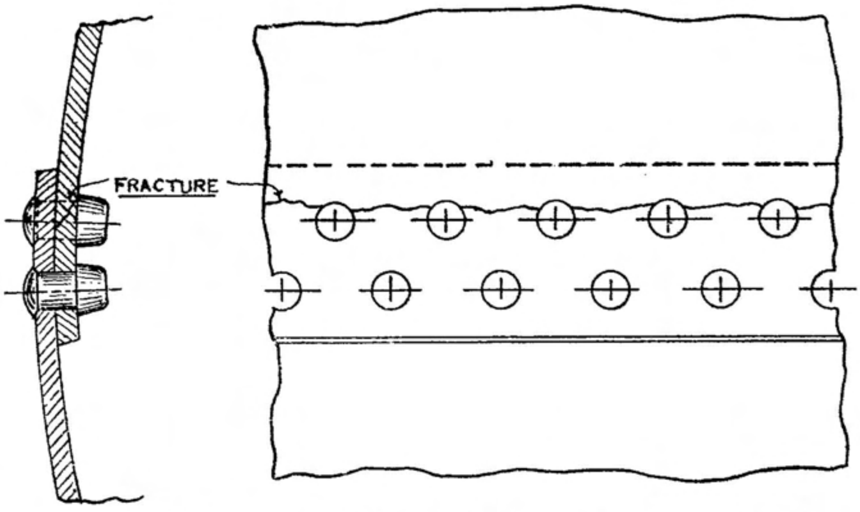
EXPLOSION OF A STEAM DRUM OF A WATER-TUBE BOILER, LAND TYPE.

An investigation into the cause of the failure under normal working conditions of the steam drum of a water-tube boiler installed in an industrial establishment, is of interest, as it serves to indicate the care necessary in the preparation of plates and building up of riveted structures subject to conditions as generally obtain in steam boilers. A circular steam drum is a simple engineering structure in which the normal stresses are very approximately known, and under ordinary working conditions any excessive stress can only be brought about by deviations from design or careless treatment during manufacture at some particular section. There is usually little doubt as to the quality of the metal if properly treated, as stringent regulations are in force governing the inspection and tests such metal has to stand. The explosion of a steam drum in a boiler, which receives normal care and treatment is a serious but fortunately a very rare accident, and it was therefore necessary in this case to carry out a particularly thorough investigation into its cause.

There was nothing unusual in the design of the boiler and it is therefore only necessary to consider the defective steam drum. This drum, which was 54 ins. diameter, was built up of three belts of $\frac{1}{2}$-in. steel plates, the two end belts being lapped over the centre belt at the circumferential seams. These seams were single-riveted. The longitudinal seams of the belts were double-riveted zig-zag, with a total lap of seam of $4\frac{1}{8}$-ins. These



longitudinal seams were situated in the steam space and were ell above the normal water-level maintained in the boiler. The two seams of the end strakes of plate were on one side of the drum and the centre strake seam diametrically opposite.

The ends of the drum were dished and flanged into the shell plates. The design of the longitudinal seams of the drum was such as would have met the B. of T. requirements for the stipulated working pressure of 160 lbs. per sq. in.

No repairs of moment had been carried out on the boiler, which was 9½ years old at the time of the explosion, beyond some tube renewals and slight caulking to the seam where the explosion occurred. This caulking was carried out 3 years previous to the explosion, when the seam was leaking slightly. As will be seen later, an incident considered of very little moment at the time in connection with the caulking, had an important bearing on the subsequent explosion investigation. The nature of the explosion was a complete rupture of the whole length of the longitudinal seam of one of the end strakes of the boiler, the upper part of the plate opening out and bursting the rivets of the circumferential seam where it joined the centre strake, the front end plate also blowing away.

The following possible causes of the explosion were considered :—shortness of water; excess of pressure; workmanship; material.

There was nothing in the evidence brought forward to attribute the cause to either of the first two mentioned. None of the boiler tubes and plates showed signs of overheating, and the safety valves, apart from slight damage due to the explosion, were found to be in good order. The boiler also at the time was connected to the main steam range. An examination of the plate after fracture showed in fact that it would not have required an excessive pressure to produce failure, and it was considered surprising that the plate actually held for so long a period, without having given indications of its condition. The fracture of the plate did not occur at what normally would be considered the line of least resistance, *i.e.*, directly between the rivet holes, and the cause of failure had therefore to be looked for under workmanship and material features.

As regards workmanship, there were one or two points that called for remark, although probably it is difficult to refer back to the original workmanship in a special case after the lapse of a number of years. It was understood, however, that the ends of the plate which lap over one another after rolling to form the longitudinal seam were pressed into the right curvature in a hydraulic press before being put into the rolls. They were then rolled into cylindrical form. In this drum the end of the plate forming the outer lap was not made the proper curvature, and therefore did not bed down closely upon the under lap; at some parts this outside lap was practically straight from the inner row of rivets to the outer caulking edge. This necessitated undue caulking in order to close the plates at the outer edge, which operation would also have a tendency to further force the plates apart. This was deduced from an examination of the seams of the other strakes of the drum. The rivet holes were true but a little rough inside due either to the speed at which they were drilled or to the use of a blunt drill. The plates on the outside were heavily marked round the heads of all the rivets by a fullering tool, but this had no effect on the part that failed, which was the underlap. The edge of the plate was tried along the caulking for any sign of bulging due to excessive pressure by the ram when riveting, but none of any consequence was found. The burrs caused by the drill were not entirely removed from the inner surfaces of the laps before riveting was begun. The foregoing defects in workmanship, although impairing the efficiency, were not in themselves, however, thought to be sufficient to account for the subsequent failure of the plate.

The question of material was gone into thoroughly, various portions of the fractured plate, and portions in similar positions in the uninjured strakes being examined and tested. There was nothing unusual in the chemical analysis of the material. The examination of the structure at the fracture was characteristic of cases in which steel has failed by the slow formation and spreading of a crack going on for a period of many years, except at the inner edge of the plate where the metal pulled down under the tensile stress when the explosion occurred. The material of the fractured plate under notched bar tests however showed that in the region of the failure it had received treatment which had rendered it more brittle than the other portions of the plate.

Reference has been made to the caulking which took place 3 years before the explosion. This was carried out at the time by an experienced boiler-maker when the pressure gauge was registering 50 lbs. in the boiler, and the seam was leaking slightly at one position. On caulking, this leak began to extend both ways, almost the whole length of the plate. At the place where the leak started, a small piece of plate at the lower part of the caulking edge broke away. This piece was about 1½ ins. long and 3/16-inch broad. This was taken to be a piece of "shear-edge" and no importance was attached to it at the time, but it necessitated the plate having to be chipped slightly to get a fresh bevelled caulking edge. Eventually the seam was made tight and gave no further trouble until the explosion.

As far as the case can be reconstructed, the crack in the plate started at the inside edge where hidden by the lap and probably at the time of the caulking, it may have already been at places through the plate, although not observable at the internal surface. This fracture gradually extended the greater length of the plate till the reduced section was insufficient to stand the stipulated working pressure. After the explosion the longitudinal seam of the back-end ring of the drum was cut out complete by means of the oxy-acetylene flame, and all the rivets were then carefully drilled out and the two pieces of plate forming the lap separated, the one from the other. These pieces of plate were thoroughly examined in strong sunlight with a magnifying glass, but no fractures could be discovered. This seam had the same characteristics of workmanship as the others, and so far as could be seen was influenced by the same circumstances and conditions as the one that failed, but had not developed the slightest sign of a crack. At the fractured seam, a portion of the underlap, almost the full length of the plate, was left in place held on by the inner row or rivets. The rivets were all carefully drilled out in a machine, and the pieces of plate separated. Before they were separated there was but very slight indication of cracks apart from that which caused the main failure, but as soon as the plates were separated and the inner surfaces exposed, a series of small fractures were discovered radiating principally but not entirely, from some of the rivet holes. The cracks all started from the surfaces of the plates that were in contact at the lap. These small cracks could not have been seen in the ordinary way, even with a careful examination when the drum was in position before the explosion, unless some suspicion had been aroused at the time of the leakage of the seam, but having regard to the fact that leakage from the riveted seams of boilers is not an uncommon occurrence, it was not held at the time to be an occasion for polishing and microscopical examination internally. Although the examination therefore revealed that the cause of the explosion was due to the slow failure of a plate, which was shown to be brittle, in the neighbourhood of the part that failed, the exact stage at which this brittleness was brought about, either in the original manufacture, or construction of the boiler, was not established.

It is now of interest to point out some essential features in the specifications for boilers for the naval service that would have a bearing on such a case. The regulations laid down for guidance of those responsible for the inspection of the materials and the construction of boilers for warships are based on the results of many years of experience and too much importance cannot be attached to their interpretation, to ensure materials of good quality and sound workmanship, by which means only serious accidents are to be avoided. In addition to stringent tests of the material of the plates, the first stage before any work is done on them is the removal of all scale by pickling in a dilute acid bath. This will reveal any surface cracks if such are present, and in conjunction with the material tests will generally determine whether the plate in this condition is in all respects satisfactory for the work to be put into it, and for its final service.

It is further specified that in cases where plates have to be heated, the greatest care should be taken to prevent any work being done upon the material after it has fallen to the dangerous limit of temperature known as " blue heat "—say from 600° to 400° F. Should this limit be reached during working, the plates should be re-heated. Also that plates which have been worked while hot are to be subsequently annealed simultaneously over the whole of each plate.

When this annealing is required, the plates are to be close annealed (or in such other manner as to prevent undue scaling) at a temperature within the limits of 850° C., and 900° C. The plates are to be evenly heated and brought to the correct temperature throughout, and after they have reached this temperature are to be withdrawn from the furnace and allowed to cool in air, the necessary precautions being taken to prevent unequal cooling.

Suitable precautions are to be taken to prevent warping and distortion, and it is to be demonstrated to the Engineer Overseer's satisfaction that the specified annealing temperature has been attained in the furnace, and that all parts of the plates have reached this temperature.

As regards workmanship, it is laid down for the Overseer that :—

> " He will satisfy himself that the laps of the seams are in agreement with the drawings and that their edges are close to the plate; that any undue work by hammering or heavy caulking tool to close up the edges of the plate is not permitted."
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> " Before rivets are put in he will see that the plates are brought properly together, and the holes are fair with one another; he will not allow drifting on any account, but will see that they are carefully rimered fair when necessary."
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> " All holes in plates are to be drilled in place after bending, the burrs produced by drilling to be carefully removed before the plates are finally put together for riveting."

It was indicated that burrs were found in the case under review between the longitudinal joint which failed and this indicates that the joint was not separated and cleared after drilling; the very slight annular ring of metal sometimes found round the rivet holes after rough drilling, especially if the plates are not held very tightly to one another, is considered sufficient to distort the plate during the process of closing and riveting. It is known too, that such slight bruising or nicking of plates exposed to stress may ultimately develop into cracks and lead to failure.

In the case dealt with, the trouble commenced on the surface of the plate covered by the outside lap, and so was not seen; the breaking away of a piece of the outside lap during caulking and tests of the fractured plate near the failure indicated that both edges of the plate were brittle, and as the remainder of the plate was sound, there are strong grounds for the conclusion that the plate in the region of the joint had received treatment during manufacture of the boiler, which had resulted in this change. The instructions previously referred to, are drawn up to preclude such treatment as may bring about changes or impair the efficiency of such sections in a boiler structure.