

FIG. 12A.—Burwood Boiler from Inside.

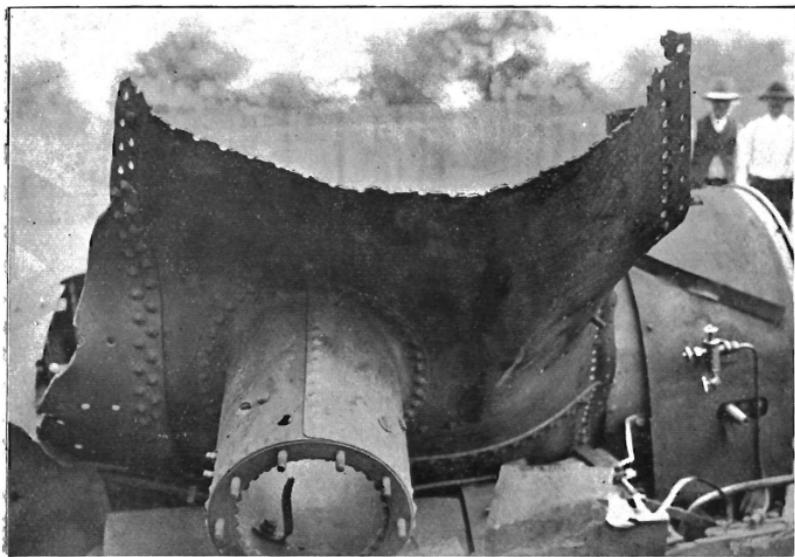
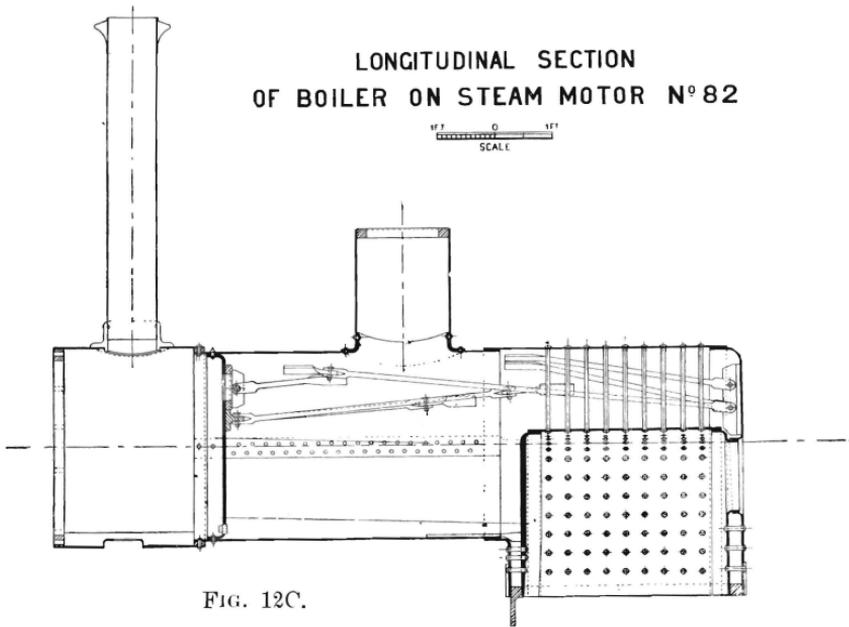


FIG. 12B.—Burwood Boiler from Outside.

loop near Burwood, where two steam trams had halted to exchange staffs previous to crossing, the two steam motors standing side by side at the instant of the explosion. Boiler No. 82 was completely wrecked (Figs. 12A and 12B) the other motor was severely damaged, and, very unhappily, the accident caused the death of both drivers. In the case of this failure, as in the Thornton one already described, there would appear to have been no unusual circum-



stances about the running of the motor prior to the accident. The safety valves were found to be still in good order after the explosion; the water gauge cocks and fusible plug were examined and found to be in quite satisfactory condition, and there is no reason to suppose that there was any abnormal condition to note in connection with the operation of the engine and boiler at the time.

A reference to Figs. 12A and 14 will show that the boiler drum had fractured along the longitudinal seam on the left hand side looking towards the smoke box, and it was found that the fracture was most marked at a point

about 12 or 15 inches from the front tube plate. When the side plate fractured, it was obviously thrown violently off to the right, tearing away the rivets on the circumferential seam at the smoke box end, and ripping through the material of the top plate at the fire box end. The fracture, in this case, occurred in the inner plate of the lap joint and along the line of the inner row of rivets. There was, of course, a good deal of incidental damage done to the stays and other internal fittings of the boiler, but a minute examination of the whole of these made it clear that they were secondary effects, and in no way the primary cause of the failure of the boiler.

12. *Construction and History of the Boiler.*—The general type and construction of the boiler on steam motor 82 will be sufficiently clear from the photographs, and from the longitudinal section, Fig. 12C. The tramway motor and boiler were originally built by the Baldwin Co., but the boiler that exploded was a new one built at the Randwick tramway shops in 1895. The plates are  $\frac{3}{8}$ " steel with  $\frac{3}{4}$ " rivets, the pitch being  $2\frac{3}{4}$ ". The rivet holes were punched before rolling the plates and were not reamed, and it was observed on examining the boiler after the accident that the plates were not punched from the faying surfaces. The important point to note in the construction is the punching of the rivet holes, as this circumstance undoubtedly fixed the precise locality where the fracture would occur. The history of the boiler was that it was put into commission in July, 1895; that all tubes were expanded and the wash-out holes re-tapped in December, 1896; that eight stays were renewed and the wash-out holes re-tapped in May, 1905, and that nineteen stays were renewed and the wash-out holes re-tapped in 1906. At a working pressure of 130 lbs. per square inch, and a joint efficiency of 70%, the stress computed in the ordinary way would be 10,000 lbs. to the square inch which, assuming an ordinary value for the strength of the material, would give a factor of safety of six. This would be considered satisfactory if looked at according to Lloyd's or the Board of Trade rules unless, perchance, the difficulties of effective inspection in this type and size of boiler were judged sufficiently great to demand special increase in the factor of safety.

It will be seen that the provision for the inspection of the internal parts of the boiler is not very good. It would be impossible to get down on to the top of the tubes for an ordinary inspection of the furnace crown and stays owing to the internal hamper in the boiler. A limited degree of inspection was possible through the steam dome, but the space is very restricted and it will be noticed that the lap joint that failed is set well down below the level of the fire tubes, and hence a minute examination of the condition of the longitudinal seam would be practically possible only



FIG. 13.—Furnace crown stays showing corrosion.

when the boiler was being re-tubed. An examination of the interior of the boiler after the explosion showed that a good deal of corrosion had been going on; many of the stays supporting the furnace crown and in the water legs being greatly reduced in section (see Fig. 13). The only openings around the fire box were at the bottom corners where the wash-out plugs were fitted, there being no inspection doors in the fire box side to allow of the stays and the furnace crown being observed. There was a marked amount of grooving on the

front tube plate close up to the flange such as is commonly found in boilers fitted with a stiff end of this type, and there was also noticeable grooving on the drum plates at the smoke box end, the grooving following practically the whole way round the circumferential seam. Although this grooving was fairly extensive, in no case was it of such consequence as to be considered dangerous. There was further a good deal of pitting over the drum plates, but it was of normal extent and not calling for any serious comment. Along the line of failure on the inside seam the pitting and grooving appear to have been very general along such line, and corresponded closely to what would have been expected from the considerations already discussed with regard to the extreme surface stresses set up in the neighbourhood of these lap joints.

13. *Character of Fractured Plate and Results of Tests.*—An examination of the fractured plate in the Burwood boiler was made on the same lines as were adopted in the Thornton boiler. The diagram, Fig. 14, shows the position of the fracture which is seen to follow more or less closely the inner line of rivet holes of the inner (i.e., the crown) plate of the drum. Numerous smaller cracks are visible, these being due largely to the injury to the plate caused by punching the rivet holes. That the punching had an extremely bad initial effect on the plate was evident also by an examination of the corresponding unfractured joint on the other side of the boiler. The rivets were cut out of this opposite joint and the edge of the plate bent back slightly under the hydraulic press, when it was evident that there were cracks here and there along this line of rivet holes also.

To determine the quality of the material in the plate, test pieces were cut out as shown in the diagram, and the results are given in the table (Appendix I.—Burwood). It is obvious from the figures obtained that the plate was of satisfactory quality, and showed no signs of being at fault in any particular.

14. *Comparison of the Two Explosions.*—A brief comparison of these two boiler explosions will be interesting, as they exhibit nearly all the characteristic features usually appearing in such failures (see Fig. 15 and Figs. 2 and 14). The crack starts always from inside the joint, and may proceed outwards as in the Thornton case, or inwards as in the

DEVELOPMENT OF FRACTURED PLATE OF BOILER  
ON STEAM MOTOR No. 82.  
VIEWED FROM INSIDE.

UNIVERSITY TEST SPECIMENS ... 1, 2, 3, 4a, 4b, 5.  
DEPARTMENT ,, ,, ... A, B.

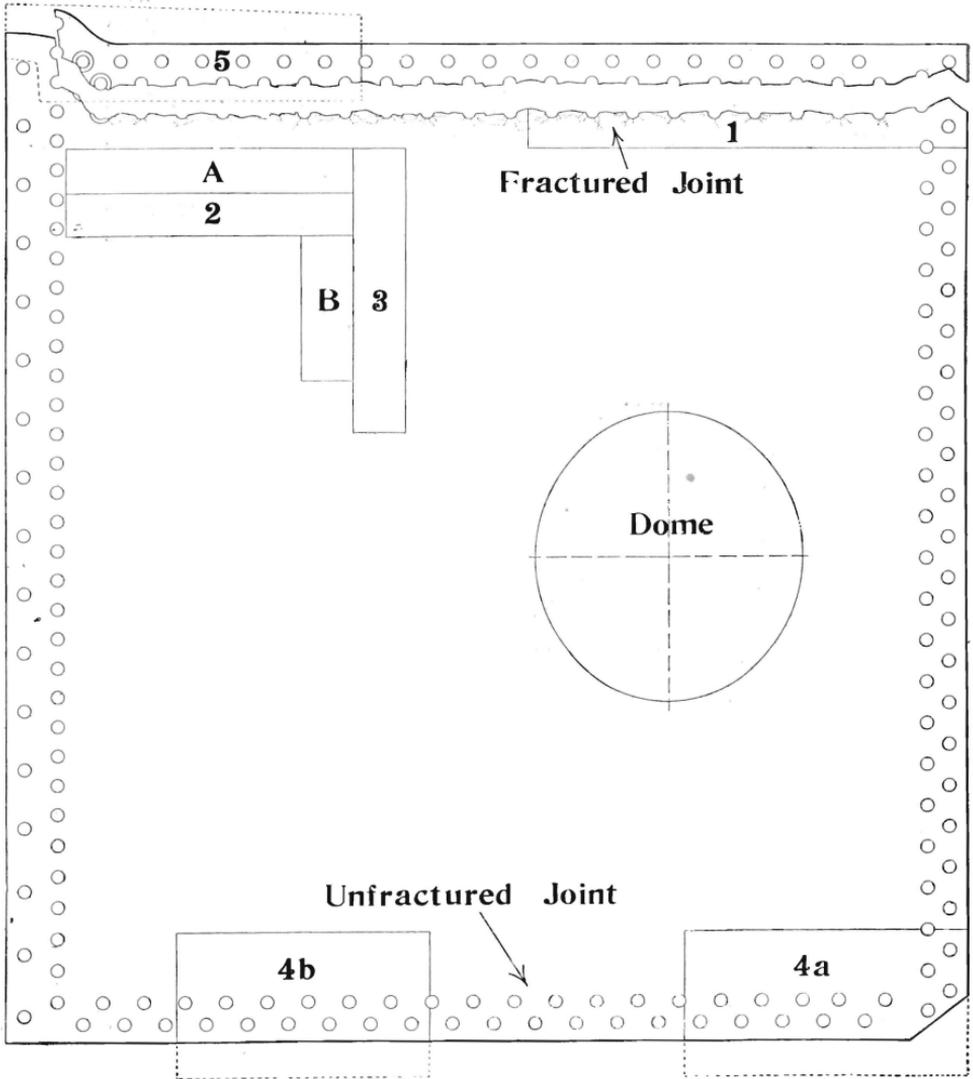


FIG. 14.—Inside View of Burwood Boiler Plate.

Burwood case. The crack may be a very distinctly marked line (usually at the edge of the landing) with very few subsidiary cracks (Thornton, Fig. 2), or may be distributed irregularly along the joint (usually following more or less the rivet holes) and with many secondary cracks (Burwood case, Figs. 14 and 14A). The dotted lines (Fig. 15) showing approximately the extreme fibre stress for both surfaces, indicate that in each case the crack passes from the surface of high tension towards the surface of compression or low tension.\*

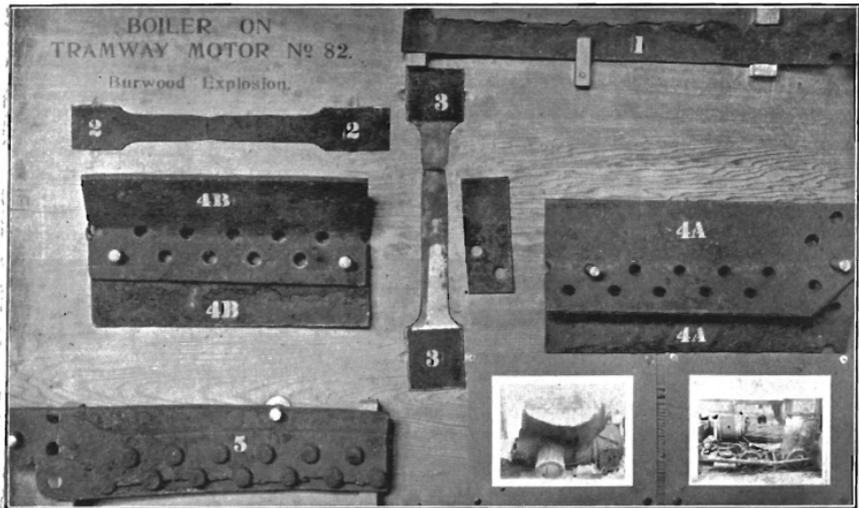


FIG. 14A.—Board of Exhibits—Boiler No. 82.

The differences in the construction of the two boilers has already been made clear. The Thornton boiler was made of iron plate with drilled holes, the plate being rolled before drilling, while the Burwood boiler was made of steel plate with holes punched before rolling. The joint of the Burwood boiler was continuously under water, while that of the Thornton boiler was only intermittently so. Neither joint was exposed to hot gases.

\*These approximate lines of stress are estimated from a consideration of the results of tests made on actual riveted joints and recorded in Part II. of this paper.

15. *Similar Action in Other Unsymmetrical Joints.*—If the arguments employed in the foregoing pages are sound, it follows as a probable consequence that a similar action and similar results will be found to follow in all other parts where stresses are applied to the material in an unsymmetrical fashion. Cases in point are the dished ends

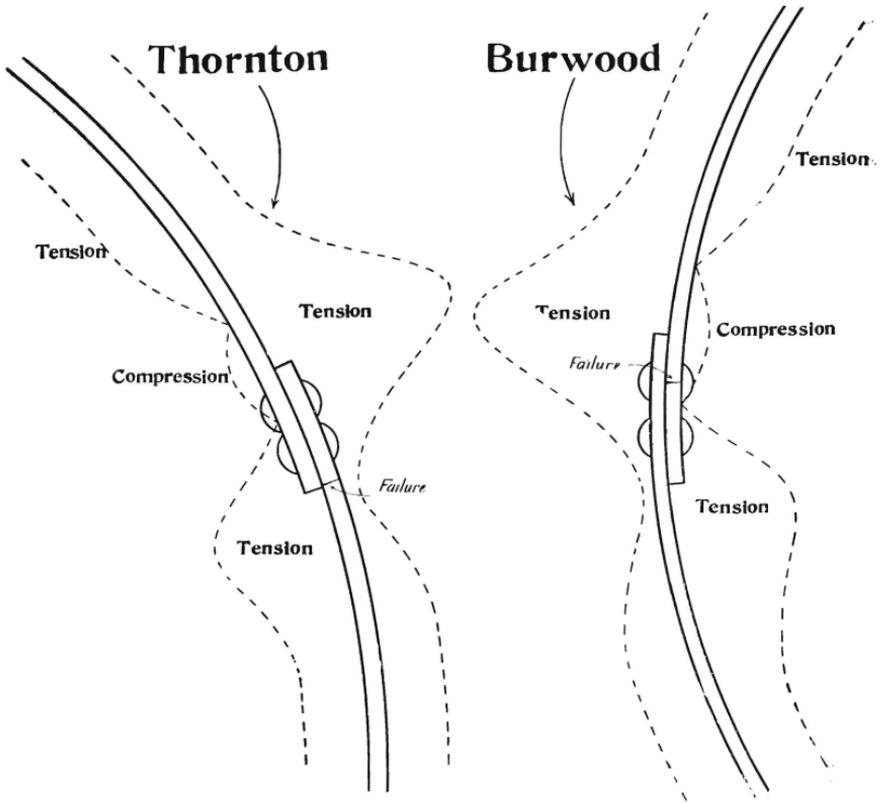


FIG. 15—Comparison of the Two Explosions.

of drums; the bottoms of the water legs of vertical boilers; and the attachments for valves, manholes, and stiffening pieces generally. An examination of the literature of boiler failures, of which there is an immense amount available, will show that failures of this character do commonly occur in the neighbourhood of such fittings. Some very striking

confirmatory results will be found in §§ 33 and 37 illustrating how the pitting and grooving of dished ends occur in the neighbourhood of maximum fibre stress.

16. *General Conclusions.*—The general conclusions at which the authors arrived as a result of the investigation of these two boiler failures may be shortly summarised as follows:—

(a) The failure in each case was due primarily to the high surface stress which is the characteristic condition obtaining in all examples of lap joints. The failures were not due to any defect in the quality or structure of the material of the plate.

(b) High proof pressures on boilers are to be avoided, especially as applied to boilers that have been worked for a considerable period, since they only tend to aggravate the trouble.

(c) Much valuable information might be obtained by a close study of the plates in the neighbourhood of riveted joints when old boilers are being broken up. Many boiler shells are scrapped each year, and their construction and life history will be found very largely written on the surfaces of their plates.

(d) The closest scrutiny should always be given to boilers with lap joints, and especially to these joints themselves. No suspicious signs in the lap joint should ever be neglected and the internal inspection of lap-jointed boilers should be more frequent than when fitted with butt joints.

(e) Above all things the one conclusion to which any reasonable observer of facts would come, is that riveted lap joints should not be employed under any circumstances in boiler construction.