ing action only, determined by the fixed mirror method. In this case it was not possible to ascertain the total extreme fibre strains, for at the time no method presented itself of determining the direct strains which existed within the plate at that part. The results are plotted in Fig. 26C, and although the curve is not a complete representation of the strains occurring, yet it is sufficient to show the presence of excessive stresses.

THIRD SERIES OF TESTS.

34. *Modified Method of Measurement Adopted.*—The method of determining the extreme fibre strain in those portions of the boiler under observation during the second series of tests was not altogether absolute, for the strain resulting from bending action alone was measured, and to this the calculated direct strain had to be added in order that the total strain in the extreme fibre might be ascertained and thus the stress deduced. This was only possible in the case of the extreme fibre strain along the test line AB (see Figs. 24 and 26), and as has been stated previously, the fixed mirror method could give no final results with regard to the stresses in the dished end of the boiler along the test line OP. Further consideration was therefore given to the possibility of directly measuring the extreme fibre strains by some modified form of Martens' mirror extensometer, and, as a result, it was found possible to satisfactorily employ the arrangement shown diagrammatically in Fig. 28. In this arrangement of the Martens' mirror extensometer, the mirror attached to the prism was well removed from the surface of the boiler plate by means of a link A (it was the fouling of the adjusting gear at the back of the mirror with the surface of the boiler plate which was responsible for the extensometer method not being previously employed in the tests upon actual boilers).

The fixed mirror was rigidly attached to the back of the extensometer bar, thereby enabling greater accuracy to be obtained than was possible with the arrangement used in the first series of tests.*

* The theory of this arrangement of the two mirrors, will be found to lead to as accurate determinations as in the case of that usually employed.

35. *Confirmatory Tests upon a Lap Joint with Straight Plates.*—With this improved form of extensometer, confirmatory tests were carried out upon a lap joint which was very similar in design to the first one mentioned in the first series of tests; in this case, however, the rivets were replaced by fitted bolts (for detail of the joint, see Fig. 16C.) Simultaneously a check was made upon the accuracy of the fixed mirror method of measurement, and the results

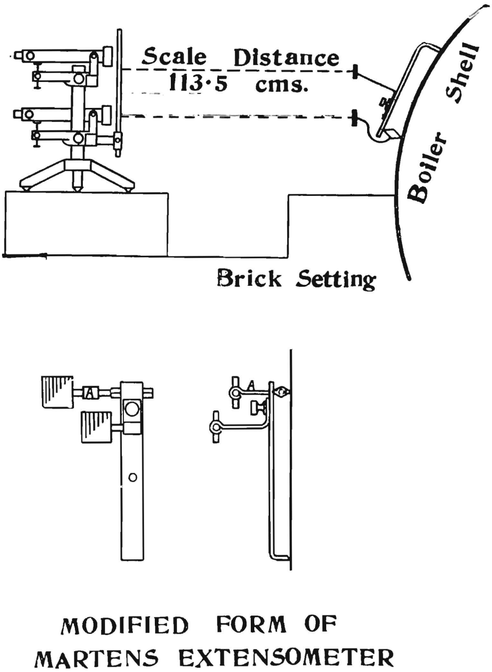


FIG. 28 (Diagrammatic).

in the form of curves of stress which were obtained from the observations made throughout the total length of both plates forming the joint are indicated in Fig. 29. On reference to this figure, it may be seen that the stress curve obtained for each plate was similar in form, but in the case of the narrow plate the intensity of stress was considerably

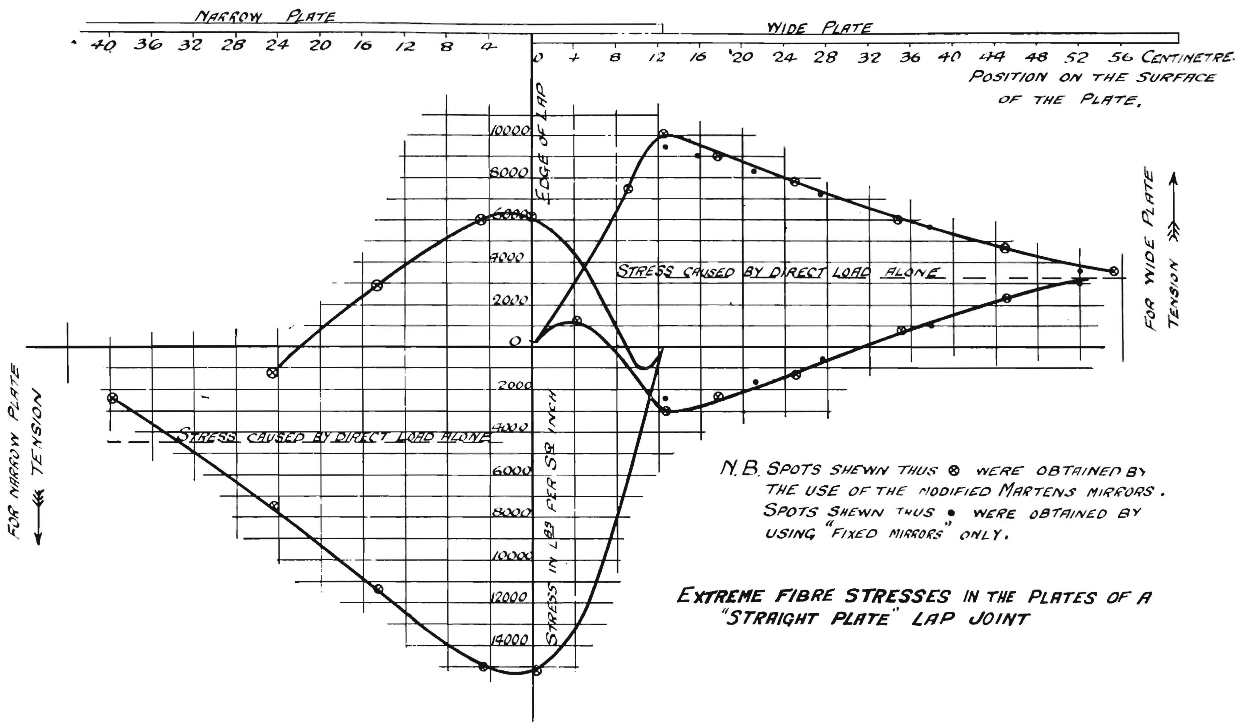


FIG. 29.—Lap Joint Stress Diagram.

above that in the wider plate. This is what one would expect, as the cross sectional areas of the plates are dissimilar. In addition, it should be noticed that the observations obtained from both methods of measurement were practically identical, and this fact gives proof as to the correctness of the "fixed mirror method" which was suggested during the first series of tests.

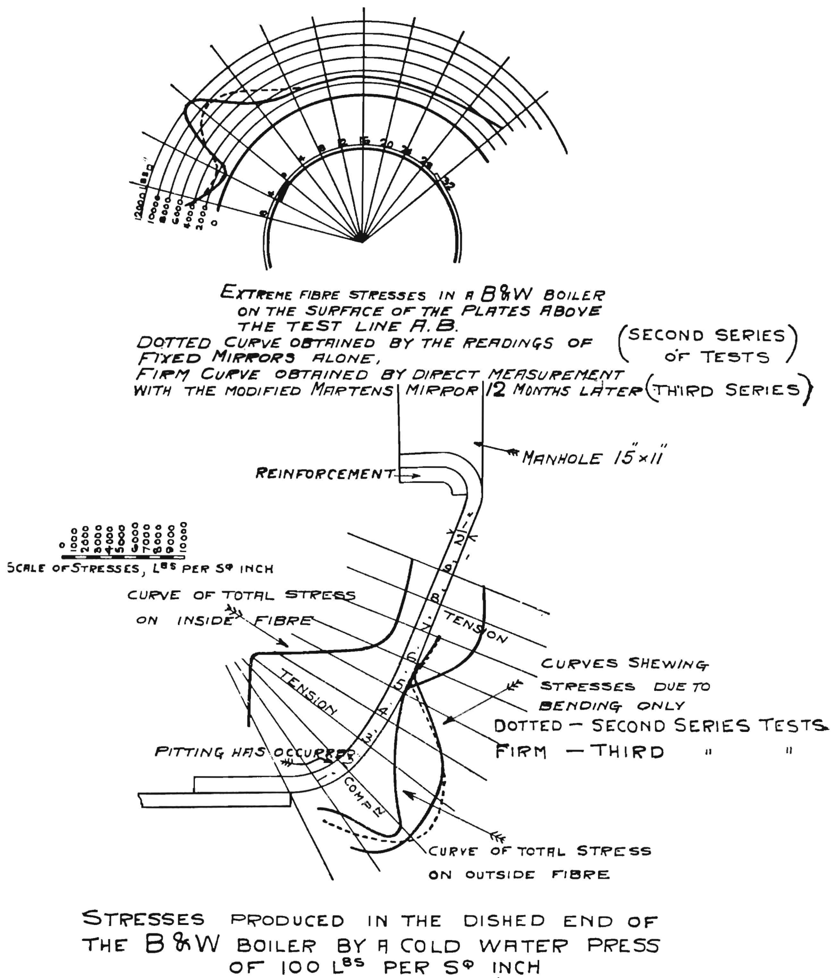
The maximum extreme fibre stress in this case was about 3.2 times the stress that would have been caused by a direct load of the same magnitude.

36. *Additional Tests upon Boiler Drum.*—Attention was then paid to the direct measurement of the strain in the extreme fibres along the same test line AB, of the B. and W. boiler previously tested during the second series of tests (see Fig. 24A).

The interpretation of results showed the presence of a maximum local extreme fibre stress of 12,000 lbs. per square inch in the vicinity of the longitudinal joint. A comparison between the curves of extreme fibre stresses during both the second and the third series of tests is given in Fig. 30. It may be seen that the type of curve is the same in each case, but that in the latter series of experiments the maximum fibre stress was somewhere about twenty per cent. greater than the value of the maximum which had been determined during the second series of experiments.

Reference is made in §37, to these deduced "stresses." It must be remembered that in all cases it is "strains" that are measured, and the stresses are deduced on the basis of certain assumptions, which, while true for the tests on the flat plate joints, are known to be only approximately so when applied to the shell of a boiler.

37. *Additional Tests upon the Dished End of the B. and W. Boiler.*—Confirmatory results were next sought as regards the magnitude of the extreme fibre strains in the plate along the test line OP (Fig. 24A). In this case observations were made by means of both the fixed mirror and the modified form of the mirror extensometer described above. The curves of stress produced by bending action only, and obtained by the fixed mirror method of measurement during the second and third series of tests are shown in Figs. 30 and 31, and are very close in their agreement.



Figs. 30 and 31.

In the same diagram the curve of total stress on the outside fibre as deduced from direct measurement of the surface strains by the modified mirror extensometer is also shown for a cold water pressure of 100 lbs. per square inch. This curve of total stress indicates the presence of a large compressive stress upon the external surface of the plate, which rapidly changes to a tension.

Having thus obtained graphical records of both the total extreme fibre stress and that produced by bending action only at all points on the surface of the end plate along the test line OP, Fig. 24, for a cold water pressure of 100 lbs. per square inch, it is possible to obtain the curve of total stress in the inside fibre under the same conditions of loading. The stress curve for the inner surface of the plate has been obtained as previously described, and is also shown in Fig. 31. It may be seen that the maximum tensile stress of the inner side of the plate has a value of about 11,000 lbs. per square inch. As this boiler has been subjected, since its manufacture, to an hydraulic test, in which the pressure was at least 250 lbs. per square inch, it follows that the extreme fibres of the plate at the position where the maximum tensile stress occurs on the inner surface of the plate, as indicated in Fig. 31, must have been about 27,500 lbs. per square inch, a value which is near the elastic limit of the material.

Subsequent to these tests it has been observed that pitting has taken place circumferentially along a line which corresponds to the point of maximum intensity of stress on the extreme fibres of the inner plate. The pitting has taken place in a portion of the boiler where the extreme fibre stress, when under pressure, is considerably above that generally present in the material of the boiler. This fact indicates that the pitting of boiler plates may with every justification be expected where stress conditions are likely to be abnormal, and is confirmatory of the action that takes place in a lap joint when used in a longitudinal seam in a boiler. The significance of this pitting, taken in conjunction with the failure of the Greenwich boiler (see §33), is obvious.

38. "*Sections of Stress.*"—Referring to Fig. 24A, it will be noticed that observations were taken on several test

lines situated at different positions along the axis of the boiler drum.

The strains measured at each fixed mirror position on these test lines enable one to plot a diagram of the strains at any section of the boiler corresponding to a test line. By plotting the results of several of the test lines, "sections of strain" can be obtained for sections of the boiler intermediate to the actual test lines, just as the plotting of the whole of these strains from a suitable datum would enable one to obtain what might be called a "surface of strain" for the plates under consideration. It must be remembered in connection with this that the strains thus plotted are measured in one direction only. By referring to Fig. 24, it can be seen that such a "surface of strain" could be obtained by plotting the strains measured on the test lines A.B., C.D. ...... to M.N., and that this surface would represent the strain in the circumferential direction.

On the test line O.P., measurements were taken in a direction parallel to the axis of the drum, and the quantities so measured are, of course, the longitudinal strains. It is interesting to note that these are approximately one-half of those measured circumferentially. If a series of lines, such as O.P., were taken, a similar surface could be obtained for the longitudinal strains.

In Fig. 32A (Plate IV.) sections of the boiler are shown in which the stresses are plotted as for the inside and the outside surfaces of the plate. These sections we have termed "sections of stress;" they show in a graphic form the observed stresses obtained by the tests and such assumed stresses in parts of the boiler not yet tested, as seemed reasonably justified. In Fig. 32B is a corresponding "Section" for a lap joint as tested in the testing machine. These two coloured diagrams may be regarded as a kind of summary of the results so far obtained.

It must be borne in mind that the measurements obtained in all cases were measurement of strain, and the assumption has been made that the stress is proportional to the strain, and that the modulus of elasticity is 29,000,000 lbs. per square inch. This assumption is probably quite near enough for practical purposes, but consideration will show that as the material is strained in two directions at right angles to each other, and as the strains are not uniform over the surface of the plate, the modulus may be a variable quantity. The "sections of stress," as shown, are on the assumption that the modulus of elasticity throughout the shell of this boiler is constant. It will be seen that if a sufficient number of test lines were taken in two directions at right angles to each other, a surface of strain for each direction could be obtained, and the study of two such surfaces of strain would assist the investigation of the conditions obtaining at any part of the shell.

It can be seen that these two surfaces would lie at different elevations above the datum line, and it is possible that they might intersect one another at certain places. To enable "the surface of strain" to be completed so that such a surface would give the actual condition of strain at any part of the shell, it would be necessary to obtain a measurement of the strain in the direction of the thickness of the plate. It would seem that if this could be obtained, it would be possible to determine the modulus of elasticity at any point in the shell, and so to correctly determine the stress condition at that point.

It must be clearly understood that the stresses that have been deduced from the two sets of strains actually measured are only approximations; it should be remembered that the curves of stress given in those parts of the paper referring to the investigations on boilers are merely strains multiplied by a constant, and that they are throughout a true representation of strain to a suitable scale, but are only an empirical representation of stress.

In Fig. 32 those portions of the boiler plate in which the extreme fibre stress is abnormally high or low can be very easily noticed, and it is a very significant fact that in all places where experiment has indicated a high value for the extreme fibre stress, pitting, grooving, and corrosion usually occur to a greater or less extent.

39. *Conclusions.* — The results of the experimental work carried out lead to the following conclusions:—

1. That in an ordinary straight plate lap joint the maximum fibre stress may amount to about four times the stress for which the joint is actually designed.

2. In the case of lap joints in boilers, owing probably to the stiffening effect of contiguous parts of the boiler, the extreme fibre stress may amount to about twice the stress for which the joint is designed.

3. That "typical lap joint failures" are the result of the extreme stress conditions present in this type of joint, and are due to the want of symmetry in the design.

4. That in the inspection of boilers particular attention should be paid to those parts where it is known that bending actions can occur, and that these parts should be most carefully examined for incipient pitting and surface cracks.

5. That where pitting has been noticed, its progress should be very carefully watched, and should it persist as a line of pit marks for any considerable distance, the examination should be most particular, as the cracks run from one pit hole to another, and the condition of the shell may be such as to be dangerous.

40. *Acknowledgements.*—The authors desire to express their indebtedness to the Chief Mechanical Engineer for Railways and to the Chief Electrical Engineer for Railways for kindly placing at their disposal all the necessary data in connection with the two boiler explosions; to Professor W. H. Warren, for the use of testing and extensometer apparatus in connection with Part II. of the paper; to Messrs. G. and C. Hoskins for the use of two boilers for test purposes; to Mr. H. E. Ross, for the loan of photographs; to Mr. W. R. Hebblewhite, for assistance in the preparation of diagrams and models; and to Mr. R. Hay for assistance in the construction of models and exhibits.

APPENDIX I.

THORNTON

Test Piece Number.	Original Dimensions. Inch. Breadth	Thickness.	Area	Tensile Stress in Pounds, Total.	Per sq. Inch.	Stress in tons per sq. Inch.	Apparent Limit of Elasticity from Auto-diagrams.	Contracted Dimensions. Breadth	Thickness.	Area.	Contraction of Area per cent.	Elongations measured after fracture. On 8in.	On 4in.	Local Elongation Ins	General Elongation per cent.	Total Elongation per cent. on 8in
1	1.5	.556	.834	43000	51600	23	13.4	1.34	.457	.613	26.6	1.36	.85	.34	12.8	17
2	1.5	.553	.83	41500	50000	22.3	10.5	1.34	.481	.645	22.3	1.16	.7	.24	11.5	14.5
3	1.5	.54	.81	38750	47800	21.4		1 36	.437	.595	26.6	1.39	.99	.41	12.25	17.4
4	1.5	.552	.828	42000	50600	22.6		1.29	.457	.592	27.5	1.39	.77	.14	15.5	17.4
NOTE.—	No. 4 was loaded up to			7000	8433	and then released to zero. It was then loaded again to breaking point.										
9	1.5	.526	.789	37500	47600	21.2	11.4	1.35	.46	.621	21.2	1.06	.73	.4	8.25	13.2
13	1.5	.55	.825	42000	51000	22.8	10.5	1.29	.445	.574	30.2	1.42	.92	.42	12.5	17.75
10	5/16	diam	.076	3750	49000	21.8	15.8		0.25 diam	.049	35.6	.47 on 3in	.36 on 1½in	.25	7.35	15.7 on 3 in.
NOTE.—	No. 10 was a special small test piece cut close to the fracture.															

BURWOOD

Test Piece Number.	Original Breadth	Thickness	Area	Tensile Total	Per sq. Inch	Stress in tons per sq. Inch	Apparent Limit of Elasticity	Contracted Breadth	Thickness	Area	Contraction of Area per cent.	On 8in.	On 4in.	Local Elongation Ins	General Elongation per cent.	Total Elongation per cent. on 8in
2	1.75	0.39	0.6825	42250	61905	27.64	12 2	1.35	0.28	0.3780	44.62	1.91	1.35	0.79	14.00	23.875
3	1.71	0.36	0.6156	38750	62947	28.10	11 6	1.28	0.232	0.2969	51.76	1.96	1.25	0.54	17.75	24.50
NOTE.—	No. 2 (Burwood) was a flat bar as taken from boiler. No 3 (Burwood) was planed to uniform thickness before testing.															

APPENDIX II.

EXTRACT FROM AMENDED REGULATIONS FOR TESTING AND EXAMINING BOILERS IN THE NEW SOUTH WALES GOVERNMENT RAILWAYS.

LOCOMOTIVE.

1. Each Locomotive Boiler must be tested, when new, to the following pressures per square inch, with hydraulic pressure. This test to be considered sufficient for the first set of tubes, provided they do not last longer than five years.

Hydraulic Test Pressure.		Working Pressure.
180 lb.	for	120 lb.
190 ,,	,,	130 ,,
200 ,,	,,	140 ,,
210 ,,	,,	150 ,,
220 ,,	,,	160 ,,
235 ,,	,,	180 ,,

2. At or before the end of the first five years of service, if the mileage executed by a passenger boiler reaches 155,000 miles or 105,000 by a goods boiler, all tubes must be removed, the boiler scaled, and thoroughly examined both internally and externally; and in three and a half years thereafter a second similar examination must be made if the additional mileage executed during that period has reached 90,000 miles by a passenger boiler, and 70,000 by a goods boiler; and for the remainder of its life it must be internally examined every three years, provided the mileage executed during such interval has not been less than 70,000 for a passenger and 56,000 for a goods boiler.

When any boiler approximates 15 years of age, or when the total mileage executed by a passenger boiler approximates 375,000, and that of a goods boiler 300,000 miles, its original working pressure must be reduced if it is continued in service. Every case to be submitted for the Chief Mechanical Engineer's decision as to the future pressure at which it may work.

3. Personal examination must be made, by the Works Manager and Foreman Boilermaker at Eveleigh, or by the Foreman in Charge of Districts, and the Boiler Inspector sent from Sydney, of the internal condition of the boiler whenever the tubes are taken out; and both internal and external examination is to be made when necessary.

4. In each instance after heavy repairs to a firebox, firebox shell, or boiler barrel, the boiler must be tested with hydraulic pressure to—

200 lb.	per square inch	for	working	pressures of	180 lb.
180 lb.	do.		do.	do.	160 lb.
175 lb.	do.		do.	do.	140 lb.

150 lb. per square inch for any working pressure under 140 lb.

5. A register of testings and examinations must be kept by the foreman Boilermaker or Locomotive Foreman of the boilers under his charge.

6. In no case is any boiler to be worked at a higher pressure than that adjusted and registered at Eveleigh.

7. Boilers that are in regular traffic must be thoroughly washed out at least once every week, and the water changed in the boiler oftener if possible.