

Discussion.

Mr. Wolfe
Barry.

Mr. J. WOLFE BARRY, C.B., Vice-President, in moving a vote of thanks to the Author, said the subject treated was of such importance as to warrant a careful and painstaking discussion, concerning as it did the welfare and safety of so many persons.

Mr. Longridge.

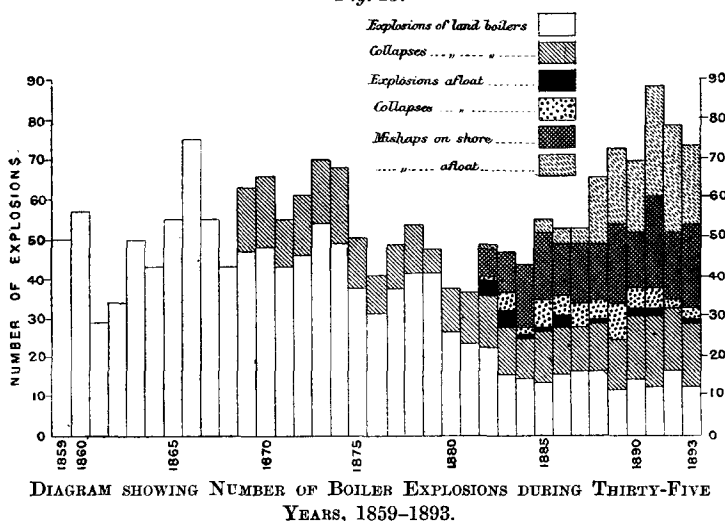
Mr. MICHAEL LONGRIDGE remarked that the subject of boiler explosions had occupied the attention of the Institution on previous occasions. He believed that two Papers on the subject had been read, both of them some time ago, and both by foreigners. In the first¹ the theory advanced was that boiler explosions were due in almost every case to the sudden development of a highly explosive force in the lower part of the body of water in the boiler. This force acted with such suddenness as to tear the bottom out of the boiler before it had time to propagate itself as far as the safety-valve and be relieved thereby. The remedy proposed was a pipe from the bottom of the boiler, with a safety-valve which should receive the impact of the explosion and so save the boiler from destruction. The discussion on that Paper was of a highly imaginative character. The second² Paper was by Mr. W. K. Hall, and in it boiler explosions were attributed to the plates becoming over-heated, and to the heat being communicated from them to the steam, which thereby became highly surcharged with caloric. In this dangerous state Mr. Hall conceived that the small quantity of water injected into that highly surcharged steam would produce an explosion which he compared to the momentum of a blow. It was asserted that in many cases the water was supplied from the body of the water in the boiler itself by the agitation incident to the opening of the safety-valve, and thus it was considered that the very appliance which was fitted to the boiler in order to save it was really the cause of its destruction. The remedy suggested was a blow-off valve actuated by a float, which, whenever the water in the boiler fell below normal level, should open and allow the whole of the water to run out of the boiler, thereby allowing it to be over-heated at leisure without doing any harm. At the conclusion of the discussion the President informed the members that it was unnecessary to invent far-fetched theories to account for

¹ Minutes of Proceedings Inst. C.E., vol. i. p. 103.

² *Ibid.* vol. xv. p. 281.

boiler explosions, since they resulted from simple causes which Mr. Longridge. could nearly always be ascertained by making a post-mortem examination of the boiler. The present Paper gave an account of these causes; but he desired to mention one, viz., the hydraulic test, which the Author had omitted, but which he knew had been fruitful of more than one explosion. He earnestly cautioned the members, who he believed were somewhat apt to prescribe that test, to consider well before doing so. A hydraulic test was a test of workmanship and of the strength of parts which could not be submitted to calculation, such as flat surfaces or oval flues; but

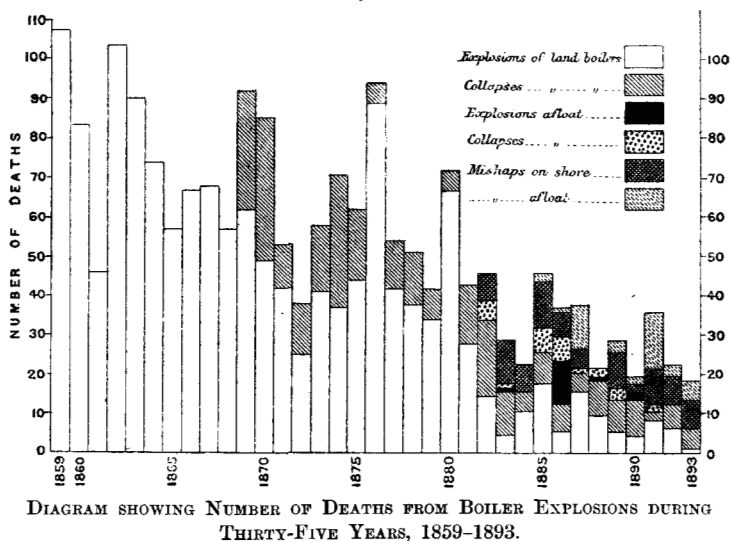
Fig. 15.



as a test of the strength of boiler-shells or of other structures which could be submitted to calculation it was very dangerous.

He desired rather than to further criticise the Paper, to supplement it by a brief statement of the extent of the evil under discussion, and the means whereby it might be abated. With regard to its magnitude, *Fig. 15* showed the number of explosions for each year from 1859 to 1893; and *Fig. 16* the number of deaths resulting from those explosions. It would at first sight appear from the *Figs.* that if less fatal boiler explosions were now more frequent than in former years. This was not the case. The apparent increase was due to several causes, but the following were the most important:— 1st. In the earlier years the records only included explosions of land boilers, and were far from being complete; 2nd. Since the

Mr. Longridge. passing of the Boiler Explosions Act in 1882, in addition to explosions and collapses of flues both on land and afloat, a number of mishaps of various kinds had been included in the returns, for under that Act "any closed vessel used for generating steam, or for heating water, or for heating other liquids, or into which steam is admitted for heating, steaming, boiling, or any other similar purpose" was held to be a "boiler." The effect of this was apparent from *Fig. 15*, which showed that if the areas representing the explosions and collapses afloat, and the numerous mishaps both on shore and on board ship were excluded, the

Fig. 16.

remaining areas, representing the explosions and collapses of flues of land boilers, instead of being greater were now less than in former years. *Fig. 16* also, representing the deaths resulting from these explosions, collapses, and mishaps, showed the very marked improvement. Indeed, this diagram proved that whatever the state of affairs had been twenty years ago, it was now fairly satisfactory. In 1893, for example, one death only had resulted from explosions of land boilers. Five deaths had, however, resulted from collapses of furnaces or flues of land boilers, and in this respect, no doubt, there was room for improvement, though so long as men were careless and intemperate, he feared collapses would occur. In addition to these there had been seven deaths from

miscellaneous mishaps on shore and five from those at sea. These Mr. Longridge, mishaps were almost as disastrous as boiler explosions themselves, and it was difficult to ensure their prevention. They included all kinds of accidents, such as the melting of fusible plugs, the blowing out of joints, fractures of tubes, steam-pipes or stop-valves, explosions of drying-cylinder ovens, tar-stills, and many other casualties. Among the most fatal of these had been the fractures of copper steam-pipes, that on board the "Elbe" in 1887 having resulted in ten, and that on board the "Jumna" in 1891, in seven deaths. As to the question of reducing the number of explosions, he believed, of the different systems of inspection, that by private associations and insurance companies, as now in operation in England, was by far the best. It was, as was proved by the figures in Table III, efficient and elastic. Tables III and IV gave the numbers and causes of explosions, collapses, mishaps and deaths which had occurred since the passing of the Boiler Explosions Act in 1882, a period of eleven and a half years. The total number of boilers in use during that period had been estimated at 140,000. Table III also showed the numbers

TABLE III.—BOILER EXPLOSIONS DURING ELEVEN AND A HALF YEARS
FROM JUNE, 1882, TO DECEMBER, 1893.

—	Numbers.	Deaths.
Explosions of land boilers	152	86
Collapses „ „	151	73
Explosions afloat	14	16
Collapses „	55	21
Mishaps on land	184	78
„ afloat	140	40
	696	314
Yearly average	60·5	27·3
Of these the following occurred to insured boilers:—		
Explosions	23	27
Collapses	50	28
Mishaps	31	10
	104	65
Yearly average	9·0	5·7

Mr. Longridge. TABLE IV.—PARTICULARS OF BOILER EXPLOSIONS DURING ELEVEN AND A HALF YEARS FROM JUNE, 1882, TO DECEMBER, 1893.

Type of Boiler.	Land Boilers.		Marine Boilers.		Cause.	Land Boilers.		Marine Boilers.	
	Number of Explosions.	Number of Collapses.	Number of Explosions.	Number of Collapses.		Number of Explosions.	Number of Collapses.	Number of Explosions.	Number of Collapses.
Plain cylindrical	42				Corrosion, external	43	17	2	1
Locomotive and portable . . . }	31	13			" internal	11	21	..	3
					" on both sides }	..	..	6	..
Cornish . . .	24	39			Corrosion, side not stated }	8	24	..	4
Vertical with internal fire-box . }	17	67	6	21	Grooving	23	2	..	..
Hot water . .	16	2	..	..	Excessive pressure	14	16	..	9
Lancashire . .	11	17	..	..	Outlets frozen or blocked . . .	12	2	..	..
Rastrick . . .	2	..	..	..	Failure of stays .	9	3	..	2
Wagon . . .	2	..	..	..	Deficiency of water . . . }	9	37	..	13
Fuel economiser .	2	..	..	..	Structural weakness . . . }	9	17	..	3
Galloway . . .	..	6	..	..	Fractures . . .	5	..	..	..
Chimney . . .	..	3	..	..	General deterioration . . . }	5	..	4	..
Miscellaneous .	5	4	..	..	Seam-rips . . .	2	..	..	..
Marine . . .	..	..	3	26	Deposit . . .	1	8	..	17
Return-flue . .	..	..	5	8	Not ascertained .	1	4	2	3
	152	151	14	55		152	151	14	55

relating to the 70,000 boilers which had been inspected during this period by the Boiler Insurance Companies. It would be seen that there had been twenty-three explosions and fifty collapses, giving an annual explosion rate of 1 in 11,000 boilers insured. The explosions had caused twenty-seven deaths and the collapses twenty-eight deaths, so that the annual death-rate had been but 1 in 14,600 boilers. These were results which, so far as he knew, had not been attained under government or compulsory inspection in any country except Holland. With regard to the 140,000 boilers, whether inspected or not, 196 deaths had resulted from

explosions and collapses in eleven and a half years, or one death per annum for every 7,100 boilers. Deducting from these totals the number of insured boilers, and of the deaths resulting from explosions of them, there appeared to be one death per annum for every 5,000 boilers not under inspection, a death-rate nearly three times as high as among inspected boilers. It was necessary, therefore, to have these boilers brought under the inspection of existing companies or of other companies working on the same system, and this he thought would be gradually brought about with the assistance of the Board of Trade without resorting to Government inspection.

Sir FREDERICK BRAMWELL, Bart., Past-President, asked whether Mr. Longridge had included explosions of domestic boilers in *Figs. 15 and 16* and Tables III and IV.

Mr. LONGRIDGE replied that they were included in the "mishaps."

Mr. H. H. WEST was much impressed with Mr. Longridge's remarks with regard to the inclusion in the returns of mishaps of all kinds, whether they were really boiler explosions or not. A case in point had been afforded by a vessel that he was concerned with which went into a harbour for shelter on account of bad weather. It became known that the joint of the feed-chest cover had blown out, and having but one boiler, the engineers had availed themselves of the shelter to remake the joint. He believed that would be recorded as an explosion. One of the causes of explosion referred to in the Paper did not occur so often in marine boilers as in land boilers, for the reason that the former were in almost all cases free from brickwork, which was a great source of corrosive influence on the outsides of the plates. There was much importance in another point which Mr. Longridge had referred to—skilled supervision. Nearly all marine boilers were under skilled supervision. In every steamer there was a skilled engineer—several in most cases—in charge of the boilers which were surveyed by Lloyd's or by the Board of Trade, and in addition by the company's marine superintendent; so that explosions of marine boilers were comparatively rare. That would be seen very markedly from the diagrams that Mr. Longridge had prepared, *Figs. 15 and 16*. He was indeed somewhat surprised to see them so considerable as they there appeared. He would like to know what had been the circumstances which had caused the large number of deaths indi-

¹ Mr. Longridge subsequently stated that his answer had been incorrect. Explosions of kitchen boilers in private houses were not included in the Tables. Hot-water boilers for heating churches, schools, and other buildings had been included among the explosions and collapses.—Sec. Instr. C.E.

Mr. West. cited by the long black mark in the year 1886, *Fig. 16*, and also whether the number of deaths was counted from the bottom of the black mark or from zero.

Mr. Longridge. Mr. LONGRIDGE said that the length of the black mark itself was proportionate to the number of deaths, which were not counted from zero. He could not remember which explosion it referred to.¹ As regarded steamships inspected by the Board of Trade the explosion rate among those vessels was, he believed, about 1 in 6,770 boilers, which was considerably greater than the rate of explosion among the voluntarily inspected boilers.

Mr. Wingfield. Mr. C. H. WINGFIELD observed that in Table II, showing the amounts of energy pent up in various types of boilers at the instant before an explosion occurred, the Author had made no mention of boilers of the water-tube type. The following Table supplied the omission, and gave the corresponding particulars for a "Thornycroft" boiler.

Type of Boiler.	Dimensions of Boiler.		Working Pressure by Gauge.	Approximate Weight.			Available Energy.			Height to which Energy would lift Boiler.	Gunpowder Equivalent to Total Available Energy.
				Boiler.	Water.	Steam.	Water.	Steam.	Total.		
	Length Feet.	Width. Ft.Ins.	Lbs. per Sq. In.	Tons.	Tons.	Lbs.	Foot-tons.	Foot-tons.	Foot-tons.	Feet.	Lbs
"Thornycroft" water-tube.	12½	10 8	205	14·57	1·84	30·5	28,420	2,060	30,480	1,855	253

This boiler, which was of the "Daring" type, had easily generated steam during a three-hours trial for a mean I.H.P. of 1,580. It was therefore of greater power than the marine boiler described in Table II,² and the pent up energy in the boilers of the two

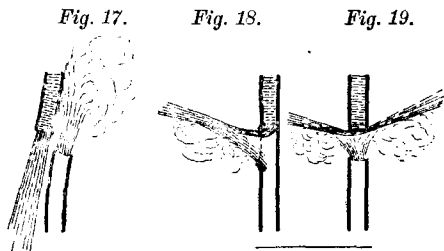
¹ Mr. Longridge afterwards stated that of the eleven deaths represented by the black area in 1886 three had resulted from the explosion of the main boiler on board a tug, and eight from the explosion of a donkey-boiler on board a steamship.—Sec. Insr. C.E.

² The heating-surface of a boiler 15 feet long and 13 feet in diameter would be between 1,940 square feet and 2,630 square feet. The surface per I.H.P. in a marine boiler was usually between 2 square feet and 2½ square feet. In naval boilers, working with 2 inches of air-pressure, 1·67 square foot was given by Seaton ("Manual of Marine Engineering") as a usual allowance per I.H.P.; hence the boiler in Table II would be at most equivalent to between $\frac{2,630}{2·5}$ and $\frac{2,630}{1·67}$, or, say, between 1,050 and 1,575 I.H.P.

types if of equal power might be taken as in the ratio of 10 to 1 at least. This would be a measure of the destructive effect if each type of boiler discharged its contents in the same time—say two seconds, which would probably be sufficient for the completion of an explosion of boilers of any of the types considered by the Author. The case of a water-tube boiler was different. If every part had originally the same factor of safety, and the whole surface corroded at a uniform rate, it was obvious that if a tube $\frac{1}{8}$ inch thick had its factor of safety reduced from, say 6 to 3, the corresponding factor for the large barrels, of, say, $\frac{3}{4}$ inch thickness, would be reduced only from 6 to $5\frac{1}{2}$, and when the former were corroded quite through, the barrels would still have a factor of safety of 5. To compensate for this a larger factor of safety was provided for the thinner portion, but in any case it was most probable that when worn out a fracture would occur in a water-tube before any other part gave way. Therefore, what with older

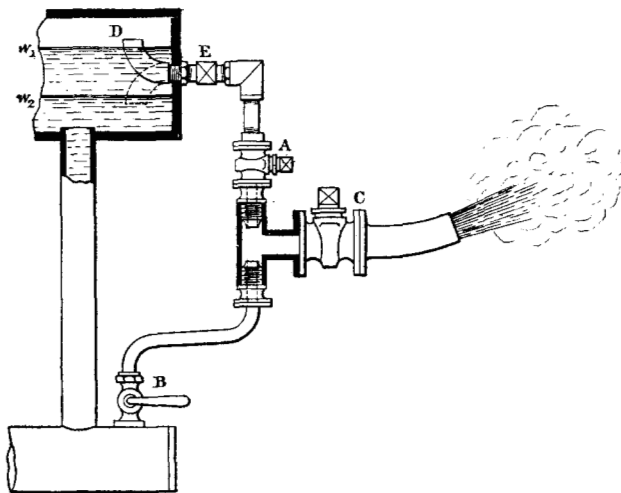
forms of boilers would have constituted an explosion had more the character of the discharge from a blow-off pipe in the case of a water-tube boiler, and the pent up energy would require minutes instead of seconds to escape; and instead of the danger to be apprehended from a marine boiler explosion being ten times as great as in the case of a Thornycroft boiler it was more probably 400 or 500 times as great. There had been no instance of a Thornycroft water-tube boiler with steel tubes having burst. There had been, however, an instance of a brass tube which had failed when plugged with wood.

He had devised an experiment in order to imitate the results of an actual explosion as closely as possible with a view to determining the relative effects of different forms of fracture. *Figs. 17, 18, and 19*, illustrated three ways in which a tube might burst. With a tough material like steel the fracture would always, or nearly always, be like that shown in *Fig. 18*, a hole opening on one side. Brass tubes might break in any of the three ways shown, but if over-heated the fractures would probably be represented by *Figs. 17 and 19*. If the boiler was of the undrowned type introduced by Mr. Thornycroft, the upper tube would be filled with steam, and it was obvious that in *Figs. 17 and 18* the



Mr. Wingfield outflow of water would be impeded by the impact of the steam. Even with a drowned tube the two streams impeded one another, but to such a slight extent that the discharge in *Figs. 17* or *18* was but little less with this type of boiler than from that indicated in *Fig. 19*. The apparatus employed for the experiment was shown in *Fig. 20*, which represented the ends of the upper and lower barrels of a water-tube boiler. Two nozzles were opposed to each other in a T-piece of much larger section, the other branch of which represented the break. If the cocks A and C only were open the discharge from the upper tube could be measured. If

Fig. 20.



B and C only were open the discharge from the lower nozzle could be ascertained. The sum of these gave the discharge from a break such as shown in *Fig. 19*. If the three cocks were opened the jets opposed each other and the discharge under the conditions of *Figs. 17* or *18*, which were assumed to be identical in effect, could be determined. As it was of interest to compare the effects of similar accidents with drowned and undrowned tubes, the pipe D was arranged so that it could be turned to the dotted position by a spanner applied at E so that its end dipped below the water. The method of experimenting was to note the time taken to blow off sufficient steam or water to reduce the water-level from W_1 to W_2 , *Fig. 20*. The reciprocal of the time so occupied was a measure (in arbitrary units) of the weight dis-

charged per second. In each case the steam-pressure was 50 lbs. Mr. Wingfield. per square inch. The results were as follows:—

Conditions of Experiment.	Time of Discharge.	Weight Discharged per Second.
	Seconds.	
<i>Drowned Type.</i>		
Top tube alone	23½	$\frac{1}{23 \cdot 5}$
Bottom tube alone	30½	$\frac{1}{30 \cdot 25}$
Both tubes separately (<i>Fig. 19</i>)	..	$\frac{1}{13 \cdot 2}^1$
„ „ simultaneously (<i>Figs. 17 and 18</i>)	14	$\frac{1}{14}$
<i>Undrowned Type.</i>		
Top tube alone	200	$\frac{1}{200}$
Bottom tube alone	30½	$\frac{1}{30 \cdot 25}$
Both tubes separately (<i>Fig. 19</i>)	..	$\frac{1}{26 \cdot 26}^1$
„ „ simultaneously (<i>Figs. 17 and 18</i>)	35	$\frac{1}{35}$

From these figures, which were carefully checked by independent observers, it appeared that—

- Ratio of discharges from tube broken as *Fig. 19* to discharge from tube broken as *Figs. 17 or 18* was

Drowned ..	$\frac{14}{13 \cdot 2} = 1 \cdot 06$ to 1.
Undrowned, ..	$\frac{35}{26 \cdot 26} = 1 \cdot 33$ to 1.
- Ratio of discharges from drowned and undrowned tubes, when broken as in *Fig. 19*

..	$\frac{26 \cdot 26}{13 \cdot 2} = 1 \cdot 985$ to 1.
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- Ratio of discharges from drowned and undrowned tubes, when broken as per *Figs. 17 or 18*

..	$\frac{35}{14} = 2 \cdot 5$ to 1.
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Hence an accident to a boiler with drowned water-tubes is at least between two and two and a half times as dangerous as a similar accident to a Thornycroft boiler. Previous experiments with the same apparatus, and with 25 lbs. pressure per square inch, gave practically identical results. He had referred to a case in

¹ These quantities were obtained by addition of the amounts discharged by the top and bottom tubes alone.

Mr. Wingfield. which a tube gave way. Some thin planks had been left by a careless workman in one of the wing-barrels, and floated up, closing the lower ends of several generating tubes. The circulation having been stopped, the tubes became overheated and, being of brass, one of them gave way near the bottom, relieving the pressure on the upper side of the plank, so that the water below it punched a hole of the diameter of the tube through the wood, and a mixture of steam and water at 200 lbs. per square inch pressure rushed into the fire-box. There had been, however, no disastrous results, and the first intimation which the stokers had received that their boiler had "exploded" was by a message from those on deck. The noise of the fan-blast prevented their hearing that due to the steam. This accident had occurred in the middle of a full-speed run when the fires were being urged to their utmost.

It had been mentioned by the Author on page 156 that the secondary rents do not always follow the seams of rivets or lines of natural weakness. Before rupture the greatest stress would probably be in the line of least section. After rupture commenced, however, the rush of water and steam forced back such a flap as

that shown in *Fig. 1* in a direction more or less normal to the plate. Under these conditions the greatest stress was no longer necessarily along the line of least section, and this he proceeded to illustrate by tearing a strip from a perforated sheet of paper, where the line of rupture proved to be in the direction shown by dotted lines in *Fig. 22*.¹ He did not suggest that, in a boiler explosion, the secondary fractures always converged, but he merely wished

Fig. 21.

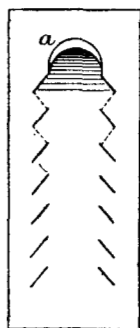
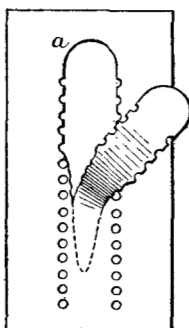


Fig. 22.



to point out that when the tearing force acted normally to the plate the line of greatest stress was not likely to be in the line of what the Author had called "natural weakness."

¹ It was a matter of common observation that when it was attempted to remove a newspaper wrapper by tearing off a narrow strip of paper the lines of rupture converged, and the strip often came off before the wrapper was torn quite across. A method had been devised of perforating the wrapper as shown in *Fig. 21*, so that when the top was pulled the lines of fracture shown in dotted lines began to converge, but were immediately widened by the next pair of slits, and so on until the entire strip was torn cleanly out of the wrapper.

The opinion had been expressed by the Author that, since a Mr Wingfield. good deal of the grooving to which boilers were sometimes subject took place in the steam-space, it could not be so much due to chemical as to mechanical action, and local strains due to sudden changes of section. He agreed with the Author's conclusion, but he considered the implied assumption that chemical action could occur but slightly in steam-space was erroneous. There were many instances in which the plates had been considerably corroded in the steam-space of boilers, and Professor Lewes had investigated the kindred case of the excessive corrosion of those plates of a hull which happened to be near the boilers¹ and had proved experimentally that, of two steel wires dipping in sea-water, the chemical action on one, which was kept in a current of hot moist air, rendered it strongly electropositive to the other. There could be little doubt that a similar chemical action would sometimes take place in hot moist steam.

The grooving from mechanical action, on which the Author rightly laid great stress, was also met with in propeller shafts.² In boilers the sudden change of stiffness near a joint enabled the metal at that point to become sufficiently "fatigued" to give way and form a crack under repeated stress. In propeller shafts the section was nearly uniform, and as these sudden changes of stress did not occur, the groove had to be started in some other way. The necessary cause was found in galvanic action between the steel shaft and the brass sleeves which formed the shaft journals in the stern-tube. A shallow groove was first formed by corrosion; the stress at the bottom being greater than at the sides of the groove, the latter quickly deepened from giving way under "fatigue." Cracks often attained a depth of several inches before showing more than a scratch at the bottom of the original groove. That this was a correct explanation appeared from the fact that if local galvanic action was prevented by covering the shaft with india-rubber, or by serving it near the brass sleeves with a few turns of marline, the cracks were prevented.

Proper arrangements of internal feed-pipes deserved more attention than they had received. It did not appear to be generally known that feed-water (containing air as it generally did) had a rapid corrosive effect if it impinged on hot boiler-plates. Discharging feed-water into the steam-space, as was sometimes done, was of more than doubtful benefit. He had known cases of priming

¹ *Engineering*, vol. lii. p. 575, and lviii. p. 399.

² *Ibid.*, vol. lvii., 1894, p. 464.

Mr. Wingfield. produced by such an arrangement, owing to sudden condensation of steam, and consequently increased ebullition. This condensation appeared to have occurred in the case described on page 167, where the pressure was reduced by turning on the feed.

Mr. Head Mr. JEREMIAH HEAD remarked, with regard to external corrosion, that where there were no leakages there was usually no corrosion. But if a boiler were out of use and exposed to the weather, external corrosion made steady and rapid progress. In a boiler in regular use, external corrosion was always due to leakage, or to the dripping of water upon some portion of it from a roof or steam-pipe, or to some damp material, such as lime or brickwork, being in contact with it and acting like a sponge. Alternate wetness and dryness was the worst enemy to boiler-plates, as it was to timber. The internal shells of boilers seemed also impervious to corrosion under ordinary circumstances. He had measured the thickness of a boiler shell which had been in use for fifteen years without detecting any diminution. Corrosion must therefore be regarded as an evil due to local circumstances. A very unfavourable condition was presented by steam and water alternately playing on one side of a plate, whilst the products of combustion were in contact with the other. This occurred to uptakes passing through steam-spaces. Boilers such as that shown in *Fig. 5* soon failed in the uptake, the portion of which between the high- and low-water level, being exposed to continuous splashing, wasted very rapidly by pitting. The uptake had usually to be renewed long before the boiler was worn out. Probably this was due to the action of the highly heated iron upon the steam, whereby some of it was decomposed, forming oxide of iron and setting free hydrogen. For the avoidance of internal corrosion it was of advantage to feed the boiler with water containing a small quantity of calcium carbonate which was deposited on the internal surfaces and formed a protective coating. He believed that it was customary to coat the internal surfaces of marine boilers with a wash of cement and water, and that this was found very efficacious in preventing corrosion. He considered that the most mysterious cases of internal corrosion were those due to scoring or grooving. No doubt, the breathing action of circular end-plates, and the tendency of the longitudinal lap-joints of cylindrical boilers to pull into a true circle were the primary causes. In the latter case he thought the remedy was to avoid lap-joints under such circumstances, and to use butt-joints and cover-plates. With the very high pressures now in use, all vessels made to withstand them should be of such form that no smaller pressure than the bursting-pressure could alter their form.

With regard to strengthening flues by tee-bar rings in the water- Mr. Head.
space, which had been suggested, he disapproved of such expedients. The rings remained steadily at the temperature of the water, whereas the flue itself varied between that and the temperature of the products of combustion. On that account it required more space for expansion and contraction than the rings would allow of, so that it became compressed or "jumped up," and in contracting was held back by the ring, and was sure eventually to relieve itself by developing longitudinal cracks. He had seen boilers attached to blast-furnaces in Lincolnshire supported in the manner shown in *Fig. 3*. The feet, however, were generally higher up, and set on the top of and not inside the brickwork. Boilers fired with gas under those circumstances could not be very dangerous, as they lasted for long periods. He knew of one case where the boilers were thirty years old, and where, after having served about twenty years, the feet had been reversed, the mounting taken from the top and put on the bottom, and the boiler turned round to start anew. This had been done four or five years ago, and so far as he knew the boilers were still working. Some thirty years ago it was the custom in the Cleveland district to use in connection with the blast furnaces plain cylindrical boilers 80 feet long by about 4 feet in diameter. They were continually failing, owing to seam-rips, which invariably started on the under side. After a certain explosion he had made a careful examination of some of these boilers which were still working. They were suspended from four cross girders. He had found that when the boilers were at work, the nuts of the suspension bolts at the two ends were slack, and when not at work those at the two middle girders were slack. The slackness amounted in some cases to a gap of as much as $\frac{1}{2}$ inch. This proved that there were alternately compression and extension stresses at the bottom of the boiler of a very severe character, and these, no doubt, led to the seam-rips. Similar boilers over which he had had control were afterwards suspended upon volute springs, which enabled them to expand and contract without setting up any destructive stresses, and no seam-rips had occurred in them. He did not think *Figs. 8* gave a good representation of the Rastrick boiler, but he agreed with the Author that the Rastrick, although of a type common in Staffordshire and in the north of England, was a very bad boiler. By the gradual supersession of wrought-iron by steel it was becoming obsolete, because, in steel-works steam was in almost all cases raised in Lancashire boilers, working at a very much higher pressure than the old ones. The Rastrick boilers generally worked at a pressure

Mr. Head. of between 30 and 40 lbs. per square inch. They were usually defended at the bottom, where they were struck by the flame, with a little brickwork, because it was at this place that the boiler was most apt to deteriorate and become thinner. One great disadvantage of such boilers was that they were surrounded with brickwork, and were placed where the men were working, so that if they did explode every brick became a bullet, and this was the reason why the consequences were often so disastrous. They were also of large diameter, and the flame being external as well as internal, and hidden from view by the brickwork, deterioration could proceed on the outside to a very great extent without being easily discerned. They had some advantages, one being that they held a considerable quantity of water, and so kept the steam-supply very equable. Where there were a number of boilers and a large range of steam-pipes, steam being drawn off from a great number of engines, it was important that there should be a number of bodies of water like that which kept the steam constant, and acted, in fact, like a fly-wheel. He thought the man who riveted the holes in *Fig 14* deserved the very worst penalty that the law could enforce.

Mr. Beaumont. Mr. W. WORBY BEAUMONT observed that the Author had assumed that a great deal resulted from variations in steam-pressure, but he had not defined the causes to which the actual stresses were due. The variations in pressure in locomotive boilers had been particularly mentioned by the Author, but he desired to know under what circumstances those great and sudden variations occurred to such an extent as to cause those stresses in the boiler to which he appealed as the causes of grooving. The breathing of boilers and its effect on certain parts had also been referred to by the Author, who had mentioned it in one place as one of the causes, at all events, of the aggravation of the grooving, while in another place he rightly showed that it was necessary, in certain of the boilers described, that the breathing action should be carefully allowed for. He referred to the occurrence of grooving where bending had caused the material to be under tensile stress, and also to the fact that these tensile stresses occurred in several places not mentioned in the Paper, but in which it was evident they might occur, owing to unbalanced areas. In *Figs. 8*, it would be seen that in consequence of the unbalanced area in the vertical internal tube, there was an unbalanced pressure of about 20 tons upon the central piece. It was impossible that that could be existing, and from time to time diminishing to nearly nothing, as from day

pressure to no pressure at night, without having considerable Mr. Beaumont. effect in varying the mechanical stresses, not only on the part of the boiler carrying that flue at the bottom but on the horizontal flue also. Again it would be seen with regard to *Figs. 5* that there was a great difference in the areas upon which the pressure was being exerted. The uptake had not given way in the example, as the Author had said, but the angle-ring connecting it to the fire-box had given way. Again, the stresses in the part in which the groove occurred were of a tensile character. Some time ago he had suggested to Mr. Thomas Andrews, who was proposing to make experiments on the relative corrosion of materials which had and had not been under stress, that it would be interesting to ascertain what would be the difference in the rate of the corrosion on specimens under and not under stress during experiment. Experiments had been made by Mr. Andrews,¹ although not in the manner suggested, and he had found that the difference was either nearly if not quite inappreciable. He had simply bent the specimens, immersed them in a saline electrolyte and passed a small current through them so as to encourage the corrosion. By simply bending a piece in that way and allowing it to return as far as the unsatisfied stresses would take it, the greater part of the stress would be eliminated and the conditions would be very different from those which would obtain in a boiler as in either of the cases referred to. In the case, for example, of the bottom of the uptake in the vertical boiler, while on the one hand there was the pressure on all but a small area in the upper part of the boiler tending to force the whole upwards, only part of that pressure was balanced by that on the top of the fire-box. There was also the change in the length of the fire-box due to the increase in temperature of the sides, and an almost equal increase in the uptake-pipe, so that there were two different stresses both tending to bend the angle-bar and to open it in the re-entrant angle, producing a tensile stress. The same thing occurred in many cases, and it would appear that corrosion did take place more rapidly, whether in steam or water, in those parts of a piece of iron under stress where the stress was great and where it was local, and of a tensile character, as in that angle-bar. Almost all the grooving, whether in the locomotive furnace boiler or in any other, took place in this way, and in places where the local stress was of that particular kind. In his reply, those points would probably be referred to by the Author, as well as the way

¹ Minutes of Proceedings, vol. cxviii. p. 356.

Mr. Beaumont. in which stresses were supposed to occur, not simply by changes of the pressure of steam, but the changes of temperature, producing the "curling up" at the ends of the boiler, which of course meant that the whole boiler was changed in form to a certain extent. In a great many cases it would no doubt be difficult to show that stresses of a measurable kind occurred in consequence of the change of form, because the change in temperature was such that the change in form might occur without bringing about any very great stress on the material.

Mr. Moberly. Mr. C. H. MOBERLY said that the Author appeared to ascribe the grooving in the ends of boilers to the change of steam-pressure and consequent temperature. He thought that the steam-pressure affected it much less than the changes of temperature in the furnace, and the varying expansion of different parts of the boiler in consequence of different temperatures to which it was exposed. That appeared to be the real difficulty in dealing with the flat ends of boilers. The grooving referred to might be partly due to pressure, but he considered it was also due to changes of temperature. Certainly in Cornish and Lancashire boilers the effect of changes of temperature in the flue was extremely important, so much so that pressure might be almost disregarded. It was prevented by providing sufficient movement in the ends of the boilers, to allow changes of form to take place without doing any harm. The top of the boiler was almost always hotter than the bottom, whilst the top of the flue was at the highest temperature of all. There was always hogging of the flue, which was measurable and must produce serious effects on the ends of the boiler, and if these were too rigidly stayed or were too thick and flat, a great deal of mischief would result. He asked for details of the construction of the boilers referred to in *Figs. 9, 10 and 11*, and he would be glad also to know the proportioning of the rivets. *Fig. 9* illustrated a most extraordinary specimen, and some further information concerning it would be interesting.

Mr. Wolfe Barry. Mr. J. WOLFE BARRY, Vice-President, suggested that the Author should give the ordinary working-pressure in tons to the square inch in the case of boilers that had exploded, and also the estimated pressure per square inch at the moment of explosion. He understood the Author to state that in one case the mean circumferential stress was about 8.6 tons per square inch, whereas the material was capable of withstanding a stress of 20.6 tons. He did not know whether those calculations took into account the abstraction by rivet-holes, and represented the greatest possible stress at any particular place. A working strain of 8.6 tons on

a material capable of bearing 20·6 tons per square inch was a large amount of strain to which such materials should be constantly exposed. It was contrary to experience in bridge-building, and it would be interesting to know what the strains usually were as compared with the ultimate strength of the material in boilers such as had been described.

Mr. Wolfe
Barry.

Mr. W. H. FOWLER said in reply that he quite endorsed Mr. Longridge's opinion with reference to the application of the hydraulic test. There was no doubt that the application of that test without taking suitable gaugings was probably in many cases productive of more harm than good. As to the necessity for compulsory inspection, and further legislation, he thought that the death-rate from boiler explosions had now been happily reduced to such insignificant dimensions in this country that any further steps in that direction were uncalled for. The case had not been overstated by Mr. Longridge as regarded the comparatively insignificant danger that arose to human life in this country on that score. As compared with America, for example, he believed that more persons were killed and injured from explosions in that country in the course of a month than were killed and injured in this country in the course of two or three years. It would be observed from *Fig. 16*, that the death-rate had largely diminished since the introduction of the Boiler Explosions Act. He had no doubt that that reduction was due to the operation of the Act, coupled as it had been with the salutary action of the Board of Trade in holding their enquiries, and occasionally appointing some of a formal character which had brought home the responsibility to boiler-owners more forcibly, and had served to emphasize the recommendations that the various inspecting and insurance companies had made from time to time, but which, prior to the passing of that Act, had had very little chance of being adopted. The owners of boilers had formerly postponed repairs as long as possible, and, in the event of a boiler bursting without causing injury to life, no inquiry followed, whereas, at present, whether there were injuries or not, there was the salutary fear of a public enquiry. In reply to Mr. West, marine-boiler explosions had not been extensively dealt with in the Paper, chiefly because there were few marine-boiler explosions to deal with, which was no doubt due to the better design of such boilers, and to the superior supervision and control which regulated them. The energy of explosions had been referred to by Mr. Wingfield. The destructive character of an explosion did not necessarily depend upon the amount of

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energy contained within the boiler, but upon the manner in which that energy was liberated. If a blow-off tap were opened the energy would be spent in course of time, but in such a case the liberation would not be attended with injury either to persons or property; but, on the other hand, if the same energy were suddenly liberated by ripping a portion of the boiler shell it might be very destructive, and not only lead to the expending of a large amount of energy in consequence of the liberation of the steam and water, but probably to the liberation of a large potential energy in the form of buildings, etc. With reference to the lines of rent to which Mr. Wingfield had referred, these must follow in any case the lines of least resistance. But many complex matters were more or less involved, so that it was impossible to predict how the lines of rent would travel. No doubt the stresses, when a rent was started, imposed on the material at the ends of such rupture were capable in many instances of producing very complicated effects. With regard to corrosion in the steam-space, Mr. Wingfield seemed to think, from his remarks as to the cases of grooving, that he (the Author) did not consider corrosion in the steam-space could take place. That was an opinion which he would not like to endorse. He was about to say that experience showed that corrosion actually occurred in the steam-space; and he did not wish that that impression should be conveyed by his Paper. Of course it was in the water-space principally that corrosion of the most serious amount occurred. With reference to those cases of grooving to which he had alluded, in the majority the sides of the groove formed an angle of about 90° ; it was in reality an open furrow; but in those special cases which had occurred on the North Eastern Railway the grooves were so fine that it would have been impossible to have discovered them by inspection. In fact, he knew of one particular case, in which a locomotive superintendent had been so much impressed by the knife-like character of the groove that he had caused the barrel to be cut open, and the plate bent back, and it was only in that way that the existence of the groove had been discovered. The boiler had been of Low-moor iron, and subsequent tests of the material went to show that the material was of good quality. It might, of course, have been thought that the grooving had been started by a caulking-tool on the inside in the first instance, but there had been absolutely no trace of any such action having been produced; and, moreover, it was not the practice at the boiler-shop to caulk the inside of the longitudinal laps. Egg-ended boilers had been referred to by

Mr. Head, who had said that they were not generally set in the Mr. Fowler manner shown in the Paper. He was happy to say they were not, but that was simply quoted as an illustration of the ignorance occasionally displayed; and he was sorry to say that engineers sometimes resorted to broad seatings, and an amount of brickwork which was absolutely unnecessary; one object he had in calling attention to them was to point out that the bearing-surface of a boiler did not require to be wide—3 or 4 inches was always sufficient to carry the weight, and that at the same time could be so arranged as not to interfere with the inspection, or afford a lodgment for moisture. The distribution of stress in a steam-boiler was a matter which must be largely decided by experience, and could not often be determined by pure mathematics. The plain egg-ended boiler, for instance, was mathematically twice as strong at the circumferential seams as at the longitudinal seams, and yet those boilers, often suddenly ripped in two at the ring-seam of rivets, where they ought to be twice as strong as at the longitudinal seam, and time after time compound explosions had been recorded in which a slight shock arising in one boiler had sufficed to start off the group and cause them to rip in this manner. A striking illustration of that had been afforded by a remarkable compound boiler-explosion that had occurred some little time ago at Shamokin, in America. There had been a group of thirty-six boilers, and the explosion of one boiler in the group appeared to have started off another twenty-six. He had recently received photographs of that explosion, and it was remarkable that in nearly every case the rents had taken place at the ring-seams, where they ought, he supposed, according to mathematics, to have been stronger. It was only another illustration of what every engineer knew—that when mathematics came to be applied to engineering structures it needed to be tempered with a good deal of common sense and actual experience. It had been asked by Mr. Beaumont when the variations in pressure in locomotives occurred which were referred to as one of the causes of the grooving described, and what was the magnitude of the actual stresses thus set up. In reply to the first of these questions, it was only necessary to consider what took place when a heavily laden goods train came to a steep gradient, and afterwards ran down an incline. Large fluctuations in pressure were well known to engine-drivers from that and other causes. These fluctuations in pressure were necessarily followed by variations in the intensity of the bending stress which occurred at the longitudinal joints when they were of overlap form. What was their

Mr. Fowler. precise magnitude it was of course impossible to say; but the grooving itself afforded irrefutable evidence of their existence. Mr. Beaumont had also said that the grooves seemed always to occur when bending had put the material under tensile stress. That, however, was not the case. The stresses which set up the grooving were sometimes alternately compressive and tensile. It was, in fact, the variation in intensity which fretted and deteriorated the material locally. With regard to the stresses to which Mr. Barry had referred, he was discussing the effect of cutting large openings in boiler shells, and he somewhat regretted that that matter had not been dealt with a little more fully. What he meant was, if the calculated stress in a length of the shell equal to the diameter of the manhole, arising from the bursting-pressure were divided over the remainder of the shell in a line passing longitudinally through that diameter, it would only give a stress of 8.6 tons per square inch, whereas, as a matter of fact, the shell had burst, the plates of which that shell was made having been proved subsequently to be capable of bearing a stress of 20.6 tons. His remarks went to show that the distribution of the stress was very irregular, and that close to any large hole there was a very great stress. What the magnitude of that was it was difficult to say, and respecting those manholes he wished to point out that the distribution of the compensating ring was a matter of great importance, as well as the mere quantity of material that was allowed. For instance, had the material in the neck, shown in *Fig. 11*, been crushed down into a flat ring on each side of that opening he had no doubt the shell would not have failed at that particular pressure. The distribution of material was such as really to afford very little help to the part of the boiler-shell immediately surrounding the hole.

Correspondence.

Dr. Emery. Dr. C. E. EMERY considered that the Paper clearly and concisely pointed out the principal causes of boiler explosions, and embodied a number of interesting illustrations based on several types of boilers employed in Great Britain. In the United States there had been explosions from similar causes, but few failures had resulted from distortion of the plates, for the reason that the system of internal bracing was in general more thoroughly carried out in detail. When the country had been undeveloped, and iron more expensive, and there had been limited facilities for dealing with heavy plates, it had been exceptional to find plates thicker