where the strain was greatest, there was the least deflection, and the least yielding to pressure, but this may be accounted for, by the equable support that the caisson acquired along the whole line of the bottom stop, or shelf of masonry, against which it was forcibly pressed. The caisson, along the lines B and C, had no supports of that kind, and hence follows the increased deflection observed in those parts. The ultimate strength of the caisson is, however, as a whole, greatly in excess of the force of the sea, whether arising from a dead pressure, or the concussion produced by the action of the surf which, at times, sets in heavily from the south-west at high-water.

The Paper is illustrated by a series of drawings, from which Plate 4, (Figs. 1 to 4,) is compiled.

Mr. Scamp said, that all deposits of mud and sand in the recess and below the caisson were prevented by the slopes on the floor, and the entrance was kept free, by sluices provided in the caisson and in the side walls. Dredging-vessels also contributed to the same result at a distance from the entrance. The object of the guide-ropes was to keep the caisson steady in stormy weather, and to avoid obstruction when entering the recess. The area of the caisson was about 3,000 feet, of which 150 feet of bearing surface was a perfectly water-tight joint, under a head of 37 feet of water-pressure. The displacement of the materials of which the caisson was constructed was equal to about 8 tons, (the water being admitted within,) when it was being ballasted for the low-water line. Additional ballast was required for any other state of the tide, in proportion to its height, the means of adjustment being provided, by water supplied from the fire-mains, to tanks in the upper part of the caisson.

It was at first a question, whether the caisson should be removed on wheels; but, on consideration, he thought that the system of floating was simpler, and more in accordance with one of the objects he had in view,—to dispense with everything liable to derangement, at the great depth of 18 feet below low-water line. The caisson required to be moved with ease and rapidity. This was accomplished, as the opening of the passage could be effected in ten minutes; and, during the operation, it was capable of resisting the force of any wind in which it would be safe to pass a ship into the lock. The cost had been about £12,000, exclusive of masonry. It would have been much more expensive to have erected gates, as two pairs would have been necessary, and a much greater extent of masonry would have been required for the entrance. The ordinary rise of spring-tides was 18 feet, but it occasionally reached 20 feet.

His attention had been directed to the improvement of caissons, from the trouble, delay, and expense he had observed in the working of those of ordinary construction. Great difficulty had been experienced at Woolwich, Malta, and at other establishments, in making a perfectly water-tight joint for caissons of the ordinary kind. In order to insure the effectual exclusion of water, it was absolutely necessary, that the corresponding faces of the timber and stone should be perfectly plane; for the sliding caisson, the surfaces were correctly prepared, and the water was perfectly excluded.

Mr. Fairbairn described the working of the sliding caisson, of which the great peculiarity was the introduction, at the lower part, of an air-chamber, which enabled it to float, and consequently, to admit vessels at all times, independently of the state of the tide: to effect this, it was only necessary to reduce the quantity of water contained in the upper part of the caisson, to which it was supplied by the water-works. It might be urged, as an objection, that the caisson was liable to tilt up on end, and such, undoubtedly, would be the case, if the water should accumulate in one corner: this, however, was rendered impossible by the guide-ropes and rollers. In judging of the expediency of adopting this plan, it was important to recollect, that the lock was to be capable of being transformed, when required, into a dry-dock; if the system of gates, therefore, had been employed, it would have been necessary to have had two pairs at each end, and the cost would have amounted to £14,000, exclusive of the masonry, of which a greater quantity would have been required. The shape which had been adopted, he believed to be the most advantageous, for making the caisson water-tight, and for fitting together its different parts: and if care was taken to bring the two surfaces of timber and masonry to a perfect plane, they would come together with the greatest accuracy. Experiment had shown, that the deflection at the lower part of the caisson, did not exceed $\frac{7}{8}$ths of an inch, under a pressure on the entire area, of 2,000 tons; nor had any difficulty been experienced in sustaining the pressure, when the opening was only partially closed, although, in that position, the caisson was often exposed to a heavy swell of the tide sweeping across the Hamoaze, at a velocity of 4 miles, or 5 miles per hour.

The introduction of the sliding caisson was an effort of engineering skill well deserving of notice, on account of the superior facilities it afforded, for passing vessels from a river, into docks with wide entrances, and the rapidity with which the operation was effected.

Mr. W. G. ARMSTRONG doubted, whether there would not be a certain amount of friction between the timber and stone, by which the former would be, eventually, abraded: the action, in this case, was not the same as that to which lock-gates were subject.

LORD RADSTOCK said, that in working the 'Jason,' which was 300 feet in length, and another vessel not so large, through the entrance into the basin at Woolwich, great apprehensions were entertained lest they should be nipped by the caisson, which was very much in the way, and caused the loss of half an hour. The form given to the new caisson seemed likely to obviate the inconvenience arising from that cause.

Mr. WALKER thought the apparatus simple and ingenious, and that it reflected great credit upon Mr. Scamp by whom it was designed.

Mr. RANKINE suggested, that divisions should be made in the upper water-tank, by which the general stability of the caisson would be increased.

Mr. J. MURRAY referred to the plan of a sliding gate, which had been proposed by a Dutch engineer, M. Singels, in 1839.[1] It was furnished with wheels, upon which it was drawn, when required, into the recess: and in order to diminish its specific gravity, a number of empty barrels were placed in the interior. There were no openings in the gate, all communication between the water outside and inside taking place through small lateral channels provided with sluice-gates. He thought there were

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[1] *Vide* "Projet d'une nouvelle construction de portes d'écluse, appelées portes-à-ornières.' Par J. C. Singels. Gorinchem, 1839.

great advantages in the employment of wheels, more especially, if they were placed on each side of the sliding gate. When the rate of current was from 2 miles to 3 miles per hour, he feared it might seriously interfere with the closing of a caisson: the straining, however, either of a gate, or a caisson, might be avoided by splaying the opposite side.

Mr. FAIRBAIRN said, that by adopting the system of divisions in the water-tank, the expense would have been greatly increased. He thought, that if some iron ballast were placed at the front corner, and allowed to run over the compartment like a sledge, it might be possible to dispense with the guide-ropes. There were pulleys with guide-frames along each side of the caisson, which prevented any rising, or sideway motion. As to the possibility of abrasion, it was, certainly, possible, that the caisson might, accidentally, press against the face, or lining, but, hitherto, nothing of the kind had occurred. The cost of the Keyham caisson had been, as before stated, £10,000, but if there should arise a great demand for these sliding caissons, they might, possibly, be constructed for one-fifth less.

LADY BENTHAM, through the SECRETARY, said, although she was gratified to find, that the Author of the Paper admitted the original suggestion of caissons, for closing the entrances of docks, to have emanated from Sir Samuel Bentham, still she must enter a protest against the originality claimed for the introduction of valves, the means adopted for giving buoyancy to the caisson, or the power of raising, or sinking it without the necessity of pumping.

On the 4th of August, 1798, Sir Samuel Bentham made the first official proposal to the Admiralty of his floating dam, as it was then called, for closing the entrance to the great basin in Portsmouth Dockyard; but he had some time previously, communicated it privately to Earl Spencer and others. In this proposal, adverting to the plans according to the usual mode, with which he had been furnished, he said:—"I have been induced, in consideration of the enormous expense attending those works, and the inconvenience of them when executed, to think of some other mode of closing the basin which should be less exceptionable. Accordingly, I would propose, that the masonry at the entrance, should be erected in the form of an inverted arch, whereby the expense of the immense number of piles which are used to tie down the bottom when it is made flat, should be saved: and for the closing the entrance, I would propose to make use of a hollow floating dam which, when lying across the entrance, should fit water-tight, being pressed against either the interior, or the exterior side of a groove formed in the masonry, according as the water is kept in, or out of the basin. This dam would be capable of being floated into, or out of, its place whenever there is water enough to permit the lightest ship to pass. Instead of a slight bridge over the entrance of the basin as at present, serving only for foot-passengers, and which requires to be taken away and replaced as often as a ship has to pass, I would propose, that a bridge of sufficient strength to bear the weight of the heaviest loaded carriage, be fixed so as to make a part of the floating dam, whereby as soon as the dam should be in its place, the communication between the opposite piers would be immediately complete without any additional trouble."

On the 10th of September 1798, he submitted a detailed plan, which being approved of by the Admiralty, was carried into effect, and on the 12th of January 1801, the caisson was placed at the opening of the basin. A copy of this second letter was published in the 'Mechanics' Magazine' for 1848,[1] together with the copy of a letter from the Master Shipwright of Portsmouth Yard, giving an account of the first employment of the caisson, which "was floated out of its place, and replaced, with the greatest ease in the world." On reference to that proposal, it would be seen that, after speaking of the ballast that would be required to give stability to the caisson, the General continued:—"What little additional weight it will require to keep the vessel from rising out of the groove at the time of high-water, is to be obtained by letting water into one, or more of the cisterns formed in the vessel, immediately under the dock. This water would, of itself, run out of the cistern at the time of low-water, even at neap-tides, by means of the penstocks, or valves, as shown in the profile."

It was, therefore, evident, that no pumping was requisite for raising water out of the Portsmouth caisson. Being, however, scrupulously exact in providing for extreme cases, he added,

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[1] *Vide* Mechanics' Magazine, No. 1,317, November 4, 1848, p. 441.

that "if at the top of high-water it should be requisite to open the gate, on the sudden, the water, in this case, must be pumped out of the cisterns." Now, it did not appear, that under similar circumstances, the water in the Keyham caisson, could be got rid of otherwise than by pumping. It might, consequently, be asserted, that in respect to valves for freeing the Keyham caisson from water, no advance had been made upon the practice established half a century ago, and continued up to the present time, as would be seen from the following extract of a letter from a gentleman, who had been, for many years, the Master Shipwright of Portsmouth Dockyard:—"In regard to any novelty in the idea of admitting water to the caisson by means of penstocks, or valves, I have to say, that I have never known a caisson without such an arrangement. It is a notorious fact, that the caissons in the Royal dockyards are weighted with water admitted in such a way, and that the water is let out by opening the valves. Some alteration has been made since the introduction of iron caissons, in the method of opening the valves;—a screw is used for that purpose, but that is only a simple mechanical contrivance to carry out the same principle:" he further adds, "that General Bentham had no less the merit of the valve than he had of the caisson itself." It was precisely in respect to the valve, that Sir Samuel Bentham's caisson differed most from foreign examples, which were all constructed on the principle of pumping out the water.

The assertion that these caissons were only applicable to special localities, was negatived, by the introduction of them by the inventor, in the appropriation of an old work, the boat-camber in Portsmouth Yard, to docks for one, two, or three frigates at will, the entrance being opened, and closed to three different lengths by the same caisson. The following testimony was borne, as to the facility with which this caisson was arranged, by one who had had long experience in the principal dockyard of the kingdom:—"I never had any inconvenience in floating this caisson, (General Bentham's,) out of its place, either at Portsmouth, or any other yard where I have been."

The time consumed in opening, or closing the entrance at Keyham, was stated in the Paper, respectively, to be ten minutes, and eight minutes; whether this was the average time, or only the time occupied on some special occasion, was not mentioned. In any case, the difference in this respect between the original caisson and that at Keyham was hardly appreciable, inasmuch as the reply from Portsmouth to the question upon the subject, was:—"The average time required to float the caisson out of, or into its place, is about ten minutes." The water being supplied at Keyham, from the fresh-water pipes, might cause the difference of two minutes in its favour, in sinking that caisson.

As to the superior advantages of a rectangular caisson, that was purely an engineering problem. In the proposal of the 10th of September 1798, Sir Samuel Bentham stated:—"Instead of a flat bottom of wood-work, and side walls only of masonry, the whole is of masonry, in the form of a reversed arch. . . . A floating dam is made to fit water-tight into a groove wrought in the arch of masonry, by which means, the entrance will be shut up, and the water will be kept in, or out of the basin. This floating dam . . is built much in the form of a navigable vessel. . . . . The curvature given to the sides, at the same time that it affords a degree of capacity to the vessel, sufficient to make it support the weight of the superincumbent bridge, together with a sufficient quantity of ballast to give it stability, enables the sides, likewise, the better to resist the pressure of the water at the greater depth."

The caisson at Keyham was very costly in itself, and still more so in the arrangements for its sliding, which did not present any peculiar advantage; two, or three scavelmen were sufficient for manœuvring the Portsmouth caisson, so that the Keyham caisson had no advantage in this respect. The latter was worked by capstans, but the floating dam at Portsmouth used to be moved in the way ships were brought into the basin, that is, by guy-ropes. The costliness of the Keyham caisson was principally occasioned by the great expense for the walls, which must, necessarily, be as deep as the caisson, and strong enough to resist the pressure of nearly 40 feet of water. That amount of pressure was spared, as occasionally, high tides kept back the water of the Tamar to an extraordinary height in the river, and in the whole of the Hamoaze. Advantage would possibly have been taken of the slate rock out of which the yard at Keyham was excavated, and enough of the rock might have been left to save much masonry. The chasm in the wharf was covered over in a rude way: a groove had been formed at the sides of the chasm, into which planks were placed to form a passage over it.

Mr. SIMPSON,—President,—said, that the tackle generally employed for gates and caissons, was not sufficiently strong to inspire confidence in the labourers, and the ordinary capstan was very troublesome to manage: all these mechanical difficulties might, however, be overcome. With reference to the plan of M. Singels, it should be observed, that there could be no difficulty in constructing a sliding gate in the Zuyder Zee, as the rise of tide was very small.

May 16, 1854.

JAMES SIMPSON, President, in the Chair.

No. 915.—"On the Fatigue and consequent Fracture of Metals."[1] By FREDERICK BRAITHWAITE, M. Inst. C.E.

THERE are reasons for believing, that many of the appalling, and apparently unaccountable accidents on railways, and elsewhere, are to be ascribed to that progressive action which may be termed, the 'fatigue of metals.' This fatigue may arise from a variety of causes, such as repeated strain, blows, concussions, jerks, torsion, or tension, &c.

Metal, in a state of rest, although sustaining a heavy pressure, or strain, as in a girder, and exhibiting the deflection due to the superposed weight, will continue to bear that pressure, without fracture, so long as its rest is not disturbed, or the same strain is not too often repeated, but, if its rest is too frequently disturbed, the metal becomes deteriorated, and worn out, at the part subject to the reiterated strain, and fracture will, ultimately, ensue.

The history of some, apparently, unaccountable accidents which have happened, will furnish sufficient grounds for the consideration of the Members of the Institution, whether the

[1] The discussion upon this Paper extended over portions of two evenings, but an abstract of the whole is given consecutively.