

SPRING
ON THE
REMODELLING & EQUIPMENT
AND
MITCHELL
ON THE
ALTERATION OF THE FORM
OF
MADRAS HARBOUR.

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the coming into force of the Madras Harbour Trust Act, whereby the direct control, properties, duties, and liabilities in connection with the port passed to a Board of Trustees. So, at the end of 1886 the question of the position of the entrance was revived by the new Board, and their proposal met with the strong approval of the Governments of Madras and India. The result was the appointment by the Secretary of State of a new Committee, stronger this time in nautical experts, consisting of Admirals Sir Nowell Salmon and Sir George Nares and Sir John Cooke, Past-President Inst. C.E., who, in 1887, reported in favour of the adoption of a north-east entrance. In the following year a similar suggestion was made by Mr. A. L. Pogson, who had succeeded to the harbour-engineership; but this, on going forward to the Secretary of State, with the strong support of the Governments of Madras and of India, was again rejected by that high authority with instructions that the harbour should be completed on the old design with an eastern entrance. The harbour on this design was completed in 1895. During the next 9 years various schemes were put forward by Sir A. M. Rendel, M. Inst. C.E., Mr. W. B. de Winton, and Mr. F. J. Wilson, M. Inst. C.E., for ship-docks, boat-docks, or quay-walls of sundry designs; but the feeling of the practical mercantile men, of whom for the most part the Harbour Board is ordinarily composed, was that, however desirable such luxuries might be in the future, the trade of Madras was not then of sufficient magnitude to afford them, and that the matter of real and immediate urgency was that the shore side of the harbour should be suitably equipped with piers, cranes, sheds, sidings, roads, etc., on an adequate scale for the traffic offering itself. The harbour, however, continued to be very rough and uncomfortable, so in 1902 the matter was referred by the Secretary of State for India to a Committee composed of Admiral Sir George S. Nares, Assoc. Inst. C.E., Sir Charles A. Hartley, M. Inst. C.E., and Mr. (now Sir) Wm. Matthews, Past-President Inst. C.E., who reported strongly in favour of the design of entrance which has since, finally, been adopted. Eventually in 1903 definite proposals and estimates were submitted, based on the advice of Sir Alexander Rendel, obtained during a visit to Madras, for the construction of a north-eastern entrance and for the closure of the old one, at a cost of 45 lakhs of rupees; and these works, having been sanctioned in due course by the Secretary of State, were put in hand under Mr. F. J. Wilson as the Port Trust's Chief Engineer. Early in 1904, on retirement from 34½ years' service with the Government, the Author came on the scene as Chairman of the Port Trust, and 2 years later he combined this

appointment with that of Chief Engineer, on Mr. F. J. Wilson's reabsorption into the Government service; and 8 years having elapsed since his connection with the port began, he is now in a position to summarize the work that has been done in that period on the remodelling and equipment of the harbour.

THE SOUTH SAND ACCRETION.

It seems advisable, at an early stage in this Paper, to refer briefly to the important subject of the large area of sand which has grown up at the south of the harbour, apparently threatening to overwhelm it—an area which has afforded opportunity for the construction of valuable sections of the remodelled harbour's equipment. The subject of this sand growth was first touched on nearly 30 years ago in the Paper by the late Mr. L. F. Vernon-Harcourt, M. Inst. C.E., already referred to. Later, in 1904, it is to be found occupying an important part of the discussion on the Paper by Mr. A. E. Carey, M. Inst. C.E. The manner in which the accretion referred to has progressed since the beginning is shown in the sections given in Fig. 2, Plate 4, where a certain line represents the state of affairs of 1878 and another line that of 33 years later. These sections go to show that those who inquired into the matter 10 years ago were not far out in the opinion expressed at that time that the average northward movement of the sand, one year with another, is not far from 550,000 tons per annum. The Author had intended to deal in this Paper with the important and difficult factors involved in this movement of sand along the Coromandel coast. For many years past, data have been collected with a view to the formation of an opinion as to the degree or extent to which, and the period within which, Madras Harbour is likely to be affected by this flow of sand. But on co-ordinating the available data, since this Paper was taken in hand, the Author has found them to be of considerably greater and more far-reaching importance than can be dealt with adequately in a few pages of a Paper on remodelling and equipment. He therefore proposes to offer to The Institution later the results of the collection of the data referred to, and to comment on them as fully as 8 years' practical acquaintance with them at close quarters seems to justify. Meanwhile, he ventures to hope that any members of The Institution to whom the subject of this sand-movement is of practical interest will kindly refrain from attempting to deal with it on the present occasion. Later, however, the fullest criticism will be welcomed. For the purpose of the present Paper it may perhaps suffice to draw attention to the

area of new land (about 260 acres) which has accreted south of the southern breakwater, to an average height of 7 feet above Indian spring low-water level, under the combined action of waves, sea, wind, and, in a minor degree, currents, as an important factor in the recent development of the working equipment of the harbour.

STATE OF AFFAIRS IN 1904.

The harbour at this date was formed by the pair of arms already described, curving round so as to leave an entrance on the east side, with full scope for the swell to roll in nearly all the year round, which made the working of vessels slow, difficult, and dangerous during many months of the year. The 5-fathom line was about $\frac{1}{2}$ mile from the shore forming the west side of the harbour, which consisted of a long flat sandy slope with surf rolling in on it but little less violently than outside. There was no place for small craft to lie in shelter in dangerous weather, and though a few dozen 10-ton lighters had come into existence alongside of the old surf-boats, they were constantly breaking loose during May and November, and, once broken from their moorings, nothing could save them from wreck. Needless to say, this greatly discouraged the provision by capitalists of an adequate tonnage of lighters. Between high-water mark and the streets of the town of Madras there were to be found a few confused and unregulated railway-sidings and two or three exiguous sheds. The beach was to be seen at all times littered with timber, coal, railway materials, general cargo, machinery, liquors, etc., all in dire confusion. Every packet of dutiable goods landed along the beach, unless too big to be so handled, was obliged to be carried on men's heads to the Government Custom House across the road, while goods arriving over the old screw-pile pier had to be pushed into the same Custom House on lorries. The entire dutiable trade of Madras had to pass in, and the empty lorries to pass out, through one 10-foot Custom House gateway. The result was that it was no uncommon thing for a consignee not to get his packages under several weeks or even months. Machinery and railway packages used to be piled up in stacks, sometimes three or four deep, on the beach, and it was constantly happening that, before the cargo of one vessel could be delivered to waiting consignees, that of another had perforce, for want of sidings, to be dumped on top of it. In fact, the arrangements were about as bad as they could possibly be. For lack of a working scheme, the Trust had got into the habit of paying off prematurely large sums of its debt, so as to avoid useless balances.

The mouth of the harbour was silting up at the rate of nearly 1 foot a year—indeed the depth of water at the entrance had diminished by just 10 feet in the 10 years 1893–1903—and, had not dredging been taken in hand, it might conceivably have had to be closed in heavy weather to vessels of deep draught, before the new entrance could be opened.

PRESENT STATE OF THE HARBOUR.

In contrast to the deplorable state of things that has just been depicted, it may be useful at this stage to offer a brief summary of what has since been done to make Madras Harbour what it now truly is, namely, one of the cheapest and most convenient in the East, whether from the point of view of steamer-owners or of exporters and importers. The plan given in Fig. 1, Plate 4, shows the present conditions, as follows:—

(a) The 515-foot eastern entrance has been closed, and a 400-foot northern entrance has been opened under the shelter of an arm projecting about 1,200 feet. The result, now proved through one south-west and two north-east monsoons, is a harbour smooth enough for working cargo into and out of lighters, alongside the ships and piers, in practically all weathers. But that is not all: it has been proved also that the water of the harbour has been rendered smooth enough for steamers to lie alongside of wharves in practically all weathers.

(b) There has come into existence a fine fleet of fifty or sixty lighters of 40 to 60 tons each, and sufficient steam-launches for towing them, as the direct result of the construction of a boat-basin in which they, as well as the Trust's own fleet of dredgers and other craft, can lie in safety in all weathers.

(c) For the use of these lighters, as well as of the old 10-ton lighters, of which seventy or eighty still remain in use, there have been erected three steel screw-pile piers, C₁, C₂, and C₃, with a frontage of 1,200 feet available for lighters, and fully equipped with cranes. There is also 1,400 feet of reinforced-concrete wharfing, C₄ and C₅, equipped with twenty hydraulic cranes. The effect of this on the speedy loading and discharging of steamers needs no comment beyond a statement of the fact that general-cargo steamers are turning round in about half the time they required a few years ago. The plant just referred to is in addition to that provided for the timber- and iron-trades referred to below at (e) and (f).

(d) Close behind the piers, wharves, and cranes referred to under (c),

there have been provided about 250,000 square feet of new steel sheds, D₁ to D₅, with all facilities for the sorting, receiving and delivery of cargo. The best comment on the value of these sheds is that, in spite of the increase of the tonnage passing through the harbour, the Port Trust's receipts from storage of cargo have fallen steadily in the last 3 years, thereby indicating that most of the goods can nowadays be removed from the premises within the free days allowed.

(e) For the timber-trade there has been provided a 2-acre basin, E, into which imported timber can be floated from ship's side at all tides, and a sufficiency of cranes, lorries, sidings, etc., for its handling. This pond is lined on three sides with reinforced-concrete wharfing, and in it, as well as in the 9-acre boat-basin referred to under (b), small craft can take shelter in bad weather.

(f) For the iron-trade there have been provided about 600 feet of reinforced-concrete wharfing, B, with five 2-ton hydraulic cranes and an adequate shore equipment of tramlines, trolleys, sheds, and weighing- and delivering-arrangements.

(g) As the rubble bases of the breakwaters have always prevented ships from lying alongside of these structures, there has been provided (Fig. 14, Plate 5) a strong steel wharf along 335 feet of the south breakwater, at which vessels drawing up to 28 feet of water can lie and work their hatches at all tides. This wharf is used also by troop-, passenger- and horse-ships and has proved very valuable in furnishing ample evidence, during three monsoons, of the truth of the forecast that, once the harbour should be remodelled, vessels could lie in all weathers alongside of quays.

(h) The railway-lines and sidings, as well as the roads all over the Trust's yard, have been so reconstructed that there is now practically no delay to carted traffic, or in the handling of railway vehicles, as is evidenced by the practical cessation of demurrage charges. It is difficult to show all these improvements in a plan, but they can be seen in Fig. 1.

THE REMODELLING OF THE HARBOUR.

So long as the eastern entrance remained open—and, strangely enough, even when only a few feet of it still remained unclosed—it was found that though certainly the water inside the harbour was, ordinarily, less rough than outside, yet, for many weeks in the year, it was far too rough for convenient working of cargo overside between ship and lighter, and that it would be quite impossible during several months of the year for vessels to lie

alongside quays. For the swell, whether due to the north-east or to the south-west monsoon, rolled in impartially, and the $\frac{3}{4}$ square mile of enclosure was not of sufficient area to dissipate it. In all weathers there was some surf near the shore, and in heavy weather, as already stated, there was enough surf to wreck many of the lighters then in use year after year. After the completion of the remodelling work, a printed circular was handed to the master of each vessel visiting the port during a period of 3 months, with the request that he would record his views as to the effect of the remodelling. The replies which have come in are unanimous in expressing the opinion that the result is all that could be desired from a nautical point of view. The Author proposes at this stage to offer a brief account of the construction of the three parts of which, in an engineering sense, the remodelling may be said to have consisted: namely, first, of the construction of the new sheltering arm or breakwater; secondly, of the opening out of the new north-eastern entrance; and thirdly, of the closing of the old eastern entrance.

The New North Sheltering Breakwater.—This work (K, Fig. 1, and Figs. 4, 5, and 6, Plate 4) has been constructed on the sloping slice-work principle, which was used for the construction of the earlier breakwaters. Its breadth is 36 feet and its height above the rubble base 43 to 50 feet. Fig. 5 shows how the blocks, weighing 25 to 30 tons, break joint. In order to help in solidifying the bond without interfering with the free settlement of the individual slices, grooves were left, as shown at G, Fig. 5, forming, at each vertical joint between the slices, chimneys which later have been rammed full of bags of concrete. When sufficient time had elapsed for a fair degree of settlement to have occurred, the top 5 feet of solid concrete capping was added, with vertical joints at every sixth slice. The whole rests on a bed of rubble stone dropped in advance from boats and levelled off by divers, just in front of the progressing slice-work. This rubble base is about 180 feet wide and 15 feet thick. Its average settlement into the sandy, and in places clayey, sea-bed, and within itself, due to the weight of the breakwater and to the vibration of the titan crane on top of it, has been about 2 feet. The settlement is, of course, more or less irregular, but as the concrete capping was not added until most of the subsidence to be expected had taken place, there was opportunity to form the top of the breakwater to a level surface.

The most troublesome part of the construction of this breakwater was the joining up of the old and the new work. This triangular part, about 300 feet long (L, Fig. 1), had not only to be joined up with the breakwater of 1895 but also to be dovetailed into the

wrecked submerged breakwater of 1881. Needless to say, it was impossible to build this part of slice-work; it had to be built up slowly, the conditions changing daily, with bag-concrete below water, with blocks of all sizes between 5 and 30 tons, and with mass concrete laid above water. The construction of this portion occupied just a year, from January, 1906, to January, 1907, or a fifth of the time required to complete the entire breakwater. This junction part, as well as about 565 feet more of the slice-work part, is on a curve of 2,000 feet radius, and in order to form this curve a radial course was introduced at every tenth slice.

Once slice-work began, in January, 1907, it went on fairly rapidly, at the rate of about 90 slices or 575 feet per annum, until the outer end was reached, where a steel caisson, 42 feet square (Fig. 10, Plate 5), was floated, sunk, and filled, forming, with its handsome granite capping, parapets, and lighthouse, a solid 5,000-ton block. The subject of the cost of this breakwater is dealt with separately, as also that of the floating, sinking, and filling of its terminal caisson. Outside the entire length of the breakwater there has been laid, pell-mell, the wave-breaking protection shown in Fig. 5. As will be seen, part of this consists of heavy rubble stone and the rest of 30- to 33-ton square blocks similar to those used (Fig. 4) in the older breakwaters since the cyclone of 1881. So far, this wave-breaking protection has not moved and seems to be entirely adequate.

Opening the North-East Entrance.—The position of this will be seen at M in Fig. 1. In order to open it, it was necessary (Fig. 8, Plate 5) first to remove the pell-mell blocks from the outside of the old north breakwater, then to remove about 600 feet in length of the old slice-work, next to dredge away the old rubble base to a depth of 36 feet, and, finally, to remake the slice-work at both ends on a gradually deepening bottom, because the old work had been founded at a depth of only 20 feet below low water on top of its 19 feet of rubble base, and it was necessary that the two ends of the new work flanking the new entrance should go down to a depth of 35 feet. The west end of the new work was easy enough, because the slice-work of the old breakwater was merely continued outwards at a gradually increasing depth. But before the slice-work at the east end could be begun it was necessary (Fig. 9, Plate 5) to build up a sloping face, or skewback, from which to start it, and this, of course, was difficult and took time. Both ends of the new entrance have been finished off with heads 36 feet wide, of square blockwork faced above water with rock-faced granite and timber-fendered in front. On these square ends stand granite-faced

reinforced-concrete lighthouses, each on a base finely finished with a heavy cut granite coping, and provided with boat-steps.

For removing the old rubble base down to a depth of 35 to 37 feet—an 80,000-ton job—a powerful 500-ton bucket hopper dredger, the “Triton,” built in 1891 by Messrs. Simons, of Renfrew, was bought from the Ceylon harbour-authorities. She carried out her work very effectively. The first block of the slice-work was blasted out in May, 1908. The whole of the opening, to its temporarily extended length of 600 feet, was finished by the 15th September, 1909. The first vessel to go out of the new opening was the British India Steam Navigation Company’s “Tara” on the 9th December, 1909, in the presence of H.E. the Viceroy of India. The entrance, however, was not used regularly for all vessels until a month later, and dredging was not completed until the month of May, 1910. Some of the authorities consulted about the change of entrance made rather a point of the disturbance likely to be found in the harbour during the two or three monsoon seasons when both the old and the new entrances would be open simultaneously; but nothing of the sort of any serious moment was experienced, doubtless because of the protection offered by the partially-finished sheltering breakwater. From these dates it will be seen that the new entrance came into regular use 18 months from the start, and that it was fully finished within 2 years.

Closing the Old Entrance.—This work consisted of the same kind of slice-work as was used in the new breakwater, of a breadth of 36 feet, as shown in Figs. 4, 5 and 6, Plate 4. The two lots of sloping slices had to start each from its own abutment—the old cylindrical-caisson heads—and to approach until they met at the bottom, leaving a V-shaped gap to be filled in at the last (Fig. 7, Plate 4). But in order to start them from the ends of the old work it was necessary somehow to build up a sloped skewback butting on each of the old cylindrical caissons, and it became clear not only that the building of two such structures would be slow and difficult, but also that they would be very liable to be overthrown by heavy seas, in which case the blocks composing them might be dangerous to navigation until removed. Therefore, unless something better could be substituted for them, the building of such skewbacks would have to be deferred until the old entrance was closed to vessels in January, 1910, and then there would be the long delay in building them piecemeal and the risk of their being wrecked in May, 1910, before they could be protected by heavy slice-work in front of them. In order to prevent such delay two steel caissons were designed, of the form shown in Fig. 12, Plate 5, to fit, more or less, against the cylindrical

caissons flanking the harbour-entrance, with a space between large enough to be stanchied by concrete in bags, and with a skew face out in front, on which the first of the concrete-block slices might lie. Such structures as these would not, it was clear, be liable when filled to be shifted by heavy seas; they might, therefore, be laid down—and one of them was laid down—while the entrance was still open to traffic; and once they had been laid, the two parts of the slice-work intended to work out towards a junction in the centre of the entrance might be begun very much earlier than would be possible if structures of form similar to the caissons had to be built up laboriously, of small blocks and bags, only after the final closing of the entrance. These two caissons formed a very interesting feature of the work and will be dealt with later in detail.

Had the two titan cranes used for the slice-work been both available simultaneously for starting work, one at each end, the final V-shaped opening might have found itself in the centre of the closed entrance. But they were not so available, and though the first slice at the north end was started on the 1st March, 1910, that at the south end could only be started about 3 months later when the titan crane had had time to get round from the new entrance—a 32 days’ journey for a crane weighing 250 tons. The consequence is that the V is 130 feet south of the middle of the gap which has been filled (Fig. 7). The new piece of breakwater filling the old entrance stands, as does the new sheltering arm, on a bed of rubble 14 feet thick and 180 feet broad, dropped from boats and levelled by divers. The settlement of the slice-work on top of the rubble has not been quite so regular as in the case of the sheltering breakwater—possibly partly because of the jamming effect of the V wedge, which prevents the slight creep outwards that slice-work is able to make during settlement when it is free at its outer end. Outside the closed entrance there are the same pell-mell blocks overlying large rubble stone as are to be found in the rest of the new work. The actual closing of the old entrance took just 6½ months; but the mass-concrete capping was delayed for a few months pending the final settlement of the slice-work. The harbour face of the new work closing the old entrance, a length of 500 feet, has been furnished with bollards, for the use of vessels desiring to lie alongside in 26 feet of water at low water. Needless to say, with so narrow a working-space as is afforded on top of the breakwater, only a limited class of vessels will probably use this place as a quay; but it will be useful for troops and passengers and for cargo intended for direct dispatch by rail, as well as for export minerals and other produce arriving direct by rail. The first vessel

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came alongside at this place in September, 1911, and since then several vessels have been dealt with there, quite satisfactorily.

*The Caissons*¹.—As useful lessons were learnt in the disposal of the three caissons, some description of the construction, sinking, and filling of them may be of interest. The first caisson to be sunk was that forming the outer end of the new sheltering breakwater (Figs. 6, 10 and 12). It weighed 110 tons and was 42 feet square, with corners rounded off on a 4-foot radius, and was made 51 feet high, though ultimately the upper 8 feet of its sides were omitted, being above water. The structure of all three caissons was built like that of a ship, with vertical and horizontal frames; but as the caissons were not of adequate strength to prevent their caving in, if submerged to their full depth and there held down and pumped out, great care was taken during the loading of them to stiffen and strut them adequately from within, with concrete blocks, concrete piles, and mass concrete, for the pressure coming on them as they were gradually submerged. The first caisson was built on the Trust's own slipway in the boat-basin, and having been launched was gradually filled until it drew 27 feet of water, displacing 1,325 tons, and there remained only 10 or 12 feet for it to sink on the rubble bed that had been prepared for it. It was then towed out into place, and on 20th March, 1909, it was sunk by opening its four 12-inch sluice-valves, which, when sinking began, were only 1½ foot below water-level. The sinking took 11 minutes, and, in view of the swell that was running at the time, on the smoothest available day for weeks before or after, this rate of sinking was found to be far too slow. In spite of all that could be done to keep it in place the caisson came down on its bed about 3 feet to the west of its intended site; but as its direction was good and the site without disadvantage, it was left there and, having in due course been filled, it now forms the base of the lighthouse at the end of the breakwater. This caisson took 107 days to erect, 72 days to be concrete ready for sinking, and, after sinking, 19 days to put 2,000 tons of concrete into it up to water-level.

The next caisson to be dealt with was the queer-shaped one at the north end of the old entrance (Figs. 7, 11 and 14). Just before sinking it drew 23½ feet of water and displaced 540 tons. This caisson took 45 days to build and launch, 41 days to prepare for sinking, and 29 days to concrete up to water-level after sinking. It was sunk on the 29th September, 1909, on what proved to be the

¹ For very full details of the caisson work see the *Indian and Eastern Engineer*, May, 1909, p. 175, and May, 1910, p. 173.

last possible day of the smooth season; but even then the very great difficulties were encountered because of swell and of the work continuing after dark, and the result was that the caisson came down on its bed (Fig. 14) 17 feet to the west of its intended site, but with fairly good direction. This caisson also sank far too slowly for effective control during the critical few minutes, whilst it was being tossed up and down to a height of 6 or 8 feet on the swell.

The lesson taught by the failure of the first of the two skewback caissons to sink exactly on its intended position led to far greater precautions being taken when, 5 months later, its fellow at the south end of the old entrance came to be sunk. This last caisson (Figs. 7, 11 and 14), which just before sinking drew 27 feet and displaced 730 tons, took 44 days to erect, 71 days to prepare for sinking, and 37 days to fill with concrete after sinking. It was very necessary that it should sit down in the exact position intended, because the wall of blocks stretching out from the north caisson had to meet that stretching out from the other fair and square. Therefore while all gear for pulling and hauling this third caisson was made stronger—a vain precaution, because ropes broke here as with the other two—it was furnished with six 12-inch sluices instead of the four used in the first and the two in the second caisson; moreover, its sluices were put 5 feet from the bottom instead of 10 feet, as in the other two. That is to say, when sinking began the six sluice-valves were 15 feet under water, instead of a couple of feet only, in order that the critical minutes might be still fewer. Also it was decided that if the caisson did not sink to the exact position it was to be pumped out until near flotation-point, and then slid along the bed by chains and union-screws. In forming the bed of this caisson, therefore, instead of leaving it like that of the others with no better surface than a few inches of road-metal laid level over the rubble base, a number of old rails were laid correctly on the base by divers and were levelled in between with road-metal. The consequence was that when, on the 26th February, 1910, the third caisson was sunk, but did not take bottom nearer than 3 feet from the predestined position, it was slid over there quite easily on the rail bed a day or two later.

Figs. 12 and 13, Plate 5, show how all three caissons were handled. All were hauled into place tight up against their heavy vertical timber guides by steam winches on board the dredger "Madras," which, for this purpose, had been furnished with a pair of inhauls and an outhaul of 7-inch manila rope. All three were pulled to the right or to the left by winches fixed

on lighters anchored at both sides. But lighters' drag-anchors or ropes break when a 1,000-ton unnavigable craft is pulling on them like a harpooned whale in a sea swell, and guide-timbers 14 inches square are liable to be smashed into matchwood by such a craft. And so it came about that not one of the three caissons sat down exactly where wanted. The right thing to do in such circumstances is to have an area of rubble base prepared broad enough to allow the caisson to get somewhat adrift without risk of tumbling over the edge of the rubble, then to cover this area with a grid of rails on which to slide the caisson later into the correct position, and lastly to provide an ample area of sluices, well under water, so as to secure quick sinking. This was done with the third caisson, and entirely successfully. As a fact, the second caisson did overhang its rubble bed a little; rubble had to be put beneath the overhang by divers, and the base to be extended a few square feet.

Dredging.—Principally in view of the rapid shoaling of the old entrance at the rate of 15 feet in 26 years, of which 10 feet occurred in the last 10 years, and also in view of the enormous quantity of sand that was being sucked by waves and blown by wind-action continually from the south sand accretion into the harbour, the Port Trust, on the advice of the Nares-Hartley-Matthews Committee, procured the 900-ton hopper suction dredger "Madras" from Messrs. Simons and Company, of Renfrew, in 1904. In the 7 or 8 years since then this vessel has done fine work, not only putting an end to all anxiety about the silting-up of the entrance—a matter of minor importance since the remodelling—but also quickly removing the shallows within the harbour caused by wave- and wind-action. It also did grand work in excavating the boat-basin (B, Fig. 1): for this purpose, once a gap was made in the old south breakwater, the suction-pipes were dismantled, joined up to form one long pipe and slung forward of the vessel's bows; then rough wooden launders and sheet-iron pipes were so rigged that, once the "Madras" got its nose through the gap in the breakwater, it continued to pump all the sand ashore, raising the whole of the area surrounding the basin to the level of the breakwater—that is, to the level designed for the working of all traffic. Since that work was finished, the "Madras" has helped with the sandy parts of the new entrance and in the dredging of vessels' berths, and lately, as described elsewhere, in the reclamation of the foreshore on which to found the wells for the new ship-quays and for the formation of land behind them when made. This vessel dredged 1,400,000 tons in 5 years, working 1,030 days at an average rate of 280,000 tons per annum, or 1,360 tons per

working-day, at 4·9*d.* per ton, or, reckoning depreciation and interest, 7·3*d.* per ton.

The 500-ton bucket hopper dredger "Triton" has been used largely for deepening coal-berths which, under the old conditions of landing, used to get filled rapidly by coal falling between ship and lighter. Also it did all the dredging needed in order to prepare the sea-bed for ships using the steel wharf (G, Fig. 1) on the south arm. But its principal work has been the removal of the rubble underlying the block-work (Figs. 8 and 8*a*, *b* and *c*, Plate 5) at the site of the new entrance. This it has done to the extent of about 85,000 tons, at a cost of about 3*s.* 6*d.* per ton; or, if a due percentage be added, as explained elsewhere, for establishment and plant, at the cost of slightly over 5*s.* per ton. This last work has been very severe on the "Triton," and it has cost a good deal to keep it in working condition, which would not have been possible had not the Port Trust had its own slipway (N, Fig. 1). All this outlay, however, is included in the per-ton rate.

Foreshore Revetment.—Much of the land on which the new sheds have been built has been reclaimed from the shallow water at the west side of the harbour and brought up to level 12 feet, which is the predestined level of all future quays and yard. But the surf inside the harbour was perpetually nibbling at the land so reclaimed, and endeavouring to undermine the foundations of the new sheds, so something had to be done to stop this action. The means employed to that end was the formation of the bank of rough rubble stone all along the front, with an apron below it, as shown in Fig. 18, Plate 5. This quite effectively stopped all erosion of the new works due to surf-action, even in heavy weather before the old entrance was closed, when waves were coming right over the 12-foot level. It has cost about Rs.40, or £2 13*s.* 4*d.*, per lineal foot, and the stone will all come in for use later in the superstructure of the ship-quay to be described farther on. About 1,500 lineal feet, or the southern half, of the western face of the harbour has been so revetted, and it is from this revetment that three of the steel piers project. Needless to say, this revetment and the steel piers projecting from it are only semi-permanent works, for use perhaps for 10 or 20 years, until such time as the financial condition of the Port or the generosity of Government shall permit their replacement by permanent, deep-water quays. This particular form of rough rubble revetment labours under the disadvantage that the stretch of foreshore protected by it is not available for use by lighters for landing and shipping, except near the ends of the projecting piers. It was the endeavour to sub-

stitute for it some other sort of protection, which might also serve as a quay for lighters, that led the Author to invent the form of reinforced-concrete wharfing referred to later, of which the special feature is that, inasmuch as it is too thin to serve as a retaining-wall, it is tied back into the land behind it by a series of adequate steel ties attached to anchors set behind the probable line of slip.

THE INTERNAL EQUIPMENT OF THE HARBOUR.

Piers and Wharves. Up to 5 or 6 years ago the only equipment possessed by the Port of Madras for landing or shipping cargo, apart from the natural sea-beach, consisted of the following:—

(1) An old 8-inch iron screw-pile pier 1,100 feet long by 42 feet wide, with a T head measuring 160 feet by 42 feet. This pier, having been erected in the days when there was no harbour, is decked at a height necessary for heavy seas but quite unnecessary in sheltered water. It cost about £10,000, or about £1 6s. 8d. per square foot, and was, and is still, furnished with a number of push-about 1-ton hand-cranes, a few 3-ton steam-cranes, and an old 20-ton hand-crane, lately converted into a 10-ton steam-crane. It was also equipped with 80 to 100 heavy hand-pushed 10-ton lorries, which were worked for the most part across the main town street through a narrow arch into the Government Custom House, and also on to the beach at both sides. Only about 500 feet in length of this old pier now projects over the water; the rest stands over reclaimed land. As already mentioned, this pier will soon be dismantled.

(2) The first addition to this utterly inadequate equipment was made in 1905, in the shape of a small 4½-inch screw-pile jetty for exports, equipped with eight hand-cranes, served by a 2-foot tramway, recently altered to metre gauge, with hand-pushed rolling stock. This pier, complete with its equipment, cost just below 9s. per square foot of deck, or 3½d. per cubic foot of its bulk over all.

(3) Subsequently there has been added a 6-inch screw-pile pier equipped with fourteen 1-ton hydraulic cranes, and with a network of metre-gauge sidings leading all through the new shedding to be described later. This last pier (Figs. 15, 17 and 17a, Plate 2) is a thoroughly effective piece of equipment. Its fourteen hydraulic cranes are bolted on 3-foot cast-iron screw cylinders forming an integral part of the 6-inch wrought-iron screw-pile structure. The decking consists of steel beams supporting 4-inch planking of New South Wales "blackbutt" the best timber the Author had ever

seen for such a purpose, if cut to moderate scantling. This pier cost 12s. per square foot, or 4½d. per all-over cubic foot, complete with all equipment except cranes.

(4) This pier was duplicated later, with differences (see Fig. 16, Plate 5), in the form of a 6-inch screw-pile pier carrying twelve 1-ton hydraulic cranes, not on cylinders like the last, but on groups of the same 6-inch piles, and equipped like the last with metre-gauge lines leading into a fine new shed. The reason why groups of four 6-inch piles were used in this pier, instead of cast-iron cylinders, for supporting the cranes was that by this time it had begun to be realized that these iron piers would have to be dismantled later; and the pile-groups will be removed more easily than cylinders full of concrete. This pier cost just 13s. 5d. per square foot, complete with all equipment except its cranes.

The best day's work that has been done at these steel piers is as follows: pier No. 1, 720 tons, pier No. 2, 1,090 tons, pier No. 3, 1,170 tons, and pier No. 4, 1,300 tons, each in one working-day, besides about 450 tons more on the south breakwater. Needless to say, the whole of this was not done on all the piers in any one day.

(5) The iron-import yard in the boat-basin is served by small 6-inch screw-pile jetties, five in number, each carrying a 3-ton hydraulic crane.

(6) The timber-pond is served by similar small jetties, six in number, each carrying a 3-ton hand-crane. These jetties in the iron- and timber-yards are served by 2-foot lines, leading conveniently from the cranes, by means of turn-tables, all over their respective yards.

Piers Nos. 3 and 4 do splendid work, each of the modern 40- to 60-ton lighters coming alongside of them being served by two of the hydraulic cranes and by as many trollies as these can deal with, the net effect being, as already mentioned, that vessels frequenting the Port are being dealt with in about half the time usual 5 or 6 years ago.

A serious defect in piers Nos. 2 to 4—a defect not shared in by piers Nos. 1, 5, and 6—is that they have steel beams for their decking. Experience has proved this to be quite wrong in a port in the tropics where the chief enemy is corrosion, due to moist, warm spray. All the piers should have had transverse and longitudinal beams of Australian hardwood—preferably, in the Author's opinion, of good jarrah—and should have been decked as at present with "blackbutt," a wood which, if the planks are not of larger size than 9 inches by 4 inches, stands alternate wetting and sun extraordinarily well. The use of steel beams has been avoided in the

construction of the latest screw-pile wharf (G, Fig. 1) on the inner side of the south harbour arm, intended for vessels drawing 28 feet of water at low water.

This last wharf, which may be called the ship-wharf (G, Fig. 1 and Fig. 16), has had to have its 8-inch piles screwed down through 5 to 15 feet of the rubble base underlying the old south breakwater. The screws for these are only 2 feet instead of $3\frac{1}{2}$ feet in diameter, and are of a longer pitch and have serrated edges, in order the more easily to go down through the rubble. Practically no difficulty was experienced in screwing them, and all but one or two were bedded to an inch. This wharf at first—partly for want of money, partly because it was an experiment—consisted of two parts separated by an interval of 190 feet, each part being 80 feet long at the breakwater and 70 feet long at the vessel's side, so as conveniently to serve a couple of hatches of an average vessel using the port. But these small experimental sections have proved so useful, and have been so much in request, that the space between them has been filled, and they have been lengthened so that the completed wharf has a length of 335 feet, which, for the present, suffices for all the requirements of the passenger-, troop- and emigrant-ships, as well as for the horse- and cattle-ships and the occasional cargo-vessels using it. In sinking the screw-piles of all these piers, and especially in sinking the 3-foot cylinders in pier No. 3, free use was made of a water-jet. Reinforced-concrete piles are now being tried for the fenders of the ship-wharf, but whether they will stand the bumping of vessels remains to be seen. In all weathers experienced during the two monsoons which have elapsed since wharf G has been used, vessels have lain alongside perfectly quietly since the old harbour-entrance was closed, and this fact has been accepted as proving, sufficiently well, that the alteration of the shape of the harbour has had the effect of making it possible to build permanent quays at which vessels can lie quietly, practically all the year round.

Reinforced-Concrete Wharfing for Lighters.—As this has recently been fully described by the Author,¹ it is not necessary to say much about it here. A length of about 4,000 feet of the perimeter of the boat-basin and the timber-pond shown in Fig. 1 has been lined with this kind of wharfing, of three grades of size and strength. In liability to corrosion of the metal contained in them, these piles and slabs only share that of reinforced-concrete pile-work in warm salt water all over the world. The

¹ "Light Reinforced-Concrete Wharfing Used in the Port of Madras." *Minutes of Proceedings Inst. C.E.*, vol. clxxxvi, p. 427.

Author does not pretend to prophesy whether such work has a life of 20, 50, or 100 years. But, in company with many eminent engineers, he has ventured to give hostages to fortune in the form of heavy expenditure on cheap reinforced-concrete wharves, believing that, in the commercial circumstances of the Port of Madras, it is preferable to give as much accommodation as possible to the present generation of merchants, rather than to allow the trade of the port to be diverted elsewhere while it is waiting for money to provide itself with something better and more expensive than it can now afford. In addition to the perimeter of the basins referred to, about 700 feet of the largest of the three grades of this wharfing (C₅, Fig. 1) has been provided in front of a fine new shed (D₅) that has just been built in another part of the harbour-face. It is the closing of the old entrance that has made the adoption of this light construction possible in the open harbour. At the back of about 1,460 lineal feet of the reinforced-concrete wharfage, twenty hydraulic cranes have been installed, each set on a group of four reinforced-concrete piles independent of the wharf-piles; and foundations have been provided for as many more, when found to be needed. It is found that, in the warm water of the port, the reinforced-concrete piles and slabs become covered in a year or two with a protective coating, 3 to 6 inches thick, of shells and marine growth which, it is hoped, will help in stanching any porous parts there may be in the concrete.

The tied-back pile-and-slab system possesses the not inconsiderable potential advantage that it can be pulled up and relaid elsewhere—it may be hoped comparatively unimpaired—if ever it should be desired to replace it by deeper quays. The temporary use of wharfage of the character referred to will be found to be fully justified—in the financial circumstances of a poor port like Madras—by its low cost, namely, £2 6s. 8d., £3 5s. 4d., and £6 13s. 4d. per lineal foot, according to design, as against perhaps three or four times as much for wharfing of the more usual kind, which, later, it might not be easy to remove if the site should be wanted for work of a more ambitious character. The wharves referred to have put an end to the savage system of landing goods through the surf on the sandy shore—except in the case of about half the coal landed at the port, for which, however, better quays, fit for use by ships, are now being provided. The Author believes that this particular form of construction may be found useful in many places where, as in Madras, the soil is sand, and something is wanted which may have to be removed later when more money is available.

The Total Face-Length of Wharfing.—The length of wharves and piers now in use for the working of lighters for ordinary cargo—not counting the wharfing in the timber-pond and in its approaches, or the parts of the piers that stand in shallow water—is 3,200 feet, equipped with fifty-one hydraulic, nine steam, and twenty hand-cranes, at which about fifty or sixty lighters of 40 to 60 tons capacity may be worked simultaneously. The steel ship-wharf is also available for one steamer, and two more steamers may, if desired, lie one alongside the new north arm and the other alongside the closed old entrance, both of which have been bollarded, and the former fendered also, for this purpose. In addition, a beginning has been made on a line of ship-quays which it is hoped will extend, north to the south end of the east side of the harbour. About 800 lineal feet of this last important development is now in hand and will be described later.

Sheds.—Up to May, 1908, Madras port possessed only about 50,000 square feet of sheds of its own, in addition to another 50,000 feet afforded by the old Custom House (P, Fig. 1), situated at a very inconvenient distance from the only pier for imports then existing and from the sandy beach. It now possesses, in addition, about 250,000 square feet of sheds (D_1 to D_5), consisting of four steel sheds of the general type of three-bay sheds shown at A in Fig. 19, Plate 5. These new sheds have cost Rs.3·75, or 5s. per square foot, complete with foundations, walls, gates, floor, and equipment. Needless to say, the cost per square foot has been an important factor in the design of the sheds, and better and more permanent ones, like the future masonry sheds shown at B in Fig. 17, would have been built if the available money had sufficed. The type adopted consists of a steel roof, carried on rolled steel columns, which rest on masonry foundations going down to 4 feet above low-water datum, the floors being 12 feet above that datum. The steel sheds are self-supporting, the brick walls being only screens or fillings between the columns. The roof-covering is corrugated iron, and all has been designed for a live load of 80 lbs. per square foot. Two important problems had to be dealt with when building these sheds, namely, the design of the floors and the protection of the corrugated roof from corrosion. The floors, resting on the universal sand, at first consisted of two 4-inch layers of lime concrete and a top 4-inch layer of cement concrete. The greatest pains were taken to make the top layer of concrete good. It was made 1:2½:5 of cement, sand, and granite passing through a ¾-inch ring. But even after long setting

the upper surface of this top layer proved a complete failure under heavy barrow-traffic and the dumping of cased cargo, working up into dust and leaving hollows and wheel-ruts after only a few months of use. The problem has been satisfactorily dealt with by adding a 1-inch layer of asphalt on top of the cement concrete. This stands perfectly, and if any part of it gets damaged, it is repaired and restored to traffic in a few hours, instead of having, as in the case of concrete, to be fenced off for weeks in order to set properly. Granite cubes in cement would probably have been better than anything else; but there is no horse traffic inside the shed, so that asphalt is good enough, and moreover granite-cubes would have cost too much. With regard to corrosion of the corrugated roofing, experience shows that in the salt, warm, damp air of Madras corrugated roofs, of No. 18 B.W.G. and galvanized under the best supervision, are corroded through in 4 or 5 years. The roofs of the new sheds were therefore painted on the inside with white-lead paint, and on the outside with a kind of cream of Portland cement laid on like paint, in three layers. In practice it was found best to lay on this cream late in the evening, sending it up fresh to a score or two of native labourers, who lay it quickly on the roof with brushes; and after a cool and perhaps dewy night it is found to be set sufficiently well in the morning. About once a year, during the rains, a new coat is laid on. The plan seems, so far, to act quite satisfactorily. It would be better, were it possible, to paint the whole of each sheet with this wash before sending it up, but it was found that, what with handling and riveting, the wash chipped off if this were done.

Two of the sheds, D_4 and D_5 , are served entirely by barrows from the cranes standing on the wharves that extend along their sea face. The others, D_1 , D_2 and D_3 , are served by hand-pushed metre-gauge lorries running on lines of rails from the cranes on the piers, with turntables all over the sheds. The former method seems better when a wharf is parallel to and not far from a shed, and the latter method when a shed is served by a pier standing out at right angles. The latter method has so far given full satisfaction under the Madras conditions of labour. The first of the new sheds, D_2 , served by pier C_2 , was designed for dutiable imports only and was walled, windowed, gated, officed, and partitioned according to Custom House requirements. The next sheds, D_1 and D_3 , served by piers C_1 and C_3 , were intended for exports and for non-dutiable imports, and were not so elaborately walled and gated as was the first shed. But now all sheds are being walled and gated in such a way that any desired

shed or part of a shed may be allotted at will to any desired purpose, whether for dutiable or non-dutiable imports or for exports, according to the momentary exigencies of traffic. The sheds are capable of being parcelled off by movable partitions into large or small areas where desired, so that the cargo of one vessel may go into one area, without risk of mixing. There is a special walled-in area for small undelivered remainders of cargoes, so that the space allotted to one vessel may be made available for another, even though a few tons of the cargo of the former remain undelivered. Excellent cart-roads have been laid down to serve all the sheds, and railway-wagons can be brought to their gates. Five years ago carts had to plough their way through a sandy waste to get to where their consignments were lying.

Customs and other Arrangements in the Sheds.—At Indian ports, practically all imports from outside India and Burma pay a 5-per-cent. *ad valorem* duty. This renders it necessary that a good deal of appraising should be done by the Custom House officials. So, though the general business of the Customs Department is still carried on in the old Government building (P, Fig. 1) across the main road at the back of the harbour premises, all conveniences asked for by the Government Customs Service have been afforded by the Port Trust, in its new sheds, for the business of appraising, for the opening and closing of packages, and for the preparation of all documents connected therewith. Locked rooms are allotted to the principal liquor-importers, with one side open and railed so that their operations may be visible to the Customs officials. There are also locked rooms for open packages awaiting removal, a locked cellar for liquor-casks, and a strong-room for bullion and valuables. The entire responsibility for policing the Trust's sheds and its premises generally rests with the State, whose bills are paid monthly by the Trust on presentation. By paying in this way for the policing of its premises, and by providing such sheds, walls, gates, etc., as a prudent man would provide for similar goods of his own, the Trust hopes to be held by the Courts to be a sound bailee—which under the Act of the Legislature to which it owes its existence is its status in reference to goods for which it has given a receipt. Sheds and piers are lighted electrically, and, at the demand of steamer-agents, work is carried on under certain rules during night hours when necessary—usually in order to allow a vessel to get away, or to free lighters needed for vessels arriving next morning. The 90,000 square feet of floor of the largest of the sheds, D₂, is kept swept by an electrically-worked vacuum cleaner which gets rid of all dust, though not of straw, chips, or shavings, as was hoped. There is an ample supply of

good drinking-water for the large gangs of labourers working in the sheds, as well as plenty of roofed space where they can have their midday meals.

Railway Lines.—The railway systems converging on Madras Port are the Madras and Southern Mahratta Railway of 5-foot 6-inch gauge, and the South Indian Railway of metre gauge. Each railway has a booking-office in the yard, and goods can be booked direct into or from the Trust's sheds to all stations in India. The wagons of both these systems of railway run freely everywhere over the Port Trust's lines, which are of the mixed gauge. All curves in the yard—except a few special ones of larger radius—have a radius of 400 feet, and there is a standard set of mixed-gauge points and crossings. The yard shunting-engines are of the 5-foot 6-inch gauge, and these haul trains of either gauge freely everywhere about the yard without hitch or difficulty, having specially designed buffers. Care has to be taken in designing alterations or extensions of the yard not to make anything of the nature of a “triangle,” which, of course, has the effect of reversing the side of the engine at which the third rail lies and therefore of complicating the question of the engine's metre draw-bar. Not only because at first, for convenience in the construction of the breakwater, there was such a triangle, but also because it may conceivably be desirable at any time to reverse an engine on a turn-table, the Trust's locomotives have, at each end, two draw-hooks for metre-gauge stock, one on either side of the central standard-gauge draw-hook.

Sand Blown or Sucked into the Harbour.—Until quite recently there was a good deal—as much as 70,000 tons per annum—of silting-up within the harbour, chiefly on its south-east side, due partly to the wind which blew quantities of sand over the top of the south arm from the accreted area, but chiefly to the sucking or pumping effect of swell rolling along the inner side of the south arm, which used to draw sand into the harbour from the accretion through the apertures left between the blocks. The wind trouble has practically ended since the installation of the bulk-oil works and traffic facilities on the accretion, whereby there has ceased to be a bare sand surface for the wind to sweep. The suction trouble has diminished greatly since the cessation of swell inside the harbour; but before this it had been cured very largely by the device of trenching down as low as possible outside the breakwater and filling in with engine-ashes which were soon sucked into the interstices between the blocks, and, adhering there, have so stanchd the leaks that sand has ceased to flow.

THE SHELTER AFFORDED BY MADRAS HARBOUR.

At the present date, 43 years after the commencement of the discussion, it is interesting to note how certain matters that came under notice have changed in relative importance in the estimation of those interested. Thus, in the early days, the question of the value of the harbour as a shelter for shipping during storms bulked large with the protagonists. Lists were given of all the wrecks and losses of men and goods since 1746, and it was stated that, in the 26 years ending in 1868, the vessels wrecked numbered forty-two, of an average tonnage of 480, involving the loss of 196 lives and of property worth £380,000. Again, in 1875 the Secretary of State wrote: "Many human lives are sacrificed in the tempests which annually ravage the Coromandel coast, and it is probable that a large proportion of these might be saved if the vessels which are now surprised in the roadstead could seek the shelter of a harbour." The fact really was that the port was then used by sailing ships of small tonnage for the most part, and it has to be recognized that conditions change greatly when 4,000- to 10,000-ton vessels, in smaller numbers, replace the swarms of little sailing ships of the old days. The problem of the present day is not how to afford shelter to vessels in stormy weather, but how to calm the water in which they are moored so as to enable them to work their cargo easily overside from or into lighters or at quays. Even so late as 1873 Mr. Parkes did not seem to recognize that a wave of 2 feet 7 inches, the height to which he proposed, by means of the harbour, to reduce the outside 15-foot wave, was a very formidable thing indeed from the landing and shipping point of view, especially with small lighters having a capacity between 1 ton and 10 tons. Now that the harbour has been remodelled so that heavy seas are no longer found inside it, the problem of the safety of vessels resolves itself into a question of the pressure of the wind on their sides and the adequacy of their fastenings to withstand such pressure. The Port Trust's bow moorings consist of a buoy carrying a $3\frac{1}{2}$ -inch diameter shackle, attached to a bridle of two $2\frac{1}{2}$ -inch stud chains each shackled to a 3-foot 6-inch diameter mooring-screw sunk in the sand by water-jet to a depth of 14 feet. The stern moorings consist of the same tackle, but worn down until the chain may be in places only 2 inches in diameter. Vessels attach themselves to the bow buoy by means of their own main cable, and to the stern buoy by one or more of their own ropes, sometimes wire, sometimes coir or manila, often both. The breakage, owing to wind, of the cables attached to the Trust's bow mooring-buoys is practically unknown;

but it is comparatively common for a vessel, especially if of one of the minor lines and not well found, to break her stern line and swing round, head to wind. Needless to say, in dangerous weather a clear circle of adequate diameter must be left round every bow buoy, in order to meet the contingency referred to, and this restricts the accommodation available in the harbour during fully one-half of the year.

Ordinarily, all vessels in the harbour are moored head and stern, and this was found to be an important factor in the problem to be dealt with by those who had to decide whether the cost of remodelling was necessary or not. For—and the point had better be made quite clear at this stage—no matter what may be the direction of the wind at Madras, the lines of waves approaching the shore have a general tendency to parallelism with the shore. Much of the delay in arriving at the decision to alter the entrance of Madras harbour is now seen clearly to be ascribable to the fact that some of those consulted, and whose opinion carried weight with the authorities, failed to realize that, close to the shore on the Coromandel coast, the trend of the waves does not conform to the direction of the wind in the same way as it would in the open sea. A ruler laid on the map along the line of the waves may sometimes be about 30° out of parallelism with the general lie of the shore in one direction and sometimes about as far in the other direction. Both of these sorts of waves, and of course also all waves having a direction intermediate between them, used to roll into the harbour impartially through the old entrance. No waves ever run from the north to the south or from the south to the north or anywhere near these directions, even if a strong north or south wind should happen to be blowing. Therefore, so long as the old entrance was open, a vessel moored head and stern in the harbour, if lying north and south, rolled whenever there was any sea to speak of, and found it dangerous and difficult to handle cargo overside. If she lay east and west, she pitched instead of rolling and had perhaps less difficulty with her cargo. When an east or west wind happens to be blowing, a vessel moored north and south may have, say, a 200-ton strain on her bow and stern lines, and the result in a strong wind generally is that her stern lines break and she swings; but if moored east and west she will be all right so far as her fastenings are concerned. The reverse takes place when a north or a south wind is blowing. In this case it is the vessel which is moored head to east that will break her stern lines and swing. Neither kind of wind, north-south or east-west, will affect cargo arrangements appreciably, these being affected by the swell alone, as explained.

The change of entrance in no way improves this matter of swinging due to breakage of stern lines. All it has done is to put an end effectually to the swell that used to interfere badly with the working of cargo overside when a vessel was either moored north and south, or having been moored east and west, broke her stern lines in a north or a south wind and swung north and south. Of course, with the short moorings necessary in so small a harbour, the "snub," or blow, on a chain due to a heavy swell is far worse than if a long chain could be used; and this danger, so far as it goes, has disappeared with the disappearance of swell. Nevertheless, if ever a heavy blow of wind of first-class hurricane force, or anywhere near it, should reach the port, every prudent master of a vessel will put out to sea as the safest place; because, even should he have perfect confidence in his own tackle, he cannot rely on that of his neighbours, and quite a small vessel breaking loose may in half an hour do untold damage to larger vessels locked up in the harbour, and, by sinking them, to the harbour itself. All commanders, therefore, are recommended by the port-authorities to go out to sea as soon as the "great danger" signal is exhibited on the port flagstaff.

* The fact that some of the heaviest seas that used to roll in through the old entrance have been experienced when the force of the wind in the harbour has been far below the maximum is doubtless due to their having been raised by some intense cyclonic or other wind disturbance far away out at sea in the Burma direction—a disturbance that perchance might not even be reported by passing steamers, none of which might have happened to encounter it. It is these seas that have now been shut out for good and all; but as for winds, once the "great danger" signal is up, vessels must only keep a bright look-out and clear away to sea if possible before a worse thing come upon them—just as they had to do before the harbour was remodelled. From winds, however, the small craft within the harbour, from 1,000 tons downwards, or with a draught of 12 feet or less, are perfectly safe inside the boat-basin.

Ship-Quays.—So long as the eastern entrance remained open to the swell which, during all but a very few days in the year, entered Madras harbour, it was impossible to have quays at which vessels might lie in rough weather without risk of hurting themselves. Since the remodelling, however, experience with the steel ship-wharf already described (G, Fig. 1 and Fig. 16), that projects from the south breakwater, has proved clearly that there are no longer any reasons, other than financial reasons, why quays for the accommodation of vessels should not be built. A line of quays

therefore (Q, Fig. 1 and Fig. 19), has been designed, to extend right along the shore from the north to the south breakwater for a length of 3,000 feet, giving room for six of the ordinary vessels visiting the port. A scheme has been prepared, to cost about £400,000, having this line of quays as its principal objective. About £50,000 worth of work under this scheme has already been put in hand, and a beginning has been made on about one-fourth of the length of quay-wall. Fig. 19 shows how vessels will be accommodated at the new quay, when made. But as each ship-length of it for which money can be found is finished, or even partly finished, the sea-bed in front of it will be dredged to an adequate depth. In the design so far prepared, this depth has been fixed at 32 feet. But in view of the probable deepening of the Suez Canal in the near future, it may be thought worth while to design the wells of the middle 1,500 feet of quay—say for three ships—of greater depth and thickness, so that dredging may be carried down to a depth equal to that of the canal.

The quay-wall, as now in progress, consists of a row of monoliths—in India always called "wells"—35 feet by 20 feet on plan for 26 feet depth of water alongside, and 43 feet by 24 feet for 32 feet of water. All will be sunk to a depth of not less than 50 feet below low water. The smaller wells are of the double octagon form designed by the Author for the Kistna Bridge of the Calcutta-Madras railway, in 1890.¹ This form of well, a variant from the double hexagonal well of Mr. J. R. Bell, M. Inst. C.E., has come very largely into use in India, Burma, and the Malay States, and has even been used in China. It sinks very straight. The wells, of which about seventy will be used in the 3,000 feet of quay and of which twenty are now being sunk, are placed end on, as shown in Fig. 1. A space of 1 foot 8 inches is left between each pair of wells, which is stanchied, so that the sand may not flow out from behind, by driving down, by means of a water-jet, steel shutters back and front; and after the sand in the 20-inch space between the shutters has been got out, the space is filled with mass concrete. At low water the junction of adjoining wells will be arched over, and above these arches and the wells the quay will be built up to a height of 12 feet above low-water level, which gives about 8 feet above high water. The wells rest on 8½-ton steel curbs, 4 feet high. Their walls are 5 feet thick all round, of gneiss in 1-to-4 cement mortar. This masonry makes a very heavy well,

¹ Government of India Technical Section Paper No. 71, in the Library of The Institution; also *Engineering*, vol. lxii, p. 7.

which sinks easily through sand. So far no difficulties beyond the ordinary resources of the experienced well-sinker have been met with, down to the depth of 50 feet. Mr. J. R. Bell's 40-cubic-foot grabs are being used for the sinking, with 6-ton steam hoists, and over each well a pair of gallows, precisely as shown in the Papers referred to at the foot of p. 31.

As all the site for the row of wells was in 3 to 12 feet of water at low water, it seemed at first that it might be necessary either to use floating caissons for the lower parts of the wells or—an equally expensive plan—to make reclamation from the shore, sand being brought by train for the purpose from the south sand accretion. Instead of this, however, a line of 900 feet of floating pipes of the usual character—27 inches in diameter and in lengths of 23 feet—was obtained for the suction dredger "Madras." These pipes, which with their pontoons and flexible connections were made locally, have proved very successful. The "Madras" lies the length of her floating pipe outside, and, pumping from the bottom of the harbour sand that must in any case be dredged before the quays can be used, deposits it all along the intended line of quays, thus forming new land on which the well-curbs are erected and the wells are built for sinking. The same pumping process is being used to fill up the ground behind the quays to the projected height of 12 feet.

The Demand for Ship-Quays.—The Author fully recognizes that it is distinctly open to argument whether the trade of Madras does or does not require such expensive works as ship-quays, costing, with their dredging and cranes, about £80 per lineal foot. Madras is not a terminal port where vessels ordinarily rid themselves of their residual cargo and take in fresh. It is rather a port of call, where vessels put out 100 to 2,000 tons and take in a small quantity of cargo. Hence, the chief object of a shipmaster will usually be to get his cargo into lighters and to depart as quickly as possible; and, of the agent ashore, to have lighters ready waiting for a vessel's arrival. These objects have now been fully attained, because of the coming into existence of the new lighter fleet as the direct result of the making of the boat-basin. Moreover, a given number of lighters can now be made to go twice as far as previously, because of the ample provision of cranes and wharves for unloading or loading them. Nevertheless, there has always been a strong demand among the local traders for ship-quay facilities, and there is a good deal of passenger-traffic with Burma and the Malay States, for which such quays must prove a great convenience. From the military-transport point of view also—

Burma being garrisoned chiefly from Madras—such quays are very desirable. Still, however strong the demand, the Port Trust Board would probably not have felt itself justified in entering on the expenditure needed for such a work, at the cost, perhaps, of enhanced dues, had not Government come to their aid with two successive grants amounting to £80,000. Whether more grants for the same purpose will be forthcoming later it is impossible to say at present. But it seems certain that, now that a beginning has been made on a quarter of the full length of the ship-quays, money will, one way or another, be forthcoming to bring this important work to satisfactory completion. As the quays extend farther along the foreshore, the steel and reinforced-concrete wharves which now in the intermediate years fulfil so useful a function must be removed, and the materials may be used elsewhere. Indeed, as explained in the Author's previous Paper, it is one of the most valuable features in the design of the reinforced-concrete wharf that it can be water-jetted up and most of it used elsewhere.

The Boat-Basin.—When the 900-ton hopper suction-dredger "Madras" arrived in 1904, attempts were made, but without avail, to insure it for some reasonable portion of its value, £40,000. It was therefore decided to cut a gap in the south harbour arm, broad enough for the vessel to pass through, and then to let it pump its way right into the south sand accretion until it should be sheltered against heavy weather. This was done, and the experience thus gained made it clear that, with the grabs that had been intended to be used for the purpose, the dredging of the rubble base—a matter of about 80,000 tons—of the old breakwater, at the new north-eastern entrance, could not possibly be done in any reasonable time or at any reasonable cost. A small bucket dredger, the "Manaar," was therefore hired from the Government as an experiment; and here it may be mentioned incidentally that, in the light of the knowledge acquired while the "Manaar" was employed in the small cut referred to above, through the south arm, the estimate for opening the new harbour-entrance was revised, and the 500-ton hopper bucket dredger "Triton" was bought for the purpose from the Government of Ceylon. Early in February, 1906, the "Madras" got its nose inside the cut and began to excavate a basin deep enough to float itself, pumping the sand overside as described elsewhere. The possibilities of such a basin were soon recognized, and the result was that three or four of the largest steamer-agents soon began, on their own account, to build the fleet of 40- to 60-ton lighters that have so revolutionized the conditions of landing and shipping in the port. Later, the basin as at first dug out being found

to be a tight fit for the port's own craft, as well as for the mercantile lighter fleet, it was enlarged in area, and its sides were quayed all round; and it now plays a very important part among the conveniences of the port, accommodating the entire import iron-trade and the import timber-trade, as well as a large share of the general cargo-trade. Indeed, the Author does not hesitate to say that, of all the new works added in the last 7 years for the better equipment of the port of Madras, no work has played a more important part than has the boat-basin. The basin in question, including the slipway contained in it, has cost about £33,000. It has now an area of 11 acres, of which 2 acres is a shallow part in which floated timber—chiefly teak from Burma—is dealt with.

The Bulk Oil Trade.—At the back of Madras Port there is a population of about 30,000,000, say about 6,000,000 families, each of which, if it could afford it, would consume about 5 gallons of mineral oil in a year, or a total of 30,000,000 gallons per annum. About 45,000 tons—say 108,000,000 lbs. or 12,000,000 gallons—pass through the Port yearly on an average, most of it going inland by rail in bulk wagons, but a great deal of it being canned locally, or arriving canned, for inland consumption at places where there are no bulk installations at the railway-stations. The chief sources of supply are Burma, the Dutch East Indies, and the United States. It will be seen that there is still ample scope for a very much larger import trade than exists at present. The firms connected with this important trade have large bulk tanks holding 1,500,000 gallons each and all appliances for dealing with the oil, which is pumped ashore into the tanks direct from the ships, through pipes which are the property of the Port Trust. Some of these installations are situated on the south sand accretion, and, in order to minimize the risk from burst tanks, the ground they stand on is maintained at the original low level of the accretion instead of being raised to the level of neighbouring land needed for Port purposes. The plots (4 to 6 acres each) required by the oil firms installed on the sand accretion are leased to them on favourable terms by the Port Trust.

Cranes.—By means of the port's all-round titan crane (Fig. 9, Plate 5), by Messrs. Stothert and Pitt, a weight of 33 tons can be lifted out of a steamer's hold at a radius of 60 feet, while the crane can lift 25 tons at a radius of 80 feet, running in the load on a "jinny." There is also a second titan to lift 33 tons at 48 feet, but as this has its radius fixed it is not so handy. For getting smaller loads out of lighters the Trust has a 15-ton steam gantry-crane with a radius of 30 feet, a 10-ton steam-crane, a number of

run-about steam-cranes, and about fifty hydraulic cranes, as already mentioned, of 1 to 3 tons capacity.

The Use of Hydraulic Power for Cranes.—Having devoted much thought to the choice between hydraulic and electric power for the cranes to be used in the harbour, the Author decided in favour of the former—though electric power is available locally at a fairly cheap rate for large consumers—chiefly for the following reasons. The use of electric power would have necessitated permanently the employment in the harbour of an electrical engineer; whereas, once all is in fair running order, a good mechanical engineer, who may or may not be an electrician, can keep all going if hydraulic power is used. Moreover, the supply in India of the electrical mechanic class is as yet strictly limited and not very good, whereas ordinary working mechanics, good enough to keep hydraulic cranes going, are quite plentiful. In fact, it seemed to the Author that hydraulic cranes would be more "fool-proof" than electric cranes, and, indeed, since their installation in May, 1908, stoppages due to breakdowns have been quite negligible. The plant for working the fifty hydraulic cranes now in use consists of three Cornish boilers, 20 feet by 5½ feet, with a steam-pressure of 180 lbs. per square inch, and two sets of double-cylinder engines and pumps of 18-inch stroke and cylinders 16 inches and 4½ inches in diameter, capable of pumping 110 gallons per minute against a pressure of 700 lbs. per square inch. It is the intermittent character of the work, now at one pier or wharf and now at another, that permits so many as fifty cranes to be worked by a plant which, if all were worked simultaneously, would have to be larger. The whole of the hydraulic plant is by Messrs. Armstrong, Whitworth & Co.

COST AND RATES.

The work of remodelling the harbour, including the formation of the boat-basin and much special dredging to be done later, has been carried on under the provisions of what is known as the 60-lakh, or £400,000, estimate. The other works, consisting chiefly of sheds, wharves, buildings, cranes, power, internal communications, etc., have been financed in a way different from that in which the 60-lakh estimate has been financed; so it will be convenient, in the following remarks on the subject of cost and rates, to invite attention to the £400,000 works only. The rates for piers, sheds, etc., will be found in earlier paragraphs. Among the items composing the estimate in question there are three special ones, namely, preliminary expenses, special tools and plant, and establish-

ment, which have been divided duly between all the other items of expenditure, in order to arrive at a true statement of the actual cost of these last—the cost, that is to say, as it would present itself to a contractor, or to a Harbour Board, attempting to gain some sort of a useful lesson from the figures about to be offered. The amount of these three special items bears to the rest the somewhat high ratio of 39 per cent. Treating the accounts in this way, the following results are obtained:—

The new arm which shelters the new north-eastern entrance from swell has cost Rs.27,47,000, for a length of 1,530 feet, equal to Rs.1,795, or £120 per lineal foot. If, however, the effective length of this breakwater be taken, namely, 1,470 feet, measuring from the point where it leaves the original breakwater, the rate per lineal foot becomes £125, the difference being due to considering the triangle or gusset connecting the new and the old work as a “contingency” of the effective part of the new work. Again, if from the Rs.27,47,000 the cost (Rs.1,33,000) of the caisson-head be deducted, as well as the cost of the lighthouses and the bollards and fendering intended for the use of ships lying at the arm, and the length of the arm be reduced to 1,428 feet by cutting off the caisson, a rate of about £122 per lineal foot is obtained. This covers everything—rubble base, pell-mell protection, slice-work and capping. In the Author’s opinion about £125 per lineal foot ought, *under similar conditions*, to be a fair rate for similar work. But the cost of the new north arm and of the closing of the old entrance is complicated by the fact that a large quantity of the wave-breaker blocks used in these works were old blocks removed from the site of the new entrance and debited to the works at the cost of redepositing only. Thus in the north arm nearly a million cubic feet of concrete blocks was debited at Rs.6.38 instead of Rs.64.08 per 100 cubic feet.

The 400 feet of new entrance now open for vessels cost in all Rs.7,90,000, including the extra 200 feet opened and closed again, as well as the entire removal of the old work down to 35 to 37 feet below low water, or at the rate of Rs.1,975 (£132) per lineal foot.

The closing of the old entrance has cost Rs.11,82,000, or Rs.2,296 (£153) per foot for the actual 515 feet between the converging pier-heads. This last work, however, is not yet quite completed, part of the capping having yet to be added when the slice-work shall have finished settling.

These three sums—Rs.27,47,000, Rs.7,90,000 and Rs.11,82,000, aggregating Rs.47,19,000—leave a margin, within the £400,000

sanction, of Rs.12,81,000, out of which Rs.5,07,000 have been spent on the boat-basin, leaving Rs.7,74,000 available for additional moorings, and for dredging within the harbour, the greater part of which has yet to be done.

It will be useful now to note the rates for a few of the main items making up the several parts of the work just referred to. When the due percentage for preliminary expenses, plant, and staff is added to the rates shown in the accounts, the following true rates are arrived at. About 215,000 tons of rubble, dropped in the sea and levelled off by divers fit for the slice-work to be set on it, cost, all told, 5s. 2½d. per ton; 12,000 tons of heavy rubble for laying outside the breakwaters cost, in place, 6s. 5½d. per ton. About 166,000 cubic yards of concrete cost on the average £1 4s. 8d. per cubic yard, but it varied in price between £1 7s. 2d. for concrete in bags or deposited in skips below water, to £1 3s. 1d. for wave-breaker blocks laid pell-mell. The greater part of it, about 105,000 cubic yards, consisted of blocks set as slice-work, and this cost, all told, about £1 6s. per cubic yard. Being based on so large a quantity, these are good figures. They are not contract prices, but are actual costs arrived at by the Government auditors as the result of work done by engineers dealing directly with the work themselves without the intervention of big contractors. The proportions of the materials used in the concrete were: 6 stone, 3 sand, and 1 cement. The average cost of the cement used was Rs.38.75, or £2 11s. 8d. per ton, ex store at the works.

When the works now in hand, including some further dredging but not the masonry ship-quays, have been completed, the harbour will be able to accommodate, at berths where they can work their cargo, seventeen steamers of the ordinary type frequenting the port, i.e., 350 to 600 feet long. Each berth will have cost about £95,000, and the harbour, about 200 acres in area, will have cost about £8,000 per acre. Unluckily, statistics are not readily available for the comparison of either of these two figures with corresponding figures for other harbours throughout the world. Nor would there be any value in such a comparison unless the conditions of the other harbours were exactly similar to Madras conditions; and usually Nature has done a good deal more for places which afford themselves the luxury of a harbour than she has done for Madras.

There is, however, a method whereby the cost of Madras harbour may be compared with that of other harbours; that is, to compare the cost of the breakwaters per foot of their length. All told, from first to last, including loss and scrapping, the Madras breakwaters will have cost Rs.1,63,38,000 or £1,089,000. Their length is 9,275

feet, so that their cost per lineal foot will have averaged £117. Colombo's breakwaters cost £170 per lineal foot, or 45 per cent. more. The breakwater at Portland cost £130 per foot; that at Holyhead cost £160; Alderney, £230; Plymouth, £300; Peterhead, £300; and Dover, £370. It is evident, therefore, that Madras has nothing to complain of as regards the expensiveness of the methods adopted for supplying her trade with a harbour in which lighters can now work cargo between ship and shore practically all the year round in every year.

It is, of course, impossible to compare things exactly when their conditions are not alike, but in a broad, general way it may be accepted that Madras has obtained cheap breakwaters - if any works costing £100 to £400 per lineal foot can be called cheap. The £117 per lineal foot includes the entire cost of the original very inadequate breakwater that was wrecked in the cyclone of November, 1881—every bit of which, by the way, is still to the good in strengthening the newer structure—and also the entire cost of bringing it up to its present standard of adequacy, as well as of closing the old 500-foot eastern entrance and opening out the new 400-foot northern entrance. It is common for persons whose minds are unaccustomed to deal with the figures encountered in heavy engineering works to condemn as wasteful and extravagant the work involved in the construction of the Madras breakwaters; whereas they are exceptionally cheap as well as thoroughly effective breakwaters, and the waste of money due to the cyclone of 1881 may be considered negligible when it is compared with the waste involved, or that may any moment be involved, in the construction of similar works of like magnitude, under like conditions, in any part of the world.

The Limitations imposed by hand-to-mouth Financing.—Some explanation seems to be due of the reasons which have led the Madras Port Authorities to embark piecemeal on works of comparatively minor or temporary importance, in view of the fact that it now seems likely that some at least of these works may have to be demolished later, when or if larger works supersede them. The £400,000 remodelling scheme was fortunate in having been financed on an independent basis, sufficient funds for its completion being provided since its inception in the form of annual allotments by Government up to the full amount which in successive years the Harbour Engineer found himself able to spend. One-third of these allotments was a free grant from Government, and the remaining two-thirds was a loan to be repaid by the Trust to Government within 60 years. Thus the works in question, consisting, as explained, of the remodelling and the boat-basin, had the

inestimable advantage of being able to proceed without hindrance. But the financing of the various minor works of internal equipment, in the form of accommodation and conveniences for cargo, was less easy. These had at first to be carried out from the Trust's own savings, and no more work could be counted on for certain in any year than such savings might cover. Later, these savings were supplemented by a short-term loan of about £47,000 from Government, to be paid off before the end of March, 1919. Hampered as it was by these restrictions, and yet determined to do all it possibly could for the merchants of the present generation, the Port Trust found itself driven to construct works which, if ever the great ship-quays scheme is brought to a finish, will be found to have had a life of only a few years—perhaps 10 years, perhaps 20 years, but at all events a life which, though long from the point of view of the mercantile firms now interested, is only a short life as compared with that usually counted on for similar structures in ordinary circumstances. For example, though the life of the old ocean screw-pile pier will probably have been 50 years by the time it is scrapped, that of the other steel piers described in the early part of this Paper will probably not exceed 10 to 15 years. They will, however, in the meantime, have served a very useful purpose; the existing trade of the Port will have paid for them; and the materials composing them will, to a considerable extent, be found useful for works elsewhere.

Finance.—The Trust has spent about £642,000 between the end of March, 1904, and the end of March, 1911, and this has been provided in the following manner:—

	£
Grants by Government	166,000
Loans by Government, on a 4 per cent. basis . . .	322,000
Contributed by the Trust from its own revenues . .	154,000

About £47,000 of the loan, as already mentioned, is repayable before 1919, and the balance by equated instalments of principal and interest payable monthly for a period of 60 years beginning April, 1912. The Trust is already paying off an older loan of about £430,000 in monthly equated payments, which will continue until 1945. The payments in amortization of these last two loans will amount in the future to about £25,000 per annum, a sum which the Trust can well afford out of its surplus of receipts over expenditure on ordinary revenue account, which at present comes to about £35,000 per annum. Thus, once the first or smallest of these three loans has been paid off, there will remain a surplus of about £10,000 a year, which will allow sufficient margin

for further borrowings on the basis of 60 years equated payments of principal and 4 per cent. interest. All this has been effected without having recourse to raising either the scale of harbour-dues on goods landed and shipped, or the dues levied on shipping, that have been in force for the last dozen years.

Dues on Shipping and on Goods. The average annual net registered tonnage of the vessels calling at Madras in the 4 years 1906-10, was 1,610,000 tons, while the average tonnage of goods handled overside was 696,000 tons, or 43·23 per cent. of the net registered tonnage. During the same period the average number of passengers carried in a year was 97,000. If each passenger and each ton of goods dealt with at the port had been charged at the rate of 1·68*d.*, in lieu of the present levy for port-dues and pilotage-fees on a net registered-tonnage basis, the amount collected would have been practically the same as at present. Thus 13*d.*, per ton of goods and per head of passengers actually landed or shipped at the port, is a fair measure of the average incidence on trade not only of the Government dues charged on the shipping under the Indian Ports Act, but also of those charged by the Port Trust Board on the shipping for pilotage services under its own Act.

But besides the dues paid by vessels on their registered tonnage, goods actually handled in the port pay harbour-dues on a schedule fixed by the Port Trust Board from time to time. The incidence of this averages an all-round rate of about 3*s.* per ton of goods handled, sheltered, and delivered by the port-authorities. If, however, goods not so handled are reckoned with the rest, the charge works out at about 2*s.* per ton. In view of these average rates, it cannot be said that Madras is an expensive port. Lightering goods between shore and ship adds another shilling or two to these charges on goods—an argument in favour of ship-quays.

Agency for Working Cargo between Owner and Vessel.—Under the provisions of the Act of the Legislature constituting it, the Port Trust has power to undertake the handling, between ship and owner, of any goods which in the general interests of trade it may see fit so to handle. There are certain classes of goods, e.g., coal and timber, which it has not handled for years, and, needless to say, in fixing its scale of dues it takes into consideration whether it handles or does not handle the cargo for which a rate is being fixed. Several times in the last 5 or 6 years it has deliberately abandoned the handling of certain classes of cargo, always for adequate reasons, such as, that appliances or accommodation had been provided which enabled the agents of steamers to deal direct with consignees or consignors without prejudice to the interests of others, or else because

it had become clear that, for some reason, the work could be done better by the steamer-agents themselves than by the Trust. For most kinds of cargo the intervention of the Trust was necessary so long as there were practically no conveniences or appliances on the foreshore; but now that all these things have arrived, it is felt that, save in exceptional circumstances, it is better for trade in general that a second bailee should not push himself in between a merchant and a first bailee. Therefore, in all that it has been doing in the last few years to render the harbour less of a “sticking-place” than it used to be, the Port Trust has borne this general principle in mind, and has withdrawn gradually from handling one sort of cargo after another, e.g. the coasting trade in grain, consignments intended for Government use, the import iron-trade and so on, in each case reducing its dues by an amount adequate to cover the cost for handling which the steamer must charge to the owner of the goods. The handling of “general cargo”—cases, bales, etc., for the most part, arriving usually in English or German steamers—the Trust still keeps to itself, but only until such time as it may find itself in a position to abandon it. Its first new shed, 90,000 square feet in area, was made with walls and gates fit for valuable dutiable imports. Its next new shed, of an area of 55,000 square feet, was not so well walled, being intended for coasting, bagged cargo and for exports, both non-dutiable. But this latter shed, as well as two more new sheds that have been finished, of 44,000 and 66,000 square feet area, will all be completed soon on the same lines as the first mentioned—that is, fit for any and every sort of general cargo. It will then be possible, without neglect of the interests of consignors and consignees, for the Port Trust to allot a shed or part of a shed to any given steamer, and so gradually to withdraw from the policy of coming between steamers and their customers. The Trust's function then will be to provide appliances as may be found necessary as trade develops, and to keep order in the general interest.

Labour.—There is a fine supply of excellent labour. The labourers, engaged by the Trust from day to day for the handling of cargo, are guaranteed a minimum of 6*d.* per day, though paid according to the tonnage handled. Usually, however, they are found to earn an average of 8*d.* or 10*d.* a day—a sum adequate in the climate, and in view of their simple needs and habits, to furnish them with perhaps the same ideal of domestic comfort as, *mutatis mutandis*, is reached by the Liverpool docker on his 5*s.* per day. Indeed the Madras labourer would not know what to do with them if he were offered his English brother's beefsteak and piano. The beer he would

probably find easier of comprehension; but, instead, he is able to afford slightly fermented palm-sap, drawn from the tree in the early morning, like rather mawkish lemonade, but very warming and sustaining, and adequately, if but slightly, intoxicating. On the whole, the 400 or 500 Madras harbour labourers are decent fellows, strong, brave, and self-respecting. They go out on strike occasionally, like their brothers in the West, but have not been known to stay out longer than a week, and their discontent is usually found to be ascribable to their having been robbed or bullied by some "educated," and therefore astute, Jack-in-office of their own race.

GENERAL SUMMARY.

The Author has attempted to show how, on a sandy coast, totally devoid of all natural advantages, an artificial harbour of an area of about 200 acres had been constructed at a cost of about £986,000; and yet when made, and up to 7 years ago, it was found to be of little use for the purpose in view, which was to render the transit of cargo between ship and shore easy, cheap, and expeditious. He has gone on to show how, in the last 7 or 8 years, by a further expenditure of about £350,000, conditions have been secured which enable cargo to be landed or shipped in all weathers during which vessels may see fit to lie in the harbour—a harbour still as unsheltered as ever from wind-pressure. He has shown how, by a still further expenditure of about £300,000, equipment has been provided in the shape of works on shore, such as piers, sheds, cranes, rails, roads, etc., to enable cargo to be dealt with quickly and conveniently, as well as plant for dredging the harbour in the future. He has attempted to make it clear how, in consequence of the facilities provided, a fine fleet of private-owned modern lighters, as well as launches for towing them, has sprung into existence, with the result that the time lost by a vessel in the harbour has been about halved—a result which obviously has the same effect as the addition of a further area of anchorage. He has shown that all this has been done, partly through the generosity of Government and partly by the aid of the Port Trust's own credit and resources, without its having been found necessary to effect any general rise in dues. Also he has shown that there will apparently remain, over and above all its obligations, an annual surplus capable of being used for the financing of further loans, sufficient to enable the Port Trust to complete 3,000 lineal feet of quays at which vessels may lie in 32 to 36 feet of water at low water. Finally he has given a brief engineering description of the principal parts of the

work done in the last 7 years, bringing to notice mistakes that were made, and drawing such lessons from them as appear to be deducible.

All that seems necessary to add is that since the departure in November, 1905, of Mr. F. J. Wilson, C.I.E., to whom is due the credit for getting the entrance changed, as well as for starting the quarrying, dredging, and block-making arrangements, the Author has had the able assistance of Mr. H. H. G. Mitchell, M. Inst. C.E., Executive Engineer, who has contributed a supplementary Paper¹ giving details and statistics which are best omitted from the general Paper. While quite conscious that the annals of a port doing a business of only about 700,000 tons of goods and 100,000 passengers per annum are unlikely to be of any great interest to the engineering and traffic authorities of larger ports, the Author ventures to hope that there will be found much in his Paper to interest professional and business men interested in minor ports in many parts of the world. The wants of the 30 million inhabitants at the back of Madras Port are increasing as years go on, and as it is the port may be said to have been created ^{and perhaps as few natural} place where a port has been advantages as are to be found brought into existence.

The Paper is accompanied by thirteen drawings and sketches, from which Plates 4 and 5 have been prepared.

¹ *Post*, p. 44.

(Paper No. 4012.)

"The Alteration of the Form of Madras Harbour."

By HUGH HENRY GORDON MITCHELL, M. Inst. C.E.

In the preceding Paper reference is made to the works carried out under the £400,000 estimate. The Author of the present Paper, having been in executive charge of these works from December, 1905, until their completion, presents such further details as appear likely to be of value.

WEATHER.

During construction, immunity from danger to the works and plant was due in a large measure to the accurate and timely storm-warnings supplied by the State Meteorological Department of India. The peculiarity about the storms in the Bay of Bengal is that they are all cyclonic, and practically all generated in the bay itself or in the adjacent Andaman Sea. Once formed and in movement, they invariably march in a westerly or north-westerly direction, occasionally recurring to the north-east.

There are two monsoon periods: the north-east, occurring from December to April, when pressure is high in the north of the bay and low in the neighbourhood of Ceylon, and the south-west, occurring from June to September, when pressure is high in the south of the bay and low in the north. It is chiefly in the transitional periods between the two monsoons that the cyclonic storms that affect Madras are generated.

During the reconstruction of the harbour (1885-95) work was carried out only during the fine weather; in the two danger-periods, 15th April to 15th June and 15th September to 15th December, all outside work was shut down and the cranes were withdrawn from the breakwaters. On the recent alteration-work, however, it was decided to work continuously, as it was anticipated that the advantage of making the alteration effective at an early date, and the

saving in cost due to the shorter period for which the establishment was required, would more than compensate for the additional risk incurred.

In order to reduce to a minimum the risk of damage to the work from storms, a special code of rules was framed, which came into force immediately the storm-warnings were hoisted. The warnings were hoisted by the Port Authority's marine adviser, on information telegraphed from the Government Meteorological Offices at Calcutta and Simla, read in conjunction with local observations. On the hoisting of the warning signal all plant and gear was sent ashore except that actually required for the day's work. As soon as the danger-signal went up, all work ceased, dredgers and floating craft were taken to the boat-basin, the cranes were securely moored in positions previously prepared for them, and the men came off the breakwater, bringing all portable loose gear with them.

During the 5 years the works were in progress the weather conditions were particularly favourable. An average of only two cyclonic storms a year passed near enough to affect the port at all seriously, and on no occasion did the centre of a cyclone pass over the port. Except for these cyclonic storms, the only rough weather experienced was from the usual disturbed conditions at the change of the monsoons.

MATERIALS.

The chief materials used in construction were 490,000 tons of stone and 29,000 tons of cement, with a due proportion of sand.

The major portion—382,000 tons—of the stone was obtained from quarries situated at Pallavaram, 15 miles from Madras. The stone was a granitic gneiss, weighing 166 lbs. per cubic foot, and samples crushed at between 1,100 and 1,600 tons per square foot, the absorption of water being 0.12 per cent. The quarries were worked by a Punjabi contractor using local labour. At sowing and harvest times most of the workmen, who all were farming folk, returned to their villages, and there was consequently a shortage of labour. In order to mitigate the delay thus caused to the work, and also to have an alternative source of supply should there be an outbreak of plague or cholera, a quarry was opened at Sholinghur in another district, 60 miles north-west of Madras, from which 68,000 tons of stone were procured. The stone from this latter quarry was a white granitic gneiss, weighing 164 lbs. per cubic foot, easily dressed, and largely used for building purposes in the district. Most of the quarrying of stone for ordinary use is done by lighting fires of leaves and twigs over the stone, which then flakes off in

pieces 6 to 12 inches thick, with the bed and top nearly parallel; but fuel could not be obtained in sufficient quantities to enable this method to be adopted for the comparatively large quantity required for the harbour, and the stone was blasted in the usual way.

When the work was started the material for concrete was crushed at the quarries. Owing, however, to their distance from repair-shops and the want of expert supervision, the crushers gave continual trouble. They were therefore brought down to the harbour, where the stone from them was discharged direct into the skips which fed the mixers.

The rates paid to the contractor for the various classes of stone loaded into railway-wagons at the quarries were:—

	Per Ton.
Hard boulders or quarried stone in pieces weighing 2 to 5 tons	s. d.
" " " " " " 3 cwt. to 1 ton	2 6
" " " " " " 7 lbs. to 3 cwt.	1 3
Quarried stone for crushing in pieces weighing 7 lbs. to 56 lbs.	0 11
	1 3

The Port Trust laid the railway-lines and provided the locomotive. All other expenses, including maintenance of the lines and the working of the locomotive, were paid by the contractor. The railway-freight from Pallavaram was 11*d.* and from Sholinghur 1*s.* 6*d.* per ton.

On arrival at the harbour all stone was weighed on an automatic weighbridge, on which a train of thirty wagons in motion could be weighed in 12 minutes. This machine was accurate to within 1 per cent. of the gross load. Payment was made on these weights to the stone-quarrying and depositing contractors and to the railways for freight.

All cement used complied with the requirements of the British Standard specification for medium-setting Portland cement. The cement received from England was tested before dispatch and again mechanically on delivery, and in all cases it was found to comply with the specification. It was stored in the barrels in which it was received, but was opened out and bulked for a day or two before being used. In some cases it was kept in store for more than a year before use, and when the barrels were opened the cement was partially air-set, but the lumps could be reduced to powder between the fingers. In such cases the cement was screened before being used, the residue on the sieve being broken up with the back of a shovel and again screened, when the ultimate residue, if any, was rejected. Tests of cement so treated gave satisfactory results.

The cement made locally, from shell-lime and clay, varied considerably in quality, due largely to changes in the management

of the works supplying it, and to their inexperience in the working of rotary-kiln plant. Out of 7,050 tons of this local cement that were tested, 3,760 tons passed the British Standard specification and were used on the works.

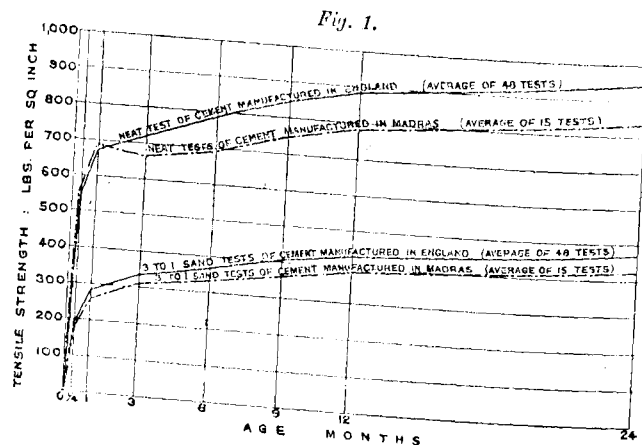
Samples of each 100- to 250-ton lot of local cement offered were tested mechanically by the Author on the works, while the chemical analysis was carried out by the Government analyst. In addition, a sample from each 1,000 tons was sent to England for testing, and the results in all cases corroborated the local tests, with the exception of the setting-time. Cements which in India gave 3 hours as the final set when tested in England set finally in less than 10 minutes. The point was taken up by experts in England, who stated in 1907 that the causes of the alteration in setting-time were not fully understood, but that cement containing a small proportion of sulphuric anhydride—as did the samples in question—often gave anomalous setting-times when made by the rotary process. No definite solution of this phenomenon was arrived at, but the tensile tests of the cement were satisfactory, and no difficulty was experienced in using it on the works.

Early in the work, inability to break a 6-months briquette gave rise to an investigation which may be worth recording. The machine in use failed to break two briquettes at 950 lbs., and they were sent to a neighbouring railway for testing where, 5 days later, they broke at less than 500 lbs. per square inch. At first this was attributed to the briquettes having been strained in the original test, as a briquette of the same age and consignment broke in the railway machine at 1,032 lbs. Subsequent investigations and a series of tests, however, proved that the breaking-stress of briquettes varies considerably with the length of time they have been out of water. In some cases the strength of the briquettes diminished from the time they were taken out of water, in others it remained unchanged or even increased for the first 3 or 4 hours and then began to fall; but almost invariably the strength of 7-day briquettes fell by something between 100 lbs. and 300 lbs. per square inch by the time they had been 12 hours out of water. In a laboratory delays in breaking briquettes after they had been taken out of water would not occur, but on construction work they are not infrequent, and these tests emphasized the necessity of breaking all briquettes within $\frac{1}{2}$ hour of their being taken from the water.

The cement-tests were all carried out in accordance with the British Standard specification, except as regards air-temperature, which normally varied between 80° and 90° F., the water used being generally 5° cooler. Tensile tests were made of all cement

used, and *Fig. 1* gives the average results of the tests of English and of locally-made cement.

The average cost of the cement ex store on the works was £2 11s. 8d. per ton, of which freight, insurance, etc., accounted for 12s. to 18s. per ton, customs duty 2s. 6d. per ton, and harbour- and landing-charges 3s. per ton; whilst a refund of about 1s. 6d. per ton was obtained by the sale of the empty casks.



Sea-sand was used and was tested regularly for fineness, the requirement being that 50 per cent. must be retained on a sieve of 50 meshes per lineal inch, and 80 per cent. on an 80-mesh sieve. The sand used was a good deal coarser than this, 70 to 80 per cent. being retained on the 50-mesh sieve.

BLOCK-MAKING.

The block-yard was served by six $\frac{1}{2}$ -cubic-yard Messent mixers, four of which were in constant work, with an aggregate normal output of 150 cubic yards per day. At times all the mixers were at work, and the output was 200 cubic yards per day. The proportions adopted for the concrete were 198 lbs. of cement by weight, 6 to 6 $\frac{1}{2}$ cubic feet of sand, and 13 $\frac{1}{2}$ cubic feet of stone crushed to pass a 2 $\frac{1}{2}$ -inch ring, unscreened. In addition, about 14 per cent. of displacers were used, weighing 50 to 100 lbs. each. The stone was crushed direct into $\frac{1}{2}$ -cubic-yard tipping wagons, which were hauled by a winding-engine up an incline in sets of three and tipped into the hoppers that fed the mixers from one side; at the

same time similar wagons with the sand and cement were hauled up and tipped into the hoppers from the opposite side.

The beds of the slice-blocks when set in the work were at a slope of 1 to 4 with the horizontal; but the blocks were made on the flat, the cores for the lewis-bars being set in at the required angle. No difficulty was experienced in lifting these blocks after 10 days with the ordinary lewis-bars. They canted to the angle of the bars while being lifted, without bending the bars or doing any damage to themselves. The possibility of thus canting the blocks, while lifting them from the horizontal bed on which they had been made, was largely due to the use of hydraulic goliaths, which gave a very steady lift.

One of these three goliaths was bought second-hand in 1879, when the breakwater was first begun, having been previously used in the construction of the Manora breakwater at Karachi, and it is still doing good work, though nearly 40 years old. The goliaths lift 33 tons on a ram with a 5 $\frac{1}{2}$ -foot travel, working in an inverted hydraulic cylinder 12 inches in diameter, the pressure being supplied by a 1-inch pump with a 12-inch stroke. The small steam-engine that drives the pump also travels the goliath by means of a chain and gipsy-wheel drive; in addition it traverses the jinny.

The slice-blocks were in three sizes, 14 feet, 12 feet, and 10 feet long, and were all 6 feet wide by 5 feet 9 inches high. The wave-breakers measured normally 9 feet by 9 feet by 6 feet thick, but a certain number of blocks were made 5 feet and 4 feet thick, for use in making up the roads for the titan cranes; these were afterwards removed and deposited as wave-breakers. Ordinarily the blocks were stored for 6 months before being set, but in exceptional cases blocks only 3 months old were used.

THE NEW SHELTERING ARM.

This arm was founded at 27 feet 6 inches below low water, on top of a bed of stone deposited on the sea-bed 40 feet below low water. It was composed of block-work in slices, with a batter of 1 in 4. Before the arm proper could be commenced, a junction had to be effected with the existing pier, and an abutment had to be formed from which the slice-work could be commenced. This junction had to be made over the remains of the original breakwater, which it was decided not to disturb because of the labour and expense that would be involved in removal. The 30-ton wave-breaker blocks, however, which had been deposited pell-mell between

the existing and original breakwaters, were picked out and reset in an orderly manner so as to form a solid base, but were not built to any preconceived form, the position of each block and the amount of bonding being decided on the spot as the work progressed.

The top of the remains of the original breakwater was levelled by means of concrete in bags of Navy canvas, on the top of which blocks were set while the bag concrete was still soft. As soon as the remains had been crossed, the bed of the block-work was stepped down as rapidly as possible, until the normal level of the bed of the breakwater was reached. The work of removing and straightening the old wave-breakers, and of crossing the original breakwater and stepping down till the bed of the blocks was $27\frac{1}{2}$ feet below low water, took exactly a year to complete. The work was rendered particularly tedious by the unceasing range of the sea over the remains of the old work; even on the quietest day there was a continuous run-up and suck-back among the blocks.

The abutment for the slice-work was formed of vertical coursed work with "piano" blocks, as shown in Fig. 3, Plate 6, and was built up in a month from the date on which the foundations had been put in. Then in February, 1907, all was ready for proceeding with the breakwater proper.

Whilst the junction was being formed, the rubble base, composed of stone of all sizes up to 3 cwt., was being deposited from 10-ton country boats, and from two 100-ton flush-decked barges. As soon as the abutment was ready, the slice block-work went on rapidly; thirty-eight slices, each 6 feet wide, were set in the first three months, and the yearly advance averaged more than 550 feet. The best month's work was done in February, 1908, when nineteen slices were set, equivalent to an advance of 114 feet.

It was found impossible to deposit the outer pell-mell protection of large stones and wave-breaker blocks rapidly enough to keep pace with the forward advance of the solid breakwater. It was therefore decided to push on with the breakwater as fast as possible, and to advance the protection as opportunity offered. Nor was this altogether a disadvantage to the work, for on the one or two occasions when the outer protection nearly caught up the head of the breakwater proper it was found that the swirl set up round the head by the swell breaking on the stone and on the wave-breakers interfered very seriously with block-setting.

In order, however, to protect the rubble foundation of the slice-work which had crept in advance of the outer protection, 30-ton wave-breaker blocks were set on top of the rubble, both on the outside and on the inside of the advancing slice-work, Figs. 2.

Plate 6. The outside blocks were buried as the rubble protection was brought forward, whilst those on the inside were subsequently picked up for use as pell-mell wave-breakers. 15493

Before the commencement of each cyclone period, i.e., in April and October of each year, the head of the work was secured by bringing up $2\frac{1}{2}$ -inch stud-link chains from a rail set in the foundation-course, as shown in Fig. 2, Plate 6, and securing them to the tenth slice back from the face by means of heavy union-bolts. The blocks in the top course, for three slices back from the face, were also cramped together with rail cramps. Work was then continued throughout the cyclonic seasons whenever weather permitted, in the hope that a cyclone would not wash away more than the slices that were set in advance of the portion of the work thus secured. As a matter of fact, the worst damage that occurred was the moving of some of the blocks in the foremost slice of unsecured blockwork; the others, however, were picked up and re-set as soon as the weather moderated.

The titan crane used to set the work ran on rails of 20-foot gauge. The wheels had central flanges, the rails being twin. The crane had six wheels on either side, the two centre wheels having a rigid wheel-base of 6 feet 6 inches, but each pair of outer wheels being fitted on to a swivelling bogie. Thus, while the total wheel-base was as much as 24 feet 3 inches, the crane was able to travel round curves of 400 feet radius. The crane had the usual travelling, sluicing, lifting and horizontal motions of the "jinny" along the jib, and could deal with loads of 33 tons at 62 feet and 25 tons at 80 feet radius. The crane weighed in working order 320 tons, of which 60 tons was kentledge. It was shipped out from England in sections, and was erected at the root of the north pier by the workshop staff in 61 days, at a cost of £751. The crane was fitted with a grabbing-barrel, releasing-gear for dropping the 30-ton wave-breaker-blocks, and a safety attachment to prevent overload. This last contrivance was not, however, of much use, as it was necessary at times to use the crane for much heavier loads than those for which it had been designed, and the safety attachment was then disconnected. The titan rails were carried on a road composed of wave-breaker blocks set on top of the slice-work, which finished at 11 feet above water, Figs. 2, Plate 6. The crane, therefore, was always travelling at the level of the finished work, 16 feet above low water, thus obviating the necessity of running the crane down from the level of the existing work on to the top of the slice-work, which would have had to be done if no wave-breaker blocks had been available. As soon as a slice was completed, wave-

breaker blocks 4 feet thick were set on it to carry the crane-track, and as settlement proceeded these were changed for 5-foot blocks, and sometimes, where the settlement was most, for 6-foot blocks.

The rubble base was first roughly levelled by grabbing with a $1\frac{1}{4}$ -cubic-yard whole-tine grab worked from the titan crane, the final levelling of the bed with small stone being done by divers. As the edges of the work tended to settle more than the centre, the beds were made with a dish of 1 inch.

In order to obtain the correct level, trussed beams were bolted down longitudinally on either side of the finished work with their ends projecting out over the third bed in advanced work with their block-work. From transverse timbers resting in advance of the toe of the levels were given to the divers, sometimes by means of these longitudinals a sounding-chain, by which to set the top of the rods and sometimes by to the required bed-level. On these a set of three longitudinal rails was used, and after the bed had been levelled a transverse screeding rail was and the foundation-blocks were set. When all rails were removed the beds were prepared 2 feet higher than the allowance for settlement the. The landward face of the breakwater had no required finished level. afford a quay alongside which vessels coming to be formed so as to portion of the work on the rubble base could lie, a not inconsiderable rubble on the inner side of the pier to be consisted in trimming the was available for this work, so it was a uniform level. No crane rigged on a transverse beam mounted on the block-work, which ran on into skips by divers and slung out, either the excess rubble was loaded the edge of the bank. From the same a derrick into slack places or over suspended at the required finished depth, a diver beam a rail was guide to the divers when levelling off. The cost of this work is all included in the unit rate for the stone deposited on the rubble base.

The divers worked in shifts of four, from two 10-ton country boats lashed together and moored in advance of the work, two men levelling off the bed while two set blocks. The divers were all Europeans trained on the works under a foreman diver brought out from England. Unskilled labourers were started as linesmen at £1 per week, and more if they were skilled in any trade; after 6 months they were put in the dress, and after six months more, as divers on probation, were classed as divers. Their pay was gradually increased until the end of the second year, when they were drawing £3 per week for a daily diving-shift of 4 hours, which with overtime came to about £5 per week. About half of the men tried turned out satisfactorily, and of the dozen or so whose services were

retained six turned out good divers. When work was in full swing twelve divers were employed.

There was a persistent tendency for the face of the blockwork to assume a flatter slope than the 1 to 4 slope for which it was designed. At first this was thought to be due to inaccurate setting of the foundation-course, but careful checking showed that it was not, and that, as the foundation-course settled under the weight of the superstructure, it actually crept forward on an average 1 inch in every slice. This creep was probably due to there being more resistance at the back of the course than at the front. In order to counteract it, three or four foundation-courses were set before bringing up the superstructure on the first of them, and the shape of the blocks was altered so as to get a better grip of the base. The creep, however, continued, and finally it was found necessary to correct the slope at every twelfth slice by putting in a taper slice, 6 feet wide at the top and 5 feet at the bottom.

The curved portion of the work, 2,000 feet in radius, was made in short lengths of straight, with a radial slice at each eighth slice; no difficulty was experienced in making or setting these radial slices.

Settlement was fairly regular over the whole block-work, averaging 1 foot 10 inches, the maximum being 2 feet 4 inches. The leading wheels of the titan crane were as a rule kept three slices, or 18 feet, back from the face of the work, so that when block-setting was in full swing the weight commenced to come on each slice 4 to 5 days after it had been set. A fortnight after the setting of a slice the settlement amounted, on the average, to 1 foot. This settlement necessitated the constant packing up of the titan running-road. This was effected in the beginning by fixing the rails to 18-inch by 12-inch timbers, and packing up under the timbers as the work settled. Latterly the timbers were discarded, and the level of the road was maintained by changing the blocks on which the road was carried, a thin bed of 9-to-1 concrete being put under the road-blocks, when necessary, to compensate for small differences in level.

The back and front of each slice had five semi-elliptical grooves left in them, so that, when set in place, elliptical holes 15 inches by 12 inches were formed which, when filled with concrete in bags, served to key the work together. These joggle-holes were filled in about a month after the blocks had been set, by which time the greater part of the settlement had taken place.

The caisson which formed the head of the sheltering arm was made 42 feet square, with rounded corners. It was launched when the sides had been built up to 18 feet, the filling of it with concrete and the building-up of the sides being continued simul-

taneously until the caisson drew 27 feet. The concrete filling was disposed so as to give the greatest support to the sides, which were not sufficiently strong in themselves to stand the external pressure after the caisson was sunk in place. A 4-foot layer of concrete was put in all over the bottom, and on this reinforced-concrete cross walls, so disposed as to form 10-foot by 10-foot pockets, were built up to a height of 22 feet above the bottom; the walls all round were also brought up to 26 feet above the bottom. Above this level 16-inch square jarrah piles were used as struts, placed transversely in the same planes as the cross walls, so as to preserve 10-foot by 10-foot openings above the lower pockets. The bed for the caisson was levelled off in the same manner as the beds for the block-work, by divers, with rails which were removed before the caisson was sunk, the bed being made 10 feet wider all round than the actual size of the caisson.

In order to guide the caisson in its descent, at the end of the slice-work, on to which two extra slices had been set temporarily, there was fixed falsework of 16-inch square jarrah piles. These were strutted securely into the face of the work both above and below water, the face of the piles being set to the required line for the face of the caisson.

The difficulties attendant on the sinking of the caisson have been described in Sir Francis Spring's Paper. As soon as the caisson had been sunk, 33-ton concrete blocks were put into it to overcome its buoyancy. The water was then pumped out by pulsometer pumps, and the kentledge blocks were removed two or three at a time and replaced with mass concrete. Some difficulty was experienced in concreting the caissons on their exposed faces, as the rise and fall of the sea outside caused the $\frac{1}{4}$ -inch plating between the framing to pulsate, and each panel had to be strutted as the concrete was brought up, to prevent the movement of the plates from breaking-up the green concrete. This difficulty would have been avoided had reinforced-concrete caissons been used. Simultaneously and the filling of the caisson the falsework between the slice-work and the caisson was removed, and the space was filled with bonded concrete.

Until the section with the shore was broken by the commencement of the rubble preening out of the new harbour-entrance in May, 1908, which it arrived at was deposited directly from the wagons in barges. The water the harbour; later it had to be deposited from a crane from the breakwater blocks were dropped in by the titan crane shown in Figs. 4, Plate 6. These were self-releasing gear fitted to the crane, and this

arrangement worked fairly well with only a slight jar to the crane as long as blocks of regular shape, to which the claws could be adjusted, were being used. It was found quite impossible, however, to adapt them to the various types of old blocks recovered from the new entrance and used as wave-breakers. To deal with these odd-shaped blocks what was known as a drop-hook was devised (Figs. 5, Plate 6). This hook was attached to one of two $1\frac{1}{2}$ -inch stud-link slings with their ends attached to a ring shackled on to the main lifting-gear of the titan crane; the slings were passed under the block to be dropped, and the grabbling wire of the crane was attached to the link that kept together the hinged halves of the drop-hook. The block was then lifted and swung out over the place into which it was to be dropped, and the link holding the drop-hook together was heaved off by the grabbling wire, causing one sling to fall away; the block then turned comparatively slowly and slid quietly out of the bight of the other sling without any jar on the crane. This method was found to be so successful that the self-releasing gear was dismantled from the crane and several thousand blocks were dropped by means of the drop-hook without mishap.

The slice-work was left to settle for at least two monsoons before the capping was commenced. The wave-breaker blocks of varying thicknesses which composed the titan road were then removed, and the capping concrete was deposited. For part of the work shuttering of the form shown in Figs. 6, Plate 6, was used. The shutters were supported on hook-bolts previously cemented into the blocks, and were held in position by tie-rods. The 1-inch hook-bolts were made with a neck $\frac{3}{4}$ inch in diameter, about 1 inch from the face of the work, so that after the shuttering had been removed the exposed portion of the bolt could be twisted off without damaging the face of the work, the small hole left being subsequently filled with cement mortar.

Over the remainder of the work the capping was faced with 5-ton concrete blocks previously moulded and matured in the blockyard. These gave the most satisfactory finish to the work, and were only slightly more costly than the mass work filled in at the back of shutters.

In both cases the mass concrete was deposited directly into place from a Lees concrete-mixer, the crane attached to which lifted the materials from barges lying alongside the breakwater and put them straight into the mixer, which it also drove. The same crane, when detached from the mixer, set and moved the shutterings, but a heavier crane was necessary when face-blocks were used.

OPENING OF THE NEW ENTRANCE.

The work to be done consisted in removing to a depth of 35 feet below low water (a) the existing breakwater for a length of 600 feet, (b) the remains of the original breakwater, (c) the wave-breaker blocks that had been deposited outside the existing breakwater and on top of the remains of the original breakwater, and (d) the rubble underlying the two breakwaters. This is shown in Figs. 8, Plate 5, of Sir Francis Spring's Paper. Every effort was made to remove the blocks intact, so that they might be available for use as wave-breakers on the new work, and 98 per cent. of the blocks were so removed.

The plant used for the removal of the block-work consisted of a travelling 33-ton titan crane with a fixed radius of 48 feet, and a 300-ton steam-barge. This steam-barge had originally been a bucket dredger, and later had been fitted with a prow and used as a hulk for changing buoys and moorings; but the hull was so badly corroded that it was decided to scrap it. The boiler, engines, main winch, prow, and all available parts were therefore taken out and built into a new hull in Calcutta, the new vessel measuring 125 feet long, 30 feet in beam, and 10 feet 6 inches deep. The main lifting-winch is driven off the main engine through worm gearing on what had been the diagonal shaft of the bucket dredger, which gave a powerful and steady pull on the fall of a four-part $5\frac{1}{4}$ -inch-circumference wire tackle suspended from the prow. Two 3-ton cranes were also fitted on this barge, with which several thousand tons of derelict coal was dredged from the bottom of the harbour and used on the works. This vessel picked up the foundation-blocks of the original and existing breakwater, though, embedded as they were in rubble and mud, it was frequently hove down to a block for an hour or more before, aided by working to and fro in the swell, it drew the block like a cork out of a bottle.

Before commencing the removal of the blocks and rubble, trenches were dredged into which the mud and sand disturbed during the operations might settle. The Trust's suction dredger formed these trenches in the soft material on either side of the proposed entrance to a depth of 40 feet below low water. The titan crane travelling on the existing breakwater then picked up as many of the wave-breakers and blocks of the original breakwater as it could reach; the 300-ton steam-barge just described picked up the outlying and foundation blocks; and, simultaneously, the bucket dredger worked parallel to the harbour side of the breakwater, as close and as deep as it was

considered safe to go without undermining the foundation of the blocks. Before the pier showed any signs of movement, the bucket dredger dredged to 31 feet at low water, 18 feet away from the breakwater, the foundations of which were at 20 feet below water. The movement however was not serious enough to prevent the titan crane from continuing work on the pier.

All the wave-breaker blocks and most of the blocks in the original breakwater had to be slung. For this purpose $1\frac{1}{2}$ -inch stud-link chain, of which there was a quantity in stock, was used. The native "skin" divers became very expert in slinging these blocks in any depth up to 20 feet, and could work when the sea was much too rough for "dress" divers. The removal of the blocks below low water was considerably complicated by the rubble and mud in which they were embedded. A jet of compressed air was used to clean around the blocks so as to clear them for slinging.

Most of the blocks were jammed together or held more or less tightly in the rubble and mud, and great care had to be exercised to prevent undue strain from being thrown on the crane. At the same time, it would have greatly hampered the progress of the work to restrict the weight to the designed load. It was found by experience that the crane could break a $1\frac{1}{2}$ -inch stud-link chain without damaging herself, and a $1\frac{1}{2}$ -inch chain was always used thereafter for lifting jammed blocks. Though many chains were broken, no accidents happened, nor was any damage done to the crane.

By the time all the outside blocks had been removed, the sheltering arm had been completed to 1,250 feet; this afforded a fair measure of protection to the new entrance when, in May, 1908, the removal of the actual structure of the breakwater was commenced.

The capping was blasted off in as large blocks as possible, holes 3 or 4 feet deep being drilled partly by hand and partly with a compressed-air plant at 3-foot intervals around the piece to be blasted. The charges consisted of 2 to 3 lbs. of dynamite, and were fired simultaneously by an electric exploder.

One row of blocks in each course was then blasted out, and the remainder of the slice-blocks were removed whole by the use of lewis-bars and chains. The lewis-holes were cleaned out by a jet of compressed air which proved very efficacious, especially below low water. Ordinary lewis-bars were used when the holes were quite clear, and the special lewis shown in Fig. 7, Plate 6, in cases where it was impossible to clear the bottoms of the lewis-holes.

As soon as 100 feet of block-work had been removed, the bucket dredger, which hitherto had been at work parallel to the breakwater, started on a transverse cut. At first it was sought to loosen up the

rubble bank by means of charges of gelignite, but it was found that this flattened out the slope of the face of the cut, and that better results were obtained without blasting, by working to a more or less vertical face about 8 feet high. Blasting was resorted to only in cases where concrete blocks which had formed part of the original breakwater were found embedded in the stone, laterite, and mud, 30 feet or more below low water.

A great deal of the difficulty of the dredging was due to the buckets and claws slipping over the top of big round boulders, 1 ton or more in weight, which had got bedded deeper than the bottom of the cut. Those that were loosened were rolled over and over into the toe of the cut without the buckets being able to get hold of them. As these large stones accumulated at the bottom of the cut they were periodically slung by divers and picked up by the cranes on the steam-barge.

The concrete apron on the inside of the breakwater was broken up by the dredger. The size of the pieces that were brought up whole, measuring, as they did, as much as 16 feet by 12 feet by 18 inches, testifies to the excellence of the concrete of which the apron was composed originally.

The tendency of the stone to arch in the hoppers rendered it necessary to restrict the bucket dredger to half-loads, in order to avoid delay in discharging. The average quantity dredged per working day was 234 tons. All dredging quantities are in tons of 20 cubic feet measured from sections taken before dredging commenced and after it was completed; these quantities are more than 50 per cent. less than those arrived at by measurement in the hoppers.

As sufficient funds were not available to obtain a new bucket dredger for dredging up the rubble base, a second-hand 500-ton, bucket hopper-dredger, built in 1892, was purchased for £5,250. To fit this for the work of dredging up the rubble, the bulk of which weighed between 1 cwt. and 5 cwt., while some of the stones weighed more than 1 ton, claws were fitted in the place of every fifth bucket, and the single-plate flap-valves, which soon buckled as the stream of stones poured over them, were replaced by double plate-valves with a 3-inch thickness of wood between the $\frac{3}{4}$ -inch plates. These double-plated wooden valves stood the wear and tear very well. A saddle-back was put in under the centre flap-valve to break the fall of the stones, and the tops of the division-plates in the hoppers on either side were protected by 12-inch square timbers fitted over them. The tops of these timbers were rounded to a 6-inch radius, and were further protected by steel plates bent to the same radius and secured by bolts. Wherever the screen-plates of the main

framing were specially exposed to blows from stones they were doubled, with a layer of wood between the plates to act as a cushion. A derrick was also rigged to command the buckets, and most stones over $\frac{1}{2}$ ton in weight were picked out of the buckets and discharged into barges. The friction-wheel on the inside of the main spur-wheel of the dredger had been so long out of use that it was found quite impossible to get it to move; so, pending the arrival of a new wheel from home, work was continued with the rigid wheel. After about 30,000 tons of rubble had been removed first one and then the other of the big dead-eye brackets broke, and had to be patched with steel plates.

Dredging was continued until more than one-half of the material had been removed, when a serious leak developed in the engine-room bulkhead, along the line where the hopper doors butt against the bulkhead on its forward side. It was at once evident that it would not be safe to send the vessel on a sea voyage again in such condition, though temporary repairs enabled work to continue a little longer. It was accordingly decided to lengthen and strengthen the small slipway for the Trust's smaller craft, which was then under construction, so as to make it capable of taking the bucket dredger.

As soon as the slipway, which is described later, had been completed, the dredger was taken up. It was found that the lower end of the engine-room bulkhead plates opposite the edges of the hopper doors was worn completely through. As the plates were pitted in other parts, the whole of the bulkhead was renewed, and in addition about 25 tons of plates and frames were renewed in the hull and main framing of the vessel, the new dead-eye brackets and a new main spur-wheel being installed at the same time. This wearing of the plates opposite the edges of the hoppers has also been very severe in the case of the Trust's suction dredger, and although it has been at work only 8 years, it has been necessary to double those plates practically all the way round—a very intricate and costly job. It is suggested that these plates should be made thicker in the first instance, or that special care might be taken in designing them so as to enable them to be renewed without its being necessary to cut the vessel to pieces to do it. The work was carried out by a Calcutta firm, who sent shipwrights to Madras for the job and took 3 months from the time the vessel was put on the slip. The damage done to the hoppers and hopper-doors by the stones was found to be extraordinarily small, in fact from 3 feet below the water-line downwards there was no damage at all.

As soon as the dredging of the rubble base was completed, the bucket dredger was again taken up for repairs, and another 30 tons

of plates were built in, "departmentally" this time. The Scotch boilers also were taken out and were extensively repaired by the Trust's own workmen. A new wrapper-ring plate was made to connect the back end of the furnace with the combustion-chamber tube-plate, and the side plate of the combustion-chamber was renewed. In order to shape this 5-inch wrapper-plate, cast-iron die-blocks were first made, and in these the plate was pressed to shape, a 33-ton concrete block being used in lieu of a press; the finishing off of the shaping was done by hand. After completion the boiler was tested hydraulically to 300 lbs. per square inch, and is now working at the 150 lbs. pressure for which it was built. This appears to the Author to be worthy of notice as a "roadside repair." On recommencing work the friction joint in the main spur-wheel was again found to have rusted up, but was started by fitting up two "Lucigen" lamps so that, while the wheel was at work, their flame impinged on the outer portion of the friction joint; the dredger was then set to work in a stiff cut, and after 2 days the joint showed signs of breaking and on the third day it was clear.

In connection with repairs to boilers it may be interesting to record a smart method of replacing leaky boiler-rivets which was devised by Mr. T. W. Mair, one of the dredging-masters. Several of the rivets on the underside of the boiler of the suction dredger were giving trouble, due probably to the boilers being hard pressed during the day and lying under banked fires at night, and the plate around them was pitting. It would have been a costly job to remove the boilers, and the space was too cramped to allow of the rivets being replaced. It was also difficult to make a tight and satisfactory job with bolts; but the interposition of a washer of the shape shown in Figs. 8, Plate 6, turned to fit the bolt, and a countersink in the outside of the boiler shell-plate, gave a perfect result. The feather edge on the washer made an absolutely tight metal-to-metal joint between the plate and the bolt when the latter was screwed up tightly.

The finished width of the new entrance had been fixed at 400 feet, but as the original breakwater had been founded at only 19 feet below low water, it was necessary to remove the block-work for 100 feet on either side of the entrance, and then to work forward again. The foundations of the breakwater were stepped down gradually, so that the pier-heads might be founded at the designed 35 feet below low water. On the west side this was easy enough, as it was only necessary to continue the slice-work, stepping down each foundation 18 inches to 2 feet. The back of each foundation-

course was built with a 2-foot chamfer along the bottom edge, so that the rubble at the toe of the last course set might be allowed to stand at a batter of 1 to 1. On the east side the work was rather more complicated, as a reverse abutment had to be prepared before the slice-work could be built. The details of this are shown in Sir Francis Spring's Paper (Fig. 9, Plate 5). In order to prevent any possibility of the overhanging slices of the original breakwater settling under the weight of the crane, they were tied well back to the solid work by chains with 2½-inch unions to tighten them. A framework made of old rails was then set to the required batter against the face of the work, and the sloping block-work was brought up course by course, the space between the new block-work and the old reverse block-work being filled with concrete in bags as each course was set. The stepping-down of the foundation then proceeded in the same manner as on the west head. The original pier was 24 feet wide, and this was widened out by 3-foot offsets until the 36-foot width required for the pier-heads was reached. In order to distribute the weight more evenly over the bed, the foundation-course was made 3 feet wider than the shaft of the head. The pier-heads were built in vertical bonded block-work, and owing to the consolidated nature of the foundations on which they were built their settlement was in no case more than 6 inches. Above the water the heads were faced with stone, and fendering was provided on the exposed corners and faces. The lighthouses to carry the entrance-lights were of reinforced concrete faced with stone, and in them were installed fixed fifth-order red lights.

From June, 1908, to June, 1910, both entrances were more or less open, but there was very little extra disturbance in the harbour. In fact, during the south-west monsoon the swell which came in through the eastern entrance passed out through the northern one instead of, as formerly, rebounding from the north pier and causing disturbed conditions in the centre of the harbour. Frequent current-readings were taken, and the greatest velocity recorded between the two entrances never exceeded 1 knot.

CLOSING THE OLD ENTRANCE.

In order to be ready to commence the closing of the eastern entrance as soon as the new northern entrance should be ready for use, two skewback caissons were sunk on prepared beds at either side of the entrance, so as to serve as abutments from which to start the slice-work. The sinking-operations are described in Sir Francis Spring's Paper. These caissons were strutted with

reinforced-concrete struts, which were subsequently buried in the concrete filling.

Not only had the two abutments been got ready, but also the rubble base had been deposited for the first 100 feet on either side of the entrance, up to 30 feet below low water, before the old entrance was finally closed to vessels in January, 1910. The seabed in the entrance had previously been dredged to a minimum of 35 feet at low water, to allow of the deposition of an adequate thickness of stone to form the base of the breakwater. During January and February 11,000 tons of rubble were deposited on the base, and on the 1st March block-setting commenced at the north end. In June, the old titan crane having arrived after her 2-mile journey from the west head of the new entrance, both cranes were at work. On the sheltering arm the rubble had been allowed to consolidate for at least two rough seasons before the breakwater was built on it; but in the old entrance, in order to reduce to a minimum the period during which both entrances were open, only a few months elapsed between the deposition of the rubble base and the building of the block-work thereon. Care was taken to deposit the rubble higher than the required bed-level, so that the act of trimming it off with the heavy grab might assist the consolidation of the base. There was no abnormal settlement in this part of the work. No hitch occurred; the slice-work was completed by August, and it only remained to fill in the wedge-shaped portion between the two sloping faces.

For the closing wedge foundation-blocks of various thicknesses had already been prepared, so that there might be no delay when once the exact distance between the faces had been measured. The foundation-blocks were put in so that the wedge might be 1 foot slack, and as the work settled, the joints closed until they were quite tight. The extreme difficulty of holding the blocks steady in the swell that was running through the gap rendered the setting of the special blocks for the final closing an arduous and somewhat dangerous operation. The last block was set on the 9th September, 1910, or 6½ months from the commencement, giving an average monthly advance of 77 feet, the best progress being made in July, when 160 feet of breakwater was set in place.

THE SLIPWAY.

In order to repair the craft employed in the work, a slipway of the section shown in Figs. 9 and 9a, Plate 6, was constructed. Originally it was intended only to use it for the smaller craft, and

consequently only hand hauling-gear was fitted. In 1908 it was decided to lengthen the slipway to 475 feet, to take the bucket dredger "Triton," so the cradle was lengthened and strengthened, and a hydraulic 15-ton capstan was installed in the place of the hand-winch. The foundation of the slipway consisted of 2 feet of stone, varying in size from 7 lbs. up to 1 cwt., deposited on the sandy bottom. Small concrete blocks, with a recess 2 feet 2 inches wide and 6 inches deep, were bedded in this foundation, and, in the chases formed by placing the block contiguously, there were laid 30-foot reinforced-concrete bearers, of which the top member was a 75-lb. rail. Wedges were used between the bearers and the inside of the chase in the blocks to bring the former into line, and after the bearers had been truly laid and connected, sand was filled in on either side to keep them in place. The cradle was supported on flanged cast-iron wheels, on the axles of which the journals bore directly, there being no bushes, and this tended to keep the friction high. The slipway was erected from a travelling carriage on which a 5-ton steam-crane travelled transversely, and the crane reached sufficiently far ahead to set the bed and blocks for 15-foot temporary bearers. The carriage was then hauled forward on to these bearers, and another 15-foot length of blocks was got ready. The crane-carriage was then hauled back, the temporary 15-foot bearers were taken out, and the permanent 30-foot ones were put in their place. The crane-carriage was then travelled forward on these ready for another length of work.

As soon as the slipway was ready, the dredger "Triton," which with the cradle weighed 550 tons, was brought up, not without some difficulty. At first a four-part tackle was used in conjunction with the 15-ton capstan, thereby giving, theoretically, a pull of 60 tons, but it was found necessary to supplement the pull by two 5-ton hand-winches. Another block was ordered, and the next time the dredger was brought up a five-part tackle was used, and this time there was no difficulty. From this it may be assumed that, for the given conditions, the power required to haul 550 tons up the 1 in 20 slope was—

Pull required to haul 550 tons up 1 in 20 slope . . .	27·5 tons.
Add friction 4 per cent. of the total weight . . .	22·0 „
	49·5 „

Assuming the efficiency of the five-part tackle to be 70 per cent., the power available was 52·5 tons.

SYSTEM OF ACCOUNTS.

The accounts were compiled and audited under the Indian Public Works Department rules; the forms in use, though slightly modified to suit special requirements, were essentially those in use in that department.

The estimate for the project was divided into several main headings and sub-headings, and the larger of the sub-headings, such as "block-work," were again divided into the several items of work, of which they were composed, called minor sub-headings. Then all expenditure was booked against the undivided sub-headings and the minor sub-headings, lists of which were supplied to each foreman and subordinate in charge. The foreman or subordinate submitted, (a) daily, a report of labour employed by him under the various headings he had in charge, and (b) fortnightly, a nominal roll of artisans and labourers employed under him during the period, which showed the wages, including overtime, earned by and payable to each. The daily reports, on being passed by the officer in charge, were checked arithmetically, and at the end of the fortnight a summary was made of the allocation to the various headings. Similarly, the nominal rolls, on receipt, were checked and passed for payment with the summary of the allocation, just mentioned, entered thereon, the correctness of which was again checked by the officer in charge. The payment made was then entered in the cash-book by sub-headings of the estimate and also in a works-abstract (prepared and maintained monthly for each sub-heading) under the various minor sub-headings required, a reference to the cash-book entry being given in the works-abstract against each payment. The pay of the monthly paid establishment was similarly allocated and entered.

The allocation of materials to various headings was noted on the bills and checked by the officer in charge at the time he passed them for payment, the entries in respect to these payments being made in the cash-book and works-abstract simultaneously. The works-abstracts were thus posted day by day as regards cash payments. Stock and adjustment transactions relating to various headings were then added in an abstract form at the end of the month, and the aggregate totals of each abstract were posted by the various headings in the "register of works." Entry was also made of the quantity of work done during the month, obtained from an independent record maintained by an engineer assistant. These amounts were added in the register to the total amounts to the end of the previous month, and the aggregate amount was then divided by the total quantity of work done.

Thus the average unit cost to date of each

sub-heading or minor heading of the estimate was always available. These progressive rates of all work done, which became available about the latter part of the month succeeding that to which the transaction related, were of the greatest possible assistance in enabling the officer in charge to detect undue expenditure at any particular point. There was also an abstract of the expenditure on the whole project, showing outlay against the main headings of the estimate, for comparison with the sanctioned estimate. When once an entry had been made in the accounts no transfers between the various headings could be made except under a written order of the engineer.

LABOUR.

Except the erecting and platelaying gangs, who came from Surat and the Punjab respectively, all labour was obtained locally, the rates varying from 6d. to 1s. per day of 8 hours. The pay of carpenters, stonemasons, and other craftsmen ranged from 1s. to 2s. per day, according to their capabilities, leading hands getting 25 to 50 per cent. more than these rates.

During the course of the work £1,000 was distributed in the shape of bonus to the foremen, divers, and others; to the foremen who drew no overtime allowances bonus was allotted on the basis of 3 months' pay for each satisfactory year's work. Bonus was allotted for division among the divers at the rate of Rs.25 (£1 13s. 4d.) for each slice of work set after the fifth slice in any one month; similarly to locomotive-drivers, crane-men and others on a smaller scale. The bonus earned was divided among the men concerned in proportion to their pay, and was credited to them in a separate account, where it remained, bearing interest at the rate of 3½ per cent. The payment of the bonus was conditional on the work being satisfactorily completed as regards quality, time, and cost, and save in a few exceptional cases was not disbursed until the completion of the project. This bonus scheme undoubtedly expedited the work, and the men appreciated the advantage of having a lump sum to draw when their services were no longer required.

PLANT AND COST.

From the original works of 1875-81 there remained, fit for use, three 33-ton goliath cranes and four light overhead travellers.

From the works of 1885-95 there were available one 33-ton crane, two locomotives, and the concrete-mixers and stone-crushers.

The new plant purchased included a 33-ton titan crane, a 500-ton bucket hopper dredger (second-hand), two locomotives (one new and one second-hand), one steam-barge with lifting prow, fitted with engines out of an old dredger, one tug, one launch, and four 100-ton barges, besides the necessary railway-lines and rolling stock, diving-gear, and workshop and general plant.

The plant brought forward from the old work was renovated at a cost of £2,000; the expenditure on plant and buildings amounted to £73,758, and their residual value after 6 years' use was estimated to be £18,740; the balance, £55,018, has been charged against the work.

The savings effected, as the work progressed, under the various sub-headings were transferred to the sub-heading "special dredging," and utilized on the work of deepening to 30 feet below low water the shallow western portion of the harbour. In the Appendix is a statement of cost, which includes plant, staff, London charges, and all other incidental expenses, but not interest on the loan during the course of construction.

With the exception of three foremen, the divers, and the officers on the dredgers, the staff employed were natives of India. Mr. Ganapathi Kudva, B.A., B.E. (Madras), the Author's chief assistant, Mr. S. Seshiah, the accountant and office-manager, Mr. G. V. Balakrishna Chetty, the head draughtsman, and Mr. E. C. Richards, the general foreman, deserve special mention for the ability and untiring energy with which they devoted themselves to the work.

The Paper is accompanied by nine drawings, from which Plate 6 has been prepared, and by the following Appendix.

[APPENDIX.

APPENDIX.

TABLE I.—ITEMS OF THE £400,000 HARBOUR ALTERATION.

Item No.	Description.	Total Expenditure.	Quantity.	Unit.	Rate per Unit.		
		£			£	s.	d.
1	Rubble under 1 ton in weight	55,939	215,125	Ton	0	5	2
2	Rubble 2- to 5-ton pieces	4,492	12,104	"	0	7	5
3	5-to-1 Portland cement concrete below water	1,688	1,246	Cub. yd.	1	7	1
4	6-to-1 Portland cement concrete in blockwork in place	142,011	105,728	"	1	6	10
5	8-to-1 Portland cement concrete in mass above water	17,783	15,140	"	1	3	6
6	6-to-1 Portland cement concrete in wave-breaker blocks in place	43,396	37,072	"	1	3	5
7	Old wave-breaker blocks, setting only	4,284	37,349	"	0	2	4
8	Steel in caissons	6,181	273	Ton	22	12	10
9	6-to-1 Portland cement concrete in caissons	7,126	5,905	Cub. yd.	1	4	2
10	Fair-picked stone in parapet coping and steps	769	4,115	Cub. ft.	0	3	9
11	Lighthouses	1,145	3	No	381	13	4
12	Fourth-order light at the head of the sheltering arm	983	1	"	983	0	0
13	Cast-iron bollards	437	15	Each	29	2	8
14	Stone facing to pier-heads, 1½ inch rock face	542	4,742	Sup. ft.	0	2	3
15	Fendered berth	1,092	13,656	"	0	1	7
16	Permanent railway lines	7,146	17,860	Ft. run	0	8	0
17	Picking up wave-breaker blocks at new entrance	3,713	11,035	Cub. yd.	0	6	9
18	Removing capping	1,167	3,989	"	0	5	10
19	Removing blockwork at new entrance	12,054	25,552	"	0	9	5
20	Dredging rubble base at new entrance	20,043	81,728	Ton	0	4	9
21	Special moorings	4,803					
22	Boat-basin	27,389					
	Slipway for vessels 500 tons d.w.	6,300					
24	Special dredging	21,688					
	Residual value of plant and buildings	392,171					
		14,786					
	Deduct amount realized by sale of the old block-yard	406,957					
		6,957					
		£400,000					

The 6:3:1 concrete blocks containing 14 per cent. of displacers formed the largest item of the works. Details of the cost per cubic yard of their manufacture are as follows:—

TABLE II.

Item No.	Description.	Book Rate per Cubic Yard.		
		£	s.	d.
1	Sand	0	0	2
2	Cement	0	7	10
3	Crushed stone	0	3	5
4	Displacers	0	0	8
5	Working mixers	0	0	5
6	„ goliaths.	0	0	4
7	Block-moulds and lewis-boxes	0	0	10
8	Blockmaking	0	1	1
9	Stacking and loading blocks.	0	0	2
10	Repairs to block-yard machinery	0	0	6
11	Upkeep and alterations to block-yard	0	0	5
	Share of preliminary expenses, tools and plant and establishment	0	4	8
	Cost in block-yard	1	0	6
	Rate for setting	0	6	4
	Total cost in place	1	6	10

Discussion.

The PRESIDENT, in moving a vote of thanks to the Authors for The President their valuable Papers, observed that whilst Sir Francis Spring was in India, it was gratifying to have Mr. Mitchell present that evening, as it was not often that the Authors of communications descriptive of work carried out at such a distance could be present. He would like to call attention to Sir Francis Spring's request that one important question connected with Madras harbour, namely, the travel of the beach and the accumulation of sand on the southern side of the harbour, which went on at a rate that almost threatened to overwhelm the harbour at some future time, should not be discussed at present, as Sir Francis was preparing a Paper on it which would enable the whole subject to be thoroughly debated.

Mr. MITCHELL exhibited a number of lantern slides illustrating Mr. Mitchell the progress of the work and the harbour in its completed state.

Sir ARUNDEL T. ARUNDEL was very glad to have the opportunity Sir Arundel Arundel. of expressing the regard and respect he had for Sir Francis Spring, and the high appreciation he had, in common with everybody who knew anything about the work in Madras, of the great achievement that had been effected in connection with the remodelling of Madras harbour. He first met Sir Francis in 1890, when he was in charge of a large district at the mouth of the River Kistna, and Mr. Spring (as he was then) came to build a great bridge over the river at Bezwada. Since then he had had many opportunities of observing Mr. Spring's perseverance, his great abilities, and his power of controlling large bodies of men; while in private life his extraordinary originality always rendered him a very interesting companion. As Chairman of the Madras Harbour Trust, Sir Francis was the guiding and impelling spirit, and the Government found him to be a man of such ability and readiness to help in every direction that he was made a Member of the Legislative Council and a Fellow of the Madras University, where his assistance, particularly in all matters connected with engineering studies and degrees, had been of the utmost value. It had been with the greatest delight that he had seen the announcement of Sir Francis Spring's honour of Knighthood of the Order of the Indian Empire. Sir Francis had transformed the harbour of Madras and the trade of the port, the arrangements for shipping and handling goods had been simplified and cheapened, and indirectly the wealth and con-

Sir Arundel
Arundel.

venience of the inhabitants of Madras, and of those parts of the Madras Presidency which were dependent on Madras, had been very largely increased. If statues were given on merit, the citizens of Madras would erect one of Sir Francis Spring looking out over the harbour. He himself had experienced the operation of embarking at Madras in a Masula boat, having had on one occasion to cross the surf just before the notice was put up forbidding all communication with the shore until the bad weather had subsided. The boat was pushed by the men through the first line of surf, which was nothing extraordinary, and then they jumped in and began rowing. The second line of surf was of considerable magnitude, but there was no very great difficulty in getting through it. Then came the third line, about 1,000 feet from the shore, which broke from a height of 14 or 15 feet; and it would be understood that there was little chance of any boat and its crew surviving if such a wave burst upon it. Rowing up as near as possible to the falling breakers, the men waited until the native steersman, seeing a favourable opportunity, shouted his orders, and the boat was rowed rapidly over the danger-point. He understood it was easier to go out than to come in, because in the former case the rowers had their backs to the danger, which was seen only by the steersman, whereas, in coming to land, the rowers saw the danger, and the steersman had to look round to see where he was, in order to give his orders. With regard to the pier which stood out from the beach, he believed he was right in saying that on one occasion, after the harbour had been made, a ship broke loose during a cyclone and drove right through the pier; which confirmed the necessity of ships going out to sea as soon as bad weather was reported. He had expressed to Sir Francis, 2 or 3 years ago, the hope that it might be found possible to remove this outstanding pier, which divided the beach-line into two and would make it much more difficult for a line of ships to draw up along the quays, as compared with what they could do when the pier had been removed; and he had been delighted to hear that Sir Francis had already reconsidered the scheme and provided for the dismantling of the pier. He hoped Sir Francis would be able to remain in Madras until he had the whole of the quays along the beach-line in process of construction, because he knew not only the Madras Government, but also the Government of India, and it was of the utmost importance, to anyone who had a large scheme in hand, to know the personnel and the routine of the Government of India, as well as of the local Government, in order to be able to feel his way for grants of money for the work. With regard to the deposit of sand, when it was made the Military Department wanted to claim

Sir Arundel
Arundel.

the whole expanse, as they said they might want to fire over it, and it was considered a great concession some years ago when a school playground was made there! Sir Francis Spring had managed to settle the whole of that matter, and had now worked out the boat-basins which were among the most important things in connection with the harbour. With reference to the former state of things, in 1877, when there was a great famine in Southern India, large quantities of rice were deposited on the beach because there were no sheds in which to put it, and the railway facilities were not sufficient to carry it to where it was wanted. A cyclone occurred, the great piles of rice, soaked through and through, became rotten and caused a great stench, and it was expected that there would be a serious outbreak of disease. He would like to ask whether, from an engineering point of view, there was not a certain amount of insecurity with regard to the bay which ran from the left end of the old opening to the end of the protecting north breakwater. Sir Francis Spring had described it as a curve of 2,000 feet radius. Might not there be danger of the cyclonic waves, which ordinarily came from the east, falling against this curved bay and thus causing greater danger to the structure than if the line were straight? So far as he knew, there had been no first-class cyclone in Madras for the last 40 or 50 years. The cyclone of 1881 which destroyed the original breakwater was not what was called a first-class cyclone, though it was a very severe one. The point he would like to see discussed was whether it was not possible that an extraordinary cyclone, such as happened in 1864, 200 miles north of Madras, when a native ship was stranded 17 miles inland, might have a very destructive effect upon the works at Madras.

Lord INCHCAPE remarked that if he had prepared a speech he would have found himself in the unfortunate position of having much of it delivered by Sir Arundel Arundel, who had said exactly what he would have liked to say in regard to Sir Francis Spring. He had known Sir Francis for 25 years and had a high opinion of his engineering qualifications, of his tact, and of his ability to carry with him not only the Government of Madras and the Government of India, but also the mercantile community. He himself landed in Madras first in 1874 and landed in a Masula boat, exactly as had been described, getting ashore drenched to the skin. He remembered the cargo of rice landed on the Madras beach during the famine of 1877, and paid a claim of something like 3 or 4 lakhs of rupees for the damage done by the storm. If a first-class cyclone did not come again, and he sincerely hoped it never would, the sheds which had been built on what used to be the beach of

Lord Incheape. Madras would be able to take such cargoes for many years to come. When in Madras about 6 weeks ago he had the opportunity of seeing the works described in the Papers. He was sorry to say he would not have recognized any of them in the diagrams except the old harbour and the boat-harbour in the south-west corner, which he strongly urged many years ago should be made to protect the boats which were constantly coming to grief when there was a breeze. Strange to say, the very idea Sir Arundel Arundel had expressed, with regard to a statue to Sir Francis Spring, had occurred to him also. He certainly thought that if any man deserved such a memorial it was Sir Francis Spring, who was as much entitled to a statue in Madras as de Lesseps was to one at the Suez Canal. Sir Francis, in fact, had done as much for Madras and the Presidency of Madras as any man who had ever existed.

Mr. Thorowgood.

Mr. F. N. THOROWGOOD remarked that Mr. Parkes, the originator of the old design, followed the successful Manora breakwater at Karachi. The result of building that, and of the dredging of the harbour, was to make Karachi one of the first ports in India. The first titan crane and the first hydraulic crane at Madras came from Karachi. The first works were sanctioned in 1875, Lord Hobart then being the Governor. The first superintending engineer was Mr. James May, from Alexandria, but he died 6 months later, and Mr. Thorowgood succeeded him in 1876. He could well remember the famine of 1877 and the tremendous piles of rice on the beach, mentioned by Sir A. T. Arundel, which were destroyed in the cyclone that attacked Madras in that year. Sir Andrew Clark had told him that he came to Madras with the intention of stopping the works because he did not believe in them, but seeing how much had been done at the time, he was overruled, and the works went on. Although the storm of 1881 was not a first-class cyclone it was a very bad one for sea. The tendency was to measure the force of a cyclone by the force of the wind, but in the cyclone of that date there was not a very high wind: on Beaufort's scale it might be put down as 8 or 9. But the sea was extraordinarily confused. From the tangent-points of the curves of the north and south breakwaters all the blocks were undermined to seaward and fell outwards, and along the two outer straights they were upset by the dynamic force of the waves and fell inwards. On that occasion, unfortunately, he had left the two titan cranes in a more advanced position than he had ever left them during previous cyclone periods. He had been through three cyclones before, and he thought that if placed midway between the outer lengths of straight the cranes

would be more secure than if they were run right back. Being ^{Mr. good} very anxious to finish the work, he perhaps erred a little in not being quite cautious enough, and the two titan cranes fell over. Shortly afterwards he came home for 10 months and appeared several times before the Committee which was composed of Sir John Hawkshaw, Sir John Coode, and Sir Gabriel Stokes, who considered, as he himself considered, that in actual weight and size the original design of the breakwater was not heavy enough for the seas: something was wanted to break the waves, as at Alexandria, and the Committee designed something similar to that shown in Fig. 4, Plate 4, a screen of pell-mell 30-ton blocks. The Manora breakwater and the original Madras breakwater were, contrary to all ideas of masonry, built without any bond. Mr. Parkes had an idea that they settled more fairly and were not so likely to crack. In the section shown in Fig. 3, however, the plan was adopted of breaking joint with joggles or projections both on the beds and on the faces, so that each block was slipped down into a sort of groove at the back. To one who knew every corner of the place it was astonishing to think that the photographs just shown represented Madras. He himself put into the sea there the first concrete block in 1876, at a time when cargo was landed on a beach subjected to a constant surf. Without wishing to touch on the question of sand-movement, he would like to record the state of things when he began to construct the north pier of the old harbour. When he arrived in Madras the Governor impressed upon him the necessity of getting on with the work quickly. The plan arranged by the consulting engineer, Mr. Parkes, was to go through the first line of surf as quickly as possible, depositing the rubble from tip-wagons through the surf; and that was done during the south-west monsoon, when the sand travelled northward up the coast. However fast the rubble mound was tipped, the sand kept pace with it, so that the public could only see the shore advancing out to sea as quickly as the engineer tipped the rubble in. This result created almost a panic, and he himself was greatly disappointed. Mr. Parkes was telegraphed for, and by the time he arrived the monsoon had changed from the south-west to the north-east, and instead of accretion of sand there was erosion. The question was, how to get the south breakwater run out rapidly enough to stop the sand from getting into the harbour at the next south-west monsoon. Unfortunately, in 1876-7 a terrible famine prevailed all over Madras and in part of Bombay, and the railway-companies could not carry stone for the work, all their wagons being required for carrying rice. He obtained permission to carry out the extension of the South

Mr. Thorow-good. Indian Railway, as it was then called, from Egmore to the south pier, to bring stone from a place called Putehamully. By pushing on the south breakwater as quickly as possible, the sand was just stopped from being permanently shut up in the harbour. All the triangular plot of land towards Fort St. George was called in derision "Parkes's land." Now it could be seen how valuable "Parkes's land" had turned out to be. The construction of the sheltering arm was a fine piece of engineering work. Knowing the coast and the climate, he could say it was very difficult to get any work of an unusual character done there, and he could only admire the manner in which the caissons had been towed out and sunk. The opening of the north-east entrance must have been very difficult, although the Papers did not refer to it as being so. When the storm of 1881 overturned the two outer pieces of the original harbour, the breakwaters were finished to within 500 feet of one another and work was proceeding at the pier-ends. There was talk of a north-east entrance, but one of the objections was the great difficulty in taking up the old work, the rubble base, right down to the bottom. The question of a north-east entrance came before the Hawkshaw-Coode-Stokes committee in 1883, but they were not in favour of it and recommended going on with the plan as designed by Mr. Parkes, with the section much strengthened, and with a screen of wave-breaking blocks outside, so as to destroy the wave of translation before it had a chance of knocking the whole thing over. The internal equipment of the harbour was also very interesting. In the old days there was no equipment except the iron pier in the middle of the harbour. For 2 years he was with the Harbour Trust Board, and put up two sheds for storing gunny bags of rice, indigo, jaggeri, etc., instead of having them thrown all over the place, in the blazing sun, covered with tarpaulins. He thought all engineers who had had to work in the tropics would be glad to read what Sir Francis Spring said about painting corrugated iron with two or three coats of thin Portland cement, and taking the precaution to do it late in the evening; because that was a valuable hint. Sir Francis referred to Mr. Parkes's calculation of the 15-foot wave outside being reduced to 2 feet 7 inches inside by the original design of the harbour. That was calculated by an elaborate formula in Stevenson's book on harbours, but he did not know how it was arrived at, or whether it was reliable. Given the width of the entrance through which a certain wave passed, and the distance it had in which to spread out, it was supposed to be possible to calculate what a 15-foot wave would be reduced to at a certain distance from the entrance. But a 2-foot 7-inch

Mr. Thorow-good. wave in a closed harbour on a shallow shore was a very troublesome thing to boats. In November, 1881, before the storm came, the two breakwaters were practically complete and the two pier-heads were being constructed; and he was putting down screws designed by Mr. Parkes and sanctioned by the Government, with a complicated network of chains across the bottom of the proposed harbour, on to which buoys were shackled at intervals. The chains were held down by large screws about 5 feet in diameter and small screws about 3 feet or 2 feet 9 inches. But even under those circumstances, when there was any sea outside there was sufficient swell inside, with the 500-foot entrance, to render it almost impossible to work the capstans of the screwing-apparatus. With regard to the direction of the waves, what Sir Francis Spring said on p. 29 agreed with his own experience. Both at Madras and at Vizagapatam there was not much difference in the strike of the waves in the south-west and north-east monsoons; they were slightly inclined one way in the south-west monsoon and the other way in the north-east monsoon. As a rule they came in nearly parallel to the shore. According to Mr. Mitchell, all the Portland cement bought in England had been stored in barrels. In the original work about 25,000 tons of Portland cement was used, and it was his practice to store it in bins in well-built go-downs of good brickwork and tiles. It had appeared to him sometimes to require a little more aerating, but Mr. Mitchell's work had been done with cement kept in barrels. With the local cement he had a great deal to do in the early days, because the Government was very anxious that it should be used as much as possible. Major-General H. R. Morgan set up some works at the back of Madras and made some very good cement, and he believed about forty blocks were made with it; but he could not use them, as they were unreliable. Sometimes, however, the cement was very good: he used it in carrying out a large intercepting drain to cut off all the drains of Madras from Fort St. George, and he hoped that drain was standing yet. He could not help recording his admiration of the drop-hook by which the 33-ton blocks were released. When he was working on the Tyne, before he went to Madras, the large 36-ton blocks protecting the foot of the north breakwater were laid with claws clutching the blocks on each side, and these claws were very unhandy. In rebuilding the north pier at Madras the blocks were easily dropped from a curious overhanging crane built by Messrs. Ransomes and Rapier specially for the work. The 30-ton blocks could be dropped into the sea from some little height—a performance which was of great interest to the public, and especially to Lord Dufferin when

Mr. Thorow-
good.

he visited the works officially. The system of keeping daily accounts of the time and money spent on each portion of the work appeared to be excellent. Personally he thought the Public Works system of accounts was not suited for such work, because it was necessary to divide everything under different heads and to estimate for the cost under each head; and if the estimate was exceeded at any period the excess was objected to by the examiner. He did not think it was practicable in sea-work to make an estimate for every part of the work so that the accounts could be audited monthly and objected to if too much had been spent in any particular month. The work had been carried out so successfully that it could be now said, as Mr. Parkes had always hoped to say of his original work, that the Madras surf was abolished.

Sir William
Matthews.

Sir WILLIAM MATTHEWS, K.C.M.G., Past-President, considered that The Institution was greatly indebted to the Authors for having brought before it their extremely valuable experience in connection with the carrying out of such important works. The Papers were a record of a prolonged fight with the sea under abnormal difficulties over a period of about 30 years. At first the fight was attended with but little success, but by perseverance, which he thought was an attribute of most engineers, the fight had been won, and a very successful result had been achieved. He had been connected with the works on two occasions, the first being in 1882-3, as chief assistant to the late Sir John Coode. The India Office appointed a Committee consisting of Messrs. Hawkshaw, Coode, and Stokes to consider the severe damage done to the works—particularly to the two arms of the outer works, the original section of which was shown in Fig. 3, Plate 4—by a cyclone in 1882. Madras was well within the cyclone area, and was therefore on occasions exposed to very heavy seas. He was deputed by the Committee to work up, under the instructions of Sir John Hawkshaw, the investigations of the Committee. His friend Mr. Parkes, whom he had met before he was associated with him on this work, explained what his ideas were when he designed the breakwaters. Mr. Parkes had had considerable experience of sea-works, and his view was that when works of that kind had to be carried out on a rubble base it was very important to provide for longitudinal and transverse settlement. Mr. Parkes provided for longitudinal settlement by using the sloping blocks, which allowed of the settlement of the work vertically without disruption; and to allow for unequal transverse settlement he adopted a vertical joint. The work therefore consisted simply of two walls brought together with a straight joint between. In his opinion—and it was the view entertained by the Committee—that straight joint was to a considerable extent the

Sir Will
Matthew

cause of the disaster which occurred at Madras. When the sea struck the work and went over the top, it carried off the uppermost blocks on the inside, leaving the external half, which was then easily demolished; and consequently the whole structure was practically broken up. The principle of construction was illustrated in Fig. 4, Plate 4. At the time the Madras work was in course of construction, the Colombo work was also being carried out, and there was a good deal of rivalry between the two ports. He happened to be connected with the Colombo works also, under Sir John Coode, the Colombo section being practically that shown in Fig. 5, but at that time without the wave-breaker blocks on the seaward fall. The section of the Madras new arm was 36 feet wide, and the Colombo section 34 feet wide, while Mr. Parkes's original section was 24 feet wide. By comparing Figs. 3 and 5 the exact difference between the Madras section and the Colombo section could be seen. The Colombo section had no straight joint. In elevation the works were very much alike, but in cross section the Colombo section was bonded, and down the entire section there were joggle-grooves filled with concrete bags, which locked the whole structure together. There had been no damage to the works at Colombo, while the work at Madras with a vertical joint failed. He felt certain that if the Colombo section had been adopted in the first instance at Madras, the accident would not have occurred. That was one of the lessons to be learnt from Sir Francis Spring's Paper, and it was one which ought to be well considered, especially by young engineers who might have to do with works of the kind in the future. His next connection with the works was in 1902. At that time the works described in the Paper, namely, the closing of the east entrance, the new arm, and the opening of the north entrance, were referred to an India-Office Committee consisting of Sir George Nares, Sir Charles Hartley and himself. Without referring to the sand-movement he could not very well explain all the reasons which led the Committee to recommend the construction of the protecting arm, but he would only touch upon it briefly. It was an important feature in the provision of the sheltering arm. South of the harbour there had been a vast accretion of sand. The Committee had before them cross sections of the shore, which showed exactly what had been going on since the works were started, and which enabled them to calculate with fair exactness the quantity of sand moving northward on the whole during that period; and they found that 550,000 tons per annum travelled northward, which represented the growth of the sand south of the south pier. It was evident, with an average of 550,000 tons per annum

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travelling from south to north, that on the closing of the east entrance the sand would travel along the back of the work, in front of the closed east entrance, and at the back of the east arm. It had occurred to some slight extent and had partially shallowed the east entrance before it was closed. The time would come when that sand would travel along, and the main difficulty the Committee had in considering the subject was how to deal with the sand. It was thought that the provision of the arm would cause the sand to gather in the form of a spit under the lee of the new work, where it could be dealt with by a dredger from time to time; and he felt sure that a dredger in that position, working in shelter, would remove the sand and keep the entrance clear. No merit attached to the Committee for the suggestion to close the east entrance, provide the arm, and open the north entrance. That plan came before the Committee for consideration, and they practically recommended the carrying out of the work, with but little modification. But the question of dealing with the sand was a new feature, and the Committee went into it very thoroughly. Sir Francis Spring had referred to the relative cost of the works at Madras per lineal foot as compared with works like those at Dover and Peterhead, but it was almost impossible to make any sort of fair or useful comparison between works so absolutely dissimilar. For instance, the Peterhead work was 65 feet high, while the Madras work was 47 feet high; the Peterhead work was 58 feet wide, and the Madras work 36 feet wide; the Peterhead work was founded in 43 feet of water, and the Madras work in 28 feet; and the Peterhead work was exposed to exceptionally heavy seas—probably no breakwater in the world was exposed to heavier. Again, the Admiralty pier at Dover, from the bottom of the foundation to the top of the parapet, was more than 90 feet in height, and the block-work was 47 feet in width. It was impracticable to form any proper or serviceable comparison between works so far distant from each other and so absolutely unlike in character.

10n. Mr. J. MURRAY DOBSON remarked that as the south sand accretion was one of the principal debatable subjects in connection with Madras harbour, the Paper promised by Sir Francis Spring on that subject would be thankfully received by The Institution; and while the question of sand-movement and sand-accretion—especially at Madras—was of great moment, under the circumstances he would refrain from making any comment upon it that evening. He had already made some observations¹ upon the condition of Madras

¹ Minutes of Proceedings Inst. C.E., vol. clvi, p. 247.

harbour, as the result of his firm having been called upon to report Mr. Dobson. upon it in 1901. With regard to the closing of the east entrance and the opening of the north entrance, he thought the Nares-Hartley-Matthews Committee were to be congratulated upon the improved condition of the harbour since the completion of the works; but although the result had been successful so far, with all due deference to the Committee he considered, as he always had considered, that the object might have been attained in some other way at less cost and with even greater beneficial results. Taking into consideration all that was said in the Papers as to the improved conditions in the harbour effected by the closing of the east entrance and the opening of an entrance in the north arm under the shelter of the projecting breakwater, he did not consider that the problem had been met in the right manner. The present harbour should have been dealt with as an outer harbour, easy of access and egress, and protected quays for the vessels to lie alongside should have been provided in a ship dock. Instead of that, the plan had been to convert the present harbour into a dock, and to make what was to some extent a new outer harbour, the result being that the outer harbour was only partly enclosed, while the dock was of inconvenient size and shape and without, so far, anything like sufficient quay accommodation. The insufficiency of the present harbour converted into a dock was shown by Sir Francis Spring's remarks on p. 30. Those remarks should be taken into consideration, together with what was said as to the failure of the attempt to insure the 900-ton dredger "Madras," and as to the results of the construction and enlargement of the boat-basin. When his firm made their report to the Madras Railway Company, they found there were two opposed camps, one in favour of the east entrance being closed and quay accommodation provided in the harbour, and the other in favour of practically leaving the harbour alone and making a dock in the south sand-accretion. The latter was the view of the Madras Government, and after very careful consideration his firm was convinced it was the right view: but the other side prevailed. What was the result? The money spent would have sufficed to build a dock on reclaimed land now said to have an area of nearly 260 acres, affording a site which could be laid out so that vessels could be moored alongside quays in perfect safety during all weathers, and at the same time permitting the extension of the dock almost indefinitely as the trade increased. The money would have provided a dock 2,000 feet long and 500 feet wide, with a depth of 31 feet at low water, capable of accommodating ten to twelve large ships moored alongside the quays. That money, however, had

Mr. Dobson. been spent in changing the entrance and building the protecting arm. His firm's estimate of the cost of the dock was £316,000, while the Paper showed that the closing of the east entrance, the opening of the north entrance, and the construction of the new arm, had cost £314,000. To-day, after that expenditure had been made, the port of Madras was still without adequate quay accommodation, the harbour was still at times not a place of safety, and vessels were warned by the authorities to leave in times of danger. It was said that the boat-basin was capable of taking in vessels of 1,000 tons drawing 12 feet and that they were perfectly safe inside the basin. Did not that prove that if the dock to which he had referred had been built all the large steamers would have been able to lie there in perfect safety, instead of being warned to leave on account of danger as in the present case? In the event of a steamer being warned to leave, it was doubtful whether the new conditions had improved matters. With the old east entrance steamers leaving the harbour faced the sea with the waves rolling inwards, a fact to which the Paper drew attention, but which was well known to him in 1901. Consequently, if a wind from seaward, after blowing strongly for a time, had been found to be increasing in force, any vessel riding on her bow moorings within the harbour would have been able to steam almost straight ahead to get out; and he would wait with interest to hear what happened to a vessel attempting to leave under such conditions through the new entrance.

Sir William Matthews.

Sir WILLIAM MATTHEWS remarked that Mr. Dobson had not referred to the blocking of the entrance by sand, which would have gone on if the arrangements his firm suggested had been carried out.

Mr. Dobson. Mr. DOBSON, alluding to the remark in the Paper respecting the maintenance of the depth at the old entrance, regretted that he was precluded from entering into an argument upon that question on this occasion. There was one point in Mr. Mitchell's Paper, with regard to the cement, to which he would like to refer. The difference in the setting-time between the tests made in England and those made in India was certainly most perplexing, since the conditions would lead one to expect opposite results. In India the cement was newer and its temperature higher; yet it took 3 hours to set there, against 10 minutes in England. The explanation given by the experts appeared to agree with the remark made by Mr. H. K. G. Bamber in the discussion on his Paper on Portland cement¹—that the effect of gypsum added to retard the setting of cement was liable to wear off in time, so that it became again quick-setting. He would like, however, to know what was meant

¹ Minutes of Proceedings Inst. C.E., vol. clxxiii, p. 185.

by "a small proportion" of sulphuric anhydride. The question of Mr. Dobson using Madras cement was referred to his firm some years ago, and they then prepared a specification which the cement failed to pass, although that specification was worked to by English manufacturers with complete satisfaction. They now specified a limit of 2 per cent. for sulphuric anhydride, and the analysis usually showed 1.2 to 1.5 per cent. The British Standard specification placed the limit at 2.75 per cent. in the form of 2 per cent. of calcium sulphide, and he could not understand the Madras cement showing such anomalies if it complied with that specification by analysis. The changes in the setting-time and the fall in the strength of the 7-day briquettes, varying between 100 lbs. and 300 lbs. per square inch by the time they had been 12 hours out of the water, would have made him dubious about using the cement.

Mr. C. S. MEIK observed that, after the eulogistic remarks made Mr. Meik. by Mr. Thorowgood, the ordinary member approached any criticism of the subject with some trepidation; but his criticisms would be directed more to the original design, with which, he took it, the Authors had had very little to do. For instance, the result of blocking up the old entrance and opening the new one had been, it was stated, to give smooth water inside, and, according to the Paper, the works were a complete success; but the Author went on to say that under certain circumstances vessels had to clear out of the harbour. That was, to say the least, an alarming statement. It might be due to his ignorance of the locality, but he ventured to think that if engineers designed a harbour at home out of which vessels had to clear in a hurricane, their employers would hardly feel much satisfaction with their work. No doubt the closing of the old entrance had resulted in a greatly improved state of things in the harbour by giving much smoother water, but it should be recollected that the harbour was originally designed with the object of affording shelter to vessels, and before it could do that vessels must be able to gain access to it. As the entrance was now, he thought sailing vessels would have very great difficulty in getting in, even if assisted by a tug. That might have been the reason why Sir John Hawkshaw's Committee objected to the new entrance, because in those days sailing vessels were predominant. Since then circumstances had altered; steam vessels were now almost universal, and they would have very little difficulty in getting into the harbour by the new entrance. Probably in 20 years' time sailing vessels would be unknown. Sir Francis Spring did not say what became of sailing vessels in a hurricane. They could not clear out, and apparently they had to trust to their moorings or go ashore. It

Mr. Meik. would seem to the average engineer that, given smooth water, it ought to be possible to make moorings secure enough to hold vessels in the strongest gales. That could be done in this country, and he thought it could also be done in Madras. It was only a question of sufficient strength in the moorings for vessels to ride out any gale, provided the water was smooth; the cause of vessels breaking from their moorings was the undue stress on the moorings due to the swell of the sea. He felt bound to raise a point of criticism in connection with the comparisons drawn by Sir Francis Spring in the matter of the cost of breakwaters, which had been referred to by Sir William Matthews. To emphasize what Sir William had said, he might read a few additional dimensions he had jotted down, which would show how difficult a comparison really was. All the dimensions were below high water, because the rise of tide varied so much in different places, and were the maximum depths at the various places. In Madras the depth below high water was 47 feet, in Plymouth 46 feet, Portland 60 feet, Dover 62 feet, Peterhead 66 feet, Holyhead 72 feet, and Alderney 150 feet. How could a fair comparison be made between those breakwaters per foot of length? There was one point in connection with the jetty to which he would like to draw attention. The jetty was made of solid steel piles, and he thought that was a mistake; better results could be obtained with hollow steel piles. The solid pile was 6 inches in diameter, while a hollow pile containing the same quantity of material would be 10 inches in diameter by 1 inch thick and would form a column twice as strong as the solid pile. A hollow steel column 40 feet long, 10 inches in diameter and 1 inch thick would be as strong as a 6-inch solid pile only 20 feet long. Bracing connections below water were a nuisance and objectionable, especially in warm water, as at Madras. He had designed piers of steel tubes and had always made a point of keeping the bracing at least 10 feet above water; and the result had justified the experiment. There was no rusting and no bracing below water to catch the sea, and the pier was much stronger and more durable in consequence. Hollow piles were easily joined by means of internal mandrels, so that there were no joints or cut surfaces exposed to the corrosion of the water.

Mr. Tripp. Mr. W. B. TRIPP said it might be of interest if he called attention to the original attempt to afford a landing-place on the surf-beaten coast of Madras. The old iron pier shown in Fig. 1, Plate 4, constructed many years ago, was formed of four lines of solid wrought-iron piles, the outer being 8 inches in diameter and the inner 6 inches in diameter, and was built by the original licensees of the Mitchell screw-piles, which were at that time a close patent. The invention

afforded facilities for building structures on sandy coasts and was Mr. Tripp. employed in making the Maplin and other lighthouses on the Thames. A great deal of the work had to be done by hand-forging, and it was considered at the time a very large job. The screws were 3 feet in diameter, made of cast iron, and fixed on to the ends of the piles; and there were lines of rails on the pier, which afforded the only landing possible at that time from ocean steamers on the coast.

Mr. MITCHELL, in reply, stated that some of the cement was Mr. Mitchell. turned out and bulked before being used, but no difference was found, in the results of the expansion-tests, between cement which had been bulked and that which had been kept in barrels; and as it was more convenient to keep it in barrels, that method of storing was adopted. With regard to cement made in Madras, none of the cement from the old vertical kilns would pass the British Standard specification, but when a rotary-kiln plant was installed, with an expert from England to work it, a fair proportion of good cement was obtained which passed the British Standard. No cement was taken unless it did pass that specification. As an additional safeguard all the cement made locally was thoroughly aerated in the old-fashioned way, although possibly that was an unnecessary precaution. With reference to the criticism of the harbour on account of ships having to clear out in bad weather, it was not pretended that the harbour was a harbour of refuge; but it was a harbour where, except during the actual passage of a cyclone, cargo could be worked in smooth water all the year round. There had not been a cyclone of any serious force during the 6 years he had been in Madras, but no doubt when such a cyclone did come the steamers would be better out at sea; it was probably safer there for them and certainly safer for the harbour, because, under such tremendous wind-force as was developed by a cyclone, a steamer might, in spite of all precautions, break adrift and do incalculable damage. Only once during the past 5 years had vessels been ordered to sea, and then the cyclone did not come, but re-curved to the north. No big sailing ship had been into the harbour since he had been there. A few native craft, mostly under 100 tons, came in during the year, and they could go quite conveniently into the boat-basin.

Sir FRANCIS SPRING, in reply, remarked that Sir A. T. Arundel's Sir Francis doubts as to the comparative security of the bay of 2,000 feet radius, Spring. between the old entrance and the north end of the new sheltering arm, might perhaps be set at rest by the explanation that the comparatively heavy wave-action here was taken into account expressly by Sir Alexander Rendel and Mr. F. J. Wilson in the

Sir Francis Spring. final design of the works, before Sir Francis came on the scene, and provision was made for a considerably larger quantity of random wave-breaker blocks in the hollow of the curve than elsewhere. Moreover, just here great additional strength was afforded by the junction-gusset between the new and the old work. Mr. Meik's point, that the harbour could not be considered to be a success because vessels might not lie in it with entire confidence in a hurricane or cyclone, had been dealt with by Mr. Mitchell. But he wished to add that on a stretch of coast so flat that, as related by Sir A. T. Arundel, a ship was carried 17 miles inland by a cyclone, an expenditure of 10 millions would be but little more effective than an expenditure of 1½ million in creating a haven such as Mr. Meik had in mind. Therefore, although something of the sort might have been thought of in the days of small sailing ships, no such intention had ever entered the minds of the modern makers of Madras harbour, and they were more than content to have created an enclosed place in which vessels could work cargo to or from the shore on perhaps 365 days in 9 years out of 10. Moreover, it was perhaps not made clear enough in his Paper that no master of a vessel was obliged to go out against his will; but, ordinarily, any prudent master of a well-found 4,000- to 10,000-ton vessel—and there were practically no others—would go out of his own accord for a few hours rather than trust to the chances of his own or his neighbour's lines, between ship and buoy, holding in a very heavy blow of wind—a rare event. With regard to the question of the comparative cost of the breakwaters, raised by Sir William Matthews and Mr. Meik, the point which he had tried to make was that Madras had not been extravagant in deciding to furnish herself with an artificial harbour by means of breakwaters costing £117 per lineal foot, in view of the fact that many another port in the world, with fewer than 500,000 people in her streets and fewer than 30 millions behind her, had thought it worth while to pay anything from £200 to £400 per lineal foot for the breakwaters forming her harbour. There was no intention of claiming comparative cheapness for the work itself per unit of bulk, especially in a Paper intended for professional men who might be presumed to be as familiar with the dimensions cited by the commentators as he was himself. The fact was that, among those who had control of the Indian public purse, it had grown into a sort of axiom that there had been serious waste and extravagance in connection with the old Madras breakwaters; and a little enlightenment on this matter seemed likely to lead to a more liberal financial attitude in the future. When Mr. Thorowgood and Mr. Dobson spoke of "Madras cement" they were not

Sir Francis Spring. talking of the same substance as that of which Mr. Mitchell had used 3,760 tons. The former was a very crude product indeed; but the cement made in Madras in the last 6 or 7 years had been the product of plant quite as up-to-date as any in the Medway valley. It did not all come up to the British Standard specification, but nevertheless the makers obtained a good price for every ton they made of it, and the harbour-works used all that they could find complying with the now well-understood specification. The docks in the sand-accretion which Mr. Dobson would have liked to see constructed would soon have proved a failure, not only because of the rapid sanding-up of the old harbour-mouth, but also because so long as that entrance remained open, unless very heavy dock-gates had been provided, there would have been—as all concerned now knew from experience in the boat-basin—such a "range" within the docks, that vessels lying therein would have been in some danger, hanging on to short springs from bollards, whenever a heavy swell rolled into the main harbour. Now that the entrance had been changed, swell no longer rolled in, and of course it was an open question whether quays in the harbour were or were not preferable to docks. At all events, it had not been, as Mr. Dobson seemed to think, a question of choice between docks and the recent remodelling. It must be remembered, however, that when lying in dock the high sides of vessels would be liable to catch as much wind as when lying at moorings or at quays in the harbour, for there was no chance of sheltering them. Small craft of less than 1,000 tons were not affected thereby to any unmanageable extent. He could confirm Mr. Thorowgood's remark that there was but little known co-ordination between local wind-force and height of swell when dangerous waves affected Madras. For it happened just as often as not that the heaviest and most dangerous waves came rolling in when there was no local wind to speak of—doubtless the result, as explained in the Paper, of a heavy disturbance hundreds of miles away, towards the Andamans. With regard to Mr. Thorowgood's appreciative comment on the work of opening up the new entrance, his experience was that all such difficulties were questions of suitable plant, of steady men, of an equable temperament, and of being content to "slog along" monotonously, like the proverbial raindrop on the rock. With the help of all these, everything got finished sooner or later. As st and, in the Paper, the opening of the new entrance was a 2-nd day for from start to finish. Moorings, though provided with st as being always nowadays water-jetted in Madras harbour, to a st that ought to be into the sand, and regardless of weather, instead of

Sir Francis
Spring.

down with capstans through a rigid shaft, as remembered by Mr. Thorowgood. Mr. Meik seemed to be much concerned about sailing vessels. Sir Francis could not go so far as to say that there were no sailing ships, but he could say that in the first of his 8½ years at the harbour he had one 1,500-ton sailing vessel—besides annually, since then, ten or a dozen of what on the south coast of Ireland would be called “hookers.” The Indian Public Works accounts system and its estimates and appropriations had no such terrors for him as it seemed to have for Mr. Thorowgood. All that was necessary, to get rid of annoyance at the hands of auditors from time to time, was to make out new estimates and to get them duly sanctioned—a perfectly simple and successively easier operation. He had had six successive estimates during the progress of the £400,000 job, each naturally closer to actual figures than its predecessor; and in consequence he had experienced no annoyance, but rather had derived great assistance from those whose somewhat dry duty it had been to audit his accounts. What the engineer wanted was to get at the true rates at which the main items of his work had been done—not contract rates, which might mean anything. For obtaining these rates, as well as for the co-ordination of expenditure with appropriations, there was no more efficient and, if it were reasonably worked, no simpler plan than the Indian Public Works accounts system.

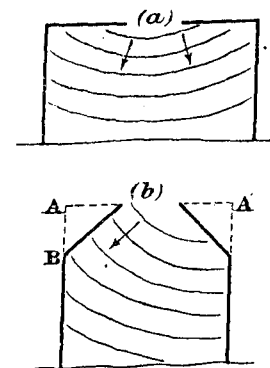
Correspondence.

Mr. Bell. Mr. WM. REID BELL observed that, putting aside the question of sand-travel, the outstanding points in connection with Madras harbour seemed to be the disturbance within the original harbour due to the swell, the light section of the breakwaters, and the narrowness of the entrance. With regard to the first point, the form of the harbour with the eastern entrance could not be improved upon, if it were desired to preserve the height of the waves. The first design for Madras contemplated a square form (Figs. 1, a). This would have allowed of a certain reduction in the wave-height until the waves met the parallel walls, when they and their reflections would have maintained their height until they broke on the shore. Would have maintained their height until they broke on the corners AA with splayed outer arms (Figs. 1, b) the wave-reducing direction would be cut off, and if the waves did not enter in a direction normal to the entrance, their full strength would be

directed to the corner B by the splayed arms. With such a Mr. Bell. harbour it was not surprising that the water-area was never calm. As to the light section of the original work, when the Madras walls were designed engineers still clung to shallow foundations on rubble, and the importance of protecting the superstructure from overwhelming seas was not fully grasped. The rubble mound was always a source of weakness, of slow settlement, and of uncertainty; and where it was employed the design of the superstructure could not easily be made to comply with the requirements of stability and speedy construction. Provided, however, the foundations were secured and the design ensured the transmission of the weight of the superstructure throughout the height under all circumstances of settlement, there was no doubt that the structure should be carried high enough above water to prevent it from being swept or overwhelmed by the seas. It must always be remembered that 2 tons of concrete above the water were equal in stability to 3 tons below water. The entrance at Madras had been a very difficult problem, the solution of which had not been facilitated by reference to so many commissions, some of the members of which had not had the intimate local knowledge possessed by the men on the spot. It was a mistake to suppose that in such cases men

brought from a distance, however experienced they might be, were necessarily in the best position to decide such questions. Lookers-on saw most of the game, and experience from other quarters—particularly when gained in branches of engineering collateral with that of the matter in hand—was of the highest value in furnishing advice, in setting forth fresh aspects of a problem, and in proposing new modes of attack. But, provided the engineers on the spot were competent men and real engineers, in nine cases out of ten the consultants should be advisers and not judges. There were many examples of the neglect of this point, both at home and abroad, and, above all, of the fatal error of the eminent engineer “playing for safety.” He felt he could not recommend a course as being absolutely the best, because he did not know all that ought to be

Figs. 1.



Mr. Bell known; but having to give his opinion as an eminent engineer within a limited time he did his best under the circumstances, and recommended the course that appeared best to make allowance for the absence of accurate local knowledge. To engineers unacquainted with India the contemplation of a coast-line of 1,000 miles, with a teeming population, and furnished with (one could not say "served by") but one harbour, having an entrance (such as the old east entrance at Madras) only 500 feet wide, and dealing with a volume of trade of less than three-quarters of a million tons per annum, gave food for much thought. How self-contained must such a country be! There was no evidence here of a call for monster ships and deep harbours: yet, with a population of 30 millions to be served, the chief difficulties and the reasons for decisions adverse to the perfection of the plan had always been financial! Such conditions were unlike any obtaining in countries inhabited by white men. And then the reports and circumlocution necessary to carry a project through! It was marvellous that in all these

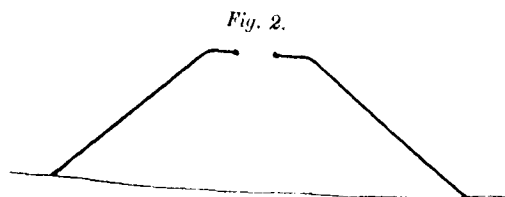


Fig. 2.

years of struggle and delay a man had not been found powerful enough to sweep aside all the volumes of writing, and give the men trained on the spot a clean sheet to begin upon. All the money spent on outside advice had not spared Madras one hour of delay in the fruition of its plans, nor one rupee of the expense of the failures. In latitudes removed from the trade winds, with the directions of prevailing seas such as at Madras, an entrance 500 feet wide would not suffice for safety in making harbour: even the present northern entrance, which was a success for Madras, did not, for such altered conditions, appeal to one. In such positions, the entrance could not be normal to heavy seas in all circumstances, it must be wide enough for the longest vessel to round up in entering, without being blown on to the lee pier-head; and if the contour of the water-area inside did not expand sufficiently to still the waves, it would be necessary to adopt some such plan as that proposed by Mr. J. Watt Sandeman, M. Inst. C.E.¹ But it appeared to Mr. Bell that money spent in providing stilling-basins in deep water at the mouth of a harbour could be applied with advantage in many cases in making the harbour of delta shape, with additional water-area (Fig. 2). The

¹ Minutes of Proceedings Inst. C.E., vol. clvi, p. 280.

Mr. Bell. section of new work shown in Fig. 5, Plate 4, was not a very economical or effective design. The top of the wall was liable to be swept by destructive waves, and the mass of rubble under the wave-breaking blocks was a source of danger. The careful specification "selected rubble 3 cwt. to 1 ton" and "large rubble 1 to 5 tons" looked very nice on a drawing: but where was the 3-cwt. rubble now? Was any of it rolling about and grinding down the concrete blocks? In the first place, the 36-foot wall must be strong enough to withstand all storms until the 5-ton rubble was put in, and outside of that, according to the Figure, came the 3-cwt. rubble. Then sufficient 30-ton wave-breaking blocks to make another wall were thrown in. According to the plan, the cross-sectional area of these wave-breakers might apparently be anything between 1,000 and 1,500 square feet. If the 36-foot wall had been thought insufficient by itself, the width might have been increased and the wall founded throughout at the level of the sea-bed, with a sufficient apron, on the sea side, of carefully laid blocks. A parapet of about 400 square feet sectional area above the present capping would have completed a structure above the reach of overwhelming seas, with less concrete than the section shown in Fig. 5, while the perishable mound of rubble would have been dispensed with. Strops could have been employed, if necessary, to enable the titans to set blocks in the additional depth of water. But these criticisms were not intended to detract from the achievements of either the pioneer, Mr. W. Parkes, or his successors, and no doubt the Authors could adduce sufficient reasons why local circumstances had led to the adoption of the design as it was. They were to be highly congratulated upon the success of the work.

Mr. G. WOULFE BRENNAN remarked that the complete success which Mr. Brennan. had attended the alteration of the entrance suggested that the work should have been essayed long before. Matters could not well have been worse than they were previously, and notwithstanding the objections raised by experienced engineers, the eastern entrance, protected by a sheltering arm, seemed always to have been the only remedy possible in this case. The sloped-block or "slice" system on a sandy sea-bed had everything to recommend it—economy, speed of execution, and a minimum of risk. The manner in which the works had been carried out reflected much credit on the Authors and the staff, and showed the great advantages gained by the Harbour Trust in carrying out the works (which were necessarily of a mixed and complicated character) without a contractor. It was a prime essential, in constructing a breakwater, to build it of ample height above high water and thus to eliminate, as far as possible, the

Mr. Brennan. fall of seas upon it; and it was true economy to break up the waves by large blocks before they reached the main structure, as exhibited in this case. The description of the reinforced-concrete wharfing¹ indicated that the slabs were not connected to the piles, but were laid against them horizontally with butt joints, being held in place by the pressure of the filling behind. This was scarcely a permanent form of construction—as, indeed, was so implied in the description. In piers Nos. 2-4, had the steel beams been filled with concrete between arches and flooring, the metal would all have been encased and only the bottom flanges and two outside faces would then have been exposed. These could be coated with cement mastic yearly, as a preventive against corrosion. There was no form of pier-flooring so strong, and of such value to the stability and solidity of the structure, as a well-bound reinforced-concrete pavement. Reinforced-concrete piles would certainly not stand as fenders against bumping by vessels. If they had been carefully built of a proper mixture and kept damp and shaded from the sun, they should not be pervious to sea-water; but the concrete would crack under repeated heavy shocks of any kind, and would thus admit sea-water to the steel. His experience showed that all reinforced-concrete piles and beams facing the shipping should be covered with strong rubbing-timbers, well bolted to the concrete members. The excellent Tables and details of cost in the Paper were much to be commended. The cost of the rubble deposited below water, and of dredging the old rubble, seemed marvellously low, as did also those of bag-work and block-work, notwithstanding the higher price of cement necessarily resulting from shipment to Madras.

Mr. Buchanan. Mr. G. C. BUCHANAN observed that Sir Francis Spring's Paper was so full in every respect that it was with great diffidence he asked for a little more information: he thought, however, that some additional statistics as to trade would be acceptable. The Author said the average aggregate tonnage of the vessels calling at Madras was 1,610,000 tons (net register) annually; that 1½d. per ton of goods and per head of passengers was a fair measure of the average incidence on tonnage for port-dues and pilotage; and that 3s. per ton represented the average cost of handling, sheltering, and delivering goods by the port-authorities. Would he be good enough to state:

- (a) The number and net registered tonnage of steamers entering the port in 1911 and in 1901, dividing them into 5,000 tons and under, and above 5,000 tons, and 28 feet draught and under, and above 28 feet.

¹ Minutes of Proceedings Inst. C.E., vol. clixvii, p. 427.

- (b) The tonnage of goods actually dealt with by the port- Mr. Buchanan. authorities during the same decade.
- (c) The actual ordinary revenue and expenditure of the Port Trust, and the proportions paid by ships and goods towards the revenue.
- (d) The value of the imports and exports of the port in 1911 and in 1901.

With this information the average reader would realize better the size and growth of the port, and its rank with other great ports of the world. He congratulated Sir Francis Spring on the success of his labours, which he could appreciate the more because during the last 10 years, in the dual capacity of Chairman and Chief Engineer, he had been developing and constructing the port of Rangoon. During that period a million and a half sterling had been expended on port-works proper; and a river-training project with very novel features, which was estimated to cost £1,000,000, was more than half finished. He hoped to present to The Institution an account of these works after their completion.

Mr. A. E. CAREY considered that those who had not had an Mr. Carey. opportunity of visiting Madras Harbour were at a disadvantage in criticizing its original design. He had, however, frequently discussed this subject with the late General Sir Andrew Clarke, who had held strong views on it; and thus the problem was theoretically familiar to him. Sand-travel was, of course, the cardinal factor in the regime of that foreshore. The reclaimed area of sand to the south of the harbour had obviously been utilized to much commercial advantage, but this did not obscure the fact that the original design of the harbour embodied an engineering tragedy. At the present time he had to deal with the problem of building a proposed harbour on a dune foreshore under conditions somewhat similar to those of Madras, except that there was an absence of monsoonal disturbance. In this case an inversion of the design of Madras had been decided on. The harbour was to be excavated in the plateau in the rear of the dunes, and, thus land-sheltered, an approach-channel was to be cut leading from the sea into it. The construction of this approach-channel was a difficult and delicate matter. He was of opinion that in a situation such as that of Madras, granting that the formation of a harbour in the sea was held to be essential, the methods of building the sheltering arms should set up, as far as possible, conditions similar to those which would eventuate from natural accretion. By pushing out a low groyne breakwater stage by stage, as the Dutch did, an artificial headland of sand could be called into being. Sufficient time should be allowed for this accumulation to become

Mr. Carey. moulded and consolidated, in the same way as if it were due to natural causes. To use abrupt measures was to court conditions of instability. High obstructions built at right angles to such a shoreline—obstructions necessarily athwart the sand-streams flowing up and down the coast—normally produced scour, the diffusion of the sand thus creating bars and shoals and setting up denudation of the coast to leeward of the harbour when built. In the bight formed under an artificial spit of sand such as he had described, it was possible to erect piers, the channel between which could be successfully dredged. There seemed to him to be two alternatives. (1) To build a solid breakwater in the open sea, provided with jetties placed at the best angle to suit local exposure, and to connect this isolated solid structure with the shore by means of a viaduct. This method had been adopted at Rosslare and at Port Elizabeth. (2) To build a sheltered harbour inland of the dunes, carrying out the outer protective works in a tentative way and avoiding those sudden transitions and reversals of current which were disastrous on a sandy coast. The plan of constructing in deep water an enclosed harbour in the form of an atoll, and connecting this with the shore by a viaduct, had a certain attraction at first sight; but the relation between the cost and the area sheltered was almost fatal to its adoption. So far as he was aware, no such harbour had ever been built. At Ceará, where there existed a coral reef parallel to the shore, a great opportunity had been missed. On that reef it would have been practicable to construct a fairly protected breakwater, under the lee of which sheltered jetties could have been built, linked with the shore by viaducts. Of course, all such deep-sea harbours afforded little wind-protection to shipping, and this was a fundamental drawback to them. He had come to the conclusion that a simple jetty, such as, he believed, the German authorities had recently built at Lome in West Africa, would have been the best solution of the problem in a situation such as existed at Madras before the harbour was built. The old jetty there, if brought up to date and extended to deep water, would probably have served the purpose. As he had stated previously,¹ according to the harbour-master the only gales at Madras were cyclones, and when those raging vessels went to sea for safety. Under this condition of intermittent discharge, what justification existed for attempting to build solid works in the sea? Was the present harbour available for the purposes of discharge in all conditions of weather, or were ships still sent to sea for safety at certain seasons? The cost of the

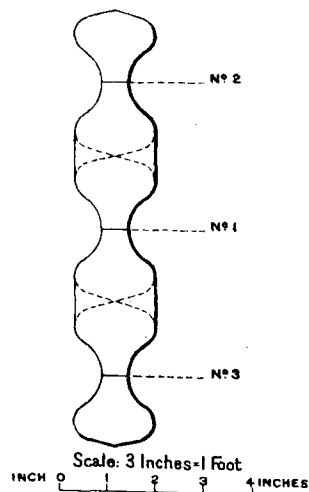
¹ Minutes of Proceedings Inst. C.E., vol. clvi, p. 228.

ship-quays at Madras (£80 per lineal foot) seemed a very large Mr. Carey. outlay for the intended object.

Mr. Mitchell's reference to the testing of cement was of much interest. He did not say whether the briquettes had been gauged with salt water or fresh, and a great deal depended upon that point. Mr. Carey had found the temperature factor of the first importance in gauging cement under comparative test. A low temperature retarded the setting, and if the temperature of the water used was within a few degrees of freezing-point, the cement practically refused to set and lay dormant until the temperature rose. In sea-works in the tropics, on the other hand, cement set much more rapidly. Concrete work exposed to a tropical sun had to be kept thoroughly wetted, or the moisture it contained could not complete the cycle of chemical change necessary for absolute setting. In a testing-room under a tropical sun it was extremely difficult to maintain conditions comparable with those of the test usually enforced on works in temperate regions. He had found that, in gauging briquettes with sea-water at a standard temperature of about 60° F., the cement attained its maximum tensile strength after about 9 months' immersion, whereas when the briquettes were gauged with fresh water the tensile results showed increase up to, at all events, 3 years. His opinion was that the salts in sea-water brought about chemical changes which induced, at an earlier period than was the case if fresh water were used, a crystalline structure of a dense and brittle character, more readily ruptured in tension, but better able to resist compressive stresses. It would be interesting to have further information as to the type of rotary kiln used at the Madras cement-works. What was the length of the cylinder of this kiln, and what fuel was used? The results stated by Mr. Mitchell seemed to him to indicate irregularity in the fusion of the clinker. The lime ingredient used in the manufacture of Madras cement was obtained from a deposit of shells, which, although nearly pure calcium carbonate, contained a residuum of organic matter. In the various instances in which shells were so used, or sought to be used, for cement-making this factor was the cause of much difficulty. Shells could not be ground satisfactorily in a raw state, as they possessed a physical quality which caused the particles to bind. From this physical peculiarity resulted an absence of grit. Attrition did not reduce the product to a state of flour, and this was essential. In order to overcome the difficulty the shells had to be roasted before being ground. When the roasting was carried to excess, the product became hard and intractable for milling purposes. These physical conditions were the cause of fluctuation in the chemical

Mr. Carey. composition of the resultant cement and appeared to be inherent to the manufacture of cement from shell deposits. It was not clear whether the cement which had a final set of 3 hours in India and 10 minutes in England was of local or of English manufacture. The vagaries of test-results mentioned by Mr. Mitchell were such that a more detailed statement would be of interest. Wide variation in the results between different briquettes drawn from one sample of cement, corresponding with variations in the period elapsing between their removal from water and the test, pointed rather to want of uniformity in manipulation when gauged than to some occult chemical action. He threw out the suggestion that

Fig. 3.



this doubt might perhaps be eliminated from laboratory tests if a triple test-piece were adopted (Fig. 3), using, of course, a special shackle. In order to avoid having to manipulate a larger volume of cement than was contained in the standard briquette, the section of these triple briquettes might be $\frac{1}{2}$ inch instead of 1 inch square. The centre briquette would first be broken, and the others at the desired longer intervals. Any wide variation in breaking-stress then still found must be due to chemical and not mechanical causes. The theory that irregularity in the setting-time was due to the presence of sulphuric acid in cement was not corroborated by Dr. F. Framm's tests of concrete slabs alternately wet

and dry in a tideway.¹ According to those tests, slabs made from cement in which sulphuric acid was in excess, withstood the effect of tidal exposure better than those in which the percentage of sulphuric acid was normal. Nevertheless, Mr. Carey was of opinion that many failures in concrete might be attributed to the addition of gypsum in excess. If clinker were not burnt uniformly, and gypsum were added, crystallization at irregular time-intervals would result, and thus the concrete would become slowly disintegrated. On the other hand, if uniformly-burnt and sound clinker had an overdose of gypsum when ground, probably, within limits, it did not do much harm. Engineers were somewhat exercised as to the variation in the physical proper-

¹ Minutes of Proceedings Inst. C.E., vol. clxxxvii, p. 366.

ties of cement burnt by the rotary process. That variation would Mr. Carey. appear to have been accentuated under the conditions of the Madras works, and therefore the tests carried out there might help to solve some of the disquieting problems which seemed to be inseparable from the latest system of manufacture.

Mr. W. DYCE CAY considered that Mr. Parkes deserved great Mr. Cay. credit as the founder or originator of the harbour, and that his method of constructing the breakwaters, though it proved to be too weak, had been followed in the recent alterations, with strengthening modifications and wave-breaker blocks added. With regard to the present works, from the indications given, Mr. Cay thought that the seas could not be very heavy, and he would be glad if the Authors would give more information on this point. He regarded a slice-work resting on a rubble deposit on a sand foundation as a faulty system of building breakwaters, as the structure was liable to subsidence: he preferred to form an unyielding foundation by driving piles all over the base, say, 4 feet apart from centre to centre. He had used this method in the restoration of the dock-entrance at Arbroath, where the bottom was quicksand. The piles might have been of reinforced concrete surrounded with rubble and sheet piling, and cut off at the level of the underside of the solid superstructure. The danger of collisions between vessels breaking loose in the harbour during hurricanes was regrettable, and the successful use of the boat-basin for shelter on such occasions pointed to the advantage to be derived from the provision of additional basins. This could be done by building moles or jetties in the harbour parallel to the new ship-quay (Fig. 1, Plate 4); or, if this were too costly, then a row of dolphins, connected by buoyed chains, could be arranged to give the necessary protection.

Mr. E. A. CULLEN expressed his appreciation of the valuable Mr. Cullen. data afforded in Sir Francis Spring's Paper, and of the Author's concise definition of efficiency. It would add to the value of the Paper if he would indicate the ruling depth at low water in the approach to the new entrance, and the distance between the axis of the new entrance, or the line on which a vessel would be when straightened up to enter, and, say, the 4-fathom and 5-fathom contours to leeward. It was stated that the old entrance had silted up 15 feet, which would leave about 30 feet at low water, and it would be interesting to know the maximum draught of vessels that used this depth with a heavy swell on. Any information beyond the amount of sending movement, or the margin necessary beyond the draught of large modern vessels, was valuable. A Court of Marine Enquiry at Melbourne had found that the S.S. "Cufic," 476 feet in

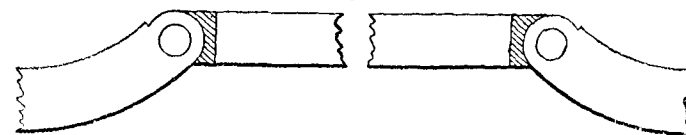
Mr. Cullen. length, and drawing 28 feet of water, injured her hull and propeller by dipping her stern and touching bottom at the entrance to Port Phillip, through encountering some exceptionally heavy rollers, although at the time there was 39 feet of water. At Madras, where labour was so cheap, the additional handling involved by lightering was perhaps of no great moment; but in Australia, where labour was costly, lighterage had to be dispensed with as soon as possible. From this point of view—owing to the additional berthage afforded—a series of piers projected from the shore-line in Madras harbour would have been preferable ultimately to the continuous quay described by the Author. In the harbours of Queensland as much berthage as possible had to be provided at the least expense, with the result that it consisted entirely of wharves, solid quays being too costly. Until a few years ago all these wharves were constructed of hardwood, but owing to the impossibility of protecting them adequately from the activities of insects—especially under water—reinforced-concrete wharves were being constructed by the Government. So far there had been no reason to doubt the wisdom of this course, and if future results confirmed the practice, it meant that suitable accommodation for large modern vessels could be provided—with labour at 8s. to 10s. per diem, and cement at 80s. per ton—for something less than £40 per lineal foot, including sheds.

Mr. Gedye. Mr. N. G. GEDYE asked how far it had been possible to screw the screw-piles referred to on p. 22 without the use of the water-jet; what reasons had made it necessary to apply the jet; what water-pressure had been used; how the supply had been obtained; and what method had been adopted for leading the pipe to the screw-blade. Had any attempts been made to sink the screw-moorings by screwing alone, without a water-jet, and with what result, and how had the jet been applied? On the River Tyne screw-moorings 4 feet in diameter could generally be sunk in compact sand to depths of more than 14 feet by means of suitable screwing-gear, without the employment of a water-jet. The Madras Port Trust's moorings were stated to consist of a bridle of 2½-inch stud chains. Were the chains of such lengths that they were taut when the buoy was floating at the highest water-level, or was any scope allowed in the chains? Information as to the pull required to draw the screws to which the moorings were attached would be of considerable interest, and he would also like to know whether any of the mooring-screws had been drawn by moored vessels during bad weather. The reduction of wave-length expected by Mr. Parkes in 1873 to result from the construction of the harbour as originally designed was stated to be from 15 feet to 2 feet 7 inches, or about

6 to 1: had the actual average reduction, based on observations Mr. Gedye made after the completion of the first harbour-entrance, been found to agree with the estimate?

Mr. J. C. LARMINIE considered that Sir Francis Spring's very Mr. Larminie. complete Paper would be of much interest to engineers generally, and especially to those members of the Madras Public Works Department who had had opportunities of inspecting the work from time to time during the course of their service. None of the works now described had been started when he last saw the harbour, so that great progress had been made and the trade facilities had been brought up to date; but, as a refuge in cyclonic weather, Madras harbour was apparently no safer than before for ships of average tonnage—a state of affairs pointing to the need for the improvement of ports farther north, e.g., Vizagapatam and Coconada.¹ The Paper did not afford much scope for criticism, but it would be interesting to know why, when closing the old east entrance, the new length of breakwater was aligned just inside the circular caissons terminating the breakwaters. Two re-entrant pockets were thus formed

Fig. 4.



which, even in a moderate sea, must cause considerable disturbance and subject these two points to severe strain. Had the centre-line of the new work been placed as shown in Fig. 4, on or about the line joining the centres of the two lighthouses, the caissons to form the skewbacks might then have been designed of the much more manageable form indicated by hatched shading, a form also more conducive to accurate sinking, as the old circular caissons would have served as guide-posts. The re-entrant pockets would have been avoided, while the new length of breakwater would have tended to buttress up the old terminals. The adoption of this plan would not, he believed, have caused any extra difficulty so far as forming the rubble base was concerned. Sir Francis Spring's promised Paper on sand-movement would be awaited with much interest. Judging by the plan of the harbour (Fig. 1, Plate 4) there did not appear to have been any great advance of the sand-accretion during recent years; but should it still be increasing, it must in time—as it was now

¹ Minutes of Proceedings Inst. C.E., vol. clxxiv, p. 247.

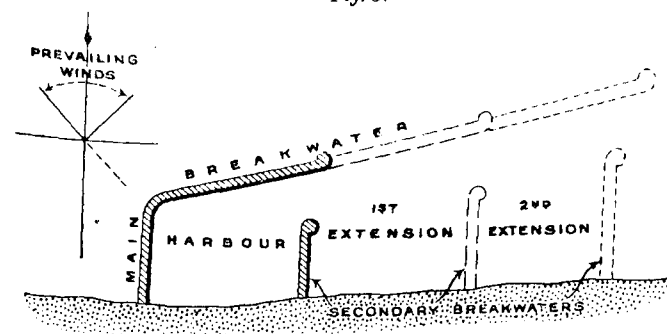
Mr. Larminie. prevented from entering the old harbour-mouth—reach the end of the sheltering arm, where dredging would then be necessary. Apparently this sheltering arm was effective in ensuring a quiet harbour, although it might be supposed that with a heavy sea during the north-east monsoon, a considerable swell might roll along its inner face with great disruptive force, causing disturbance in the angle at L. In this particular the work differed from the design recommended by the mixed Commission of June 1893,¹ in which the angular pocket at L was avoided; and it would be of interest to learn the reasons for the change. The remarks on dredging were of particular interest to Mr. Larminie, in view of the report made by him to the Madras Government in November, 1900, in favour of suction dredging; while in the purchase of the suction dredger "Madras," the recommendation made in that report had been virtually followed. The work done by the old bucket dredger "Triton" in opening the new entrance, as detailed in Mr. Mitchell's Paper, was little short of marvellous, and was a splendid testimony to her strength and power.

Prof. Luiggi. Professor LUIGI LUIGGI found the Papers of the greatest interest, both theoretical and practical. The idea of closing the former entrance and opening a new one deserved the highest praise, because it was not only the most rational solution, but also one that required considerable courage to propose and carry out. The old entrance, opening out to sea, would have been quite correct if the harbour had been intended only to shelter passing vessels, like Ymuiden or Tyne-mouth; but it was a mistake for a harbour wherein ships had to remain moored alongside quays. With the remodelled entrance there was an outer harbour proper, and a real inner harbour. It resembled closely the majority of Mediterranean harbours, which were almost all sheltered by a principal mole running nearly parallel to the general line of the coast, and a secondary mole almost perpendicular to the coast, placed with its end well within shelter of the main mole (Fig. 5). This design had yielded excellent results at Marseilles, Genoa, Naples, Barcelona, Catania, and many other ports. It also afforded the possibility of further extension to suit the increase of traffic, as shown by the dotted lines, whilst the old form of Madras harbour did not lend itself to extension seaward. The adoption of the inclined blocks was also commendable. The Mediterranean practice was to lay the blocks either pell-mell or in horizontal layers. In the latter case the blocks did not follow sufficiently the settlement of the rubble mound, and might often form a kind of arch with hollow

¹ Minutes of Proceedings Inst. C.E., vol. clvi, pp. 225 and 228.

spaces underneath. The sea could then easily open a breach in the breakwater, as happened at Leghorn when the breakwater of Vegliaia was destroyed. The use of inclined slice-blocks for breakwaters originated at Karachi and had been imitated successfully at Madras, Colombo, Teneriffe, Las Palmas, and many other ports. It was also being introduced for the first time in Italian practice, having been adopted by himself in constructing the harbours of Tripoli and Bengasi now in progress. In the north of the Mediterranean, with many days of smooth sea in the month, floating

Fig. 5.

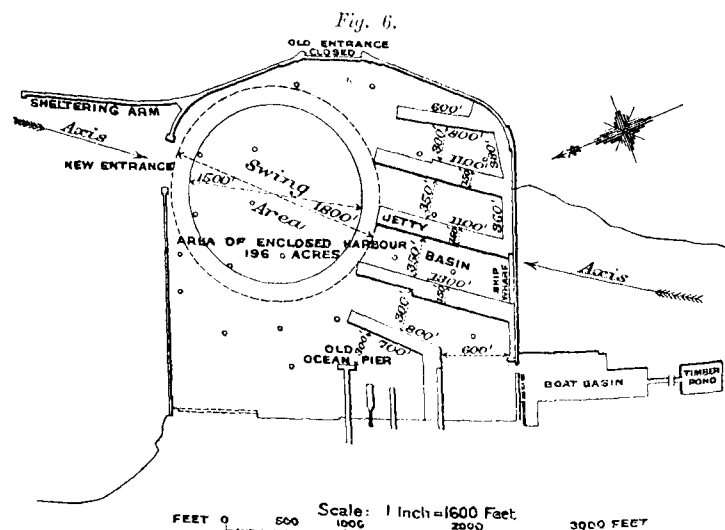


derricks were in common use; but in the southern ports, especially at Tripoli and Bengasi, the sea was rarely calm, and a titan had been adopted as the only means of permitting the laying of blocks, even in a slightly rough sea, when floating derricks could not work. Generally, he cordially endorsed the Authors' conclusions and considered that their Papers afforded very valuable information to harbour-engineers.

Mr. W. T. OLIVE had nothing but praise for the methods adopted Mr. Olive. in the execution of the works, and he admired the complete manner in which this had been described in the Papers. He desired to confine his observations to the design, so far as it had proceeded, and to suggest a form which any future extension should take in the enclosed harbour-area. He had not visited Madras, and wrote with great deference; but he had been able to glean from the past history of the port¹ information which enabled him to offer the following remarks. In any contemplated works of this nature with which he had been connected it had been usual, before

¹ Minutes of Proceedings Inst. C.E., vol. lxx, p. 16 *et seq.*; vol. lxxix, p. 406; and vol. clvi, p. 224 *et seq.*; Minutes of Proceedings International Maritime Congress, London, 1893.

Mr. Olive. entering upon the design, to ascertain locally by inquiry of citizens engaged in trade, shipping, and railway operations—particularly the shipping interest—what the requirements were likely to be. Applying this to the present case, it appeared that in 1879 the nautical men consulted advocated strongly that the entrance should be on the north-east side of the harbour. This recommendation seemed to have been ignored; hence the necessity for the extensive alterations now carried out. Again, although it was known then that 15-foot waves were to be expected at 1,000 feet from the shore (p. 28), in the original scheme the height of the projected breakwater was only 2 feet 9 inches above highest high-water level. It seemed a misnomer to designate such a structure a harbour,



when it was necessary for ships to put out to the open sea in stormy weather. Subsequently, in order to render smooth the enclosed water-area, this height had to be increased to 10 feet 9 inches above highest high-water level, and steamers might now lie alongside wharves in all weathers. From the failure to adopt the height necessary to obtain still water by the original scheme, the creation of a fleet of lighters, with a specially constructed boat-basin for its accommodation, had resulted. By doing away with lighterage between shore and ship, a saving might be effected—at an estimate of only 1s. per ton on the average of goods landed overside (696,000 tons)—which would total £34,800 annually. The provision of wharves at which vessels could

discharge direct into railway-trucks, for the interior or for local delivery by roads brought on to the wharves, seemed now to be the desideratum; and in order to meet this, he suggested (Fig. 6) the construction of 2 miles of additional wharves with water-frontage, without interfering materially with existing piers, etc., which, however, might be removed with advantage. He ventured to think that this was the best method of extending the accommodation of the port. The scheme allowed for a turning-space or swing-area 1,500 feet in diameter immediately inside the entrance, and the jetties on the south side (150 feet and 100 feet wide) would be conveniently accessible to ships and would be fully equipped with railway-lines, sheds, etc. The inclination of these jetties to the south pier would facilitate dispatch. The basins between the jetties would be 350 and 300 feet wide, and easy access to the existing boat-basin and timber-pond would be maintained. Such a scheme could be carried out by instalments and continued as funds were forthcoming. He held that it was advisable to adopt at the outset a fully-considered and completed design which should be conformed to in all constructional work which the trade of the port might warrant from time to time, as a part of an ultimate whole. It seemed unfortunate that some simpler and more efficient system of railway accommodation had not been adopted. He considered that far too much valuable ground had been devoted to this purpose, and the effect was one of haphazard progress without any general scheme in view.

Mr. F. E. ROBERTSON remarked that if those who commented on the fact that ships were advised to put to sea on the approach of a cyclone had witnessed one—as he had—they would not regard it as a reflection on the shelter afforded by the Madras harbour. The Hooghly at Calcutta (many miles from the sea) was not safe in a cyclone. The worst storm in England that he could remember was that in which the "Royal Charter" was wrecked, but that was a trifle compared with a cyclone. It must be remembered that the greatest danger to shipping was not the wind itself but the tidal wave which often accompanied a cyclone. For any English weather Madras harbour would be safe enough.

Mr. ADAM SCOTT considered that both Sir Francis Spring and the Port Trust were to be congratulated on the works and on their policy, and that, if they would continue the development of the port by providing sufficient fully-equipped deep-water quays, it should mean at last the beginning of prosperity for the port of Madras. Until the initiation of the recent works, the history of the port had been unfortunate and disappointing, and success

Mr. Scott. appeared to have been hindered by the action of the home government in refusing to carry out long ago that which had now been accomplished, and also by hand-to-mouth methods of finance. Sir Francis Spring claimed that Madras was now one of the cheapest and most efficient harbours in the East. That might be so; but it was yet far from what it should be, for no harbour where vessels needed to lie off and cargoes had to be handled by lightering could be called a modern or an up-to-date harbour; neither could such a method of working compare favourably with a system of deep-water ship-quays, fully equipped with electric cranes, capstans, etc., and having a good railway service alongside. Sir Francis Spring seemed to think that Madras would probably never be more than a port of call. Why this should be so was not clear; it should, at all events, hold its own with the other ports of India, if all modern facilities were provided. Its geographical position, from a commercial point of view, was not equal to that of Bombay, but it compared favourably with Rangoon, and it should be able to compete with Calcutta. The incomes of the chief ports of India for the year 1909-10, and their respective capital debts, were:—

	Income. £	Capital Debt. £
Calcutta	789,101	5,566,020
Bombay	506,812	6,005,119
Karachi	231,103	985,065
Rangoon	195,418	1,594,133
Madras	90,215	521,736

It might be questioned whether the policy of the Madras Port Trust were not too conservative. A bolder policy might be more advantageous. It was reported that the dock accommodation at Karachi was now to be doubled. Was there any good reason why Madras should lag behind the other ports? It had a population of more than half a million, which exceeded those of Karachi and Rangoon combined, while behind it there was a population of millions. Evidently the reason was that trade had not been encouraged sufficiently, and modern facilities had not been provided. Marked expansion of the trade of the port could not be expected until such facilities were provided, and it was difficult to understand why the Port Trust should hesitate about such a vital question, especially if there had been a strong local demand for deep-water quays. With regard to the breakwaters, if more money had been spent in the first instance, by carrying them into deeper water and by adopting a stronger and higher section, they would have been of much greater utility. The original section of the breakwaters almost invited destruction in

deep water, owing to the want of bond and to the small depth at Mr. Scott. which the artificial blocks were founded. Sir Francis Spring stated that Madras harbour had never pretended to offer any shelter from the wind. But an enclosed harbour was generally expected to give protection against the strongest winds; and if it did not do so it failed in the first essential. It did not redound to the credit of the authorities that vessels must be warned to stand out to sea when a hurricane occurred. Considerable trouble seemed to have been experienced in sinking the caissons truly in the desired positions, as not one of them had been dropped exactly in the position intended. The first caisson was filled until it drew 27 feet of water, leaving 10 or 12 feet to be sunk—whether at low or at high water was not stated; the second was loaded to a draught of 23½ feet, and the third to a draught of 27 feet. Would it not have been possible and better to fill them to a considerably greater draught, say 4 or 5 feet more? It would have steadied them, and would have greatly expedited the final sinking into position. The reasons given by Sir Francis Spring for preferring hydraulic to electric cranes were not very convincing. The cost of employing an electrical engineer could not have been much more than that of a good mechanical engineer, and in any case the difference would soon have been eliminated in the total working-expenses spread over a number of years. It was rather surprising to hear of hand-cranes being installed nowadays, and it must be difficult to justify their use. The detailed prices given in the Paper for rubble-work, concrete, and concrete blocks were very interesting, and the works appeared to have been carried out economically; but of course it had to be remembered that labour at Madras was very cheap. The comparison with other breakwaters in the matter of cost might well have been omitted, because no useful conclusions could be drawn on such a basis where the works varied greatly in respect to depth, section, and exposure, and had been carried out under different conditions.

Mr. E. W. STONEY had read Sir Francis Spring's Paper with great Mr. Stoney. interest, having known Madras since landing through the surf at the old screw-pile pier in August, 1866, and having been a member of the Harbour Board in 1903-4. The improvements made in every way since the Author became Chairman, which Mr. Stoney had had an opportunity of seeing in March, 1912, were so great that it was difficult to realize how so much had been done in the last 8 years. The descriptions given were very clear, and Sir Francis Spring was to be congratulated on having recorded the difficulties and small failures met with, knowledge of which was so useful to engineers.

Mr. Stoney. Mr. Stoney's experience of many attempts to make durable floors for railway goods-sheds, which would withstand the unloading of cases, goods, etc., from wagons, caused him to agree with Sir Francis Spring that cement concrete made with granite broken to about $\frac{3}{4}$ -inch cubes stood well when not plastered; when plastered, however, the concrete always broke up. Thoroughly efficient and durable floors were made by setting granite flags 4 inches thick in 4 to 6 inches of concrete, leaving a space of $\frac{1}{2}$ inch between the joints, which was filled with asphalt pointing. He had always found that corrugated-iron roofs were troublesome at Madras, as they constantly leaked, owing to the rivets at the joints being loosened by the severe stresses due to expansion and contraction caused by the wide range of temperature. Mangalore tile roofs were quite satisfactory and durable, and very much cheaper than iron roofs. Doubtless Sir Francis had had good grounds for not using Mangalore tiles, one probable reason being that thieves could easily make holes by lifting tiles, and so get access to the goods below. As an old bridge-builder, Mr. Stoney was much interested in the new quay-walls built of masonry "wells" 35 feet by 25 feet, and he had often wondered why this system of construction had not been more largely used, especially where the "wells" were sunk in sand, thus avoiding the expense of coffer-dams, pumping, etc. Engineers were indebted to the Author for giving clear and definite details of cost of the various kinds of work done; such information was very valuable to those who had to design, estimate for, and carry out such works, but it was often omitted from descriptive Papers.

Mr. Walmisley. Mr. A. T. WALMISLEY, as a harbour-engineer, agreed with the altered position for the entrance and with the provision of the sheltering arm to the north-east. The circumstances under which a timber deck was preferable to a metal-and-concrete deck, mentioned on p. 21, were not of universal application. With regard to corrosion, he had found, in examining the viaduct of the Prince of Wales pier at Dover, where the deck-girders had a clear headway of 15 feet above the level of high water of spring-tides, that the undersides and bearings of these girders exhibited most corrosion. Upon the supporting piles the maximum corrosion occurred at high-water level. Below this level the shell incrustation seemed to form a protection, because if it were removed by hand the black varnish covering underneath appeared to be undisturbed. The under-deck parts and the troughing in the viaduct were examined, cleaned, and black-varnished periodically, while all portions above deck were repainted. In his opinion nothing equalled black varnish, properly applied, as a protection against corrosion.

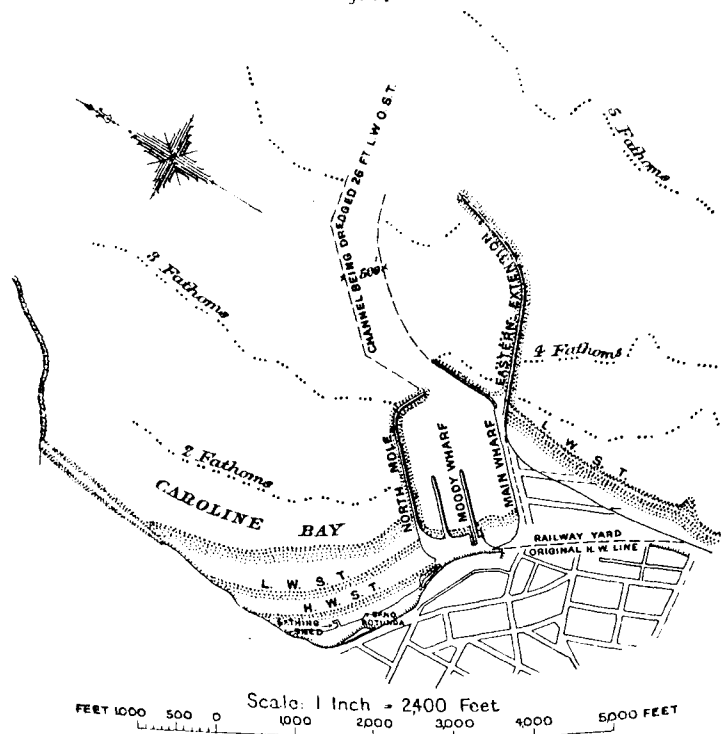
He was not surprised at the corrosion of corrugated iron mentioned in Sir Francis Spring's Paper. In 1861 the dome of the Borough Market, London Bridge, was covered with corrugated iron, and in 1891 this was found to be corroded and riddled. It was removed by Mr. Walmisley when he reconstructed the roof over the market. For the last pier-shelter at Ramsgate Harbour the Board of Trade had used corrugated zinc of No. 16 gauge. In 1884, on the removal of some sheds at Portsmouth that had been covered with zinc for many years, the zinc was found to be in good condition. Of course, in making a comparison, it must be borne in mind that there was best Vieille Montaigne zinc and commercial size zinc: so also there was No. 18 gauge corrugated iron and commercial sheets. Zinc must be of the best quality, and it would be interesting to learn the Authors' views as to the renewal of the covering to the sheds. Referring to p. 29, 200 tons wind-pressure upon the side of a ship moored stem to stern would necessitate a specially strong stern mooring; but he presumed the authorities at Madras preferred to moor in this way rather than allow vessels to swing at anchor.

Mr. H. GILBERT WHYATT remarked that it would be interesting to learn whether Sir Andrew Clark, when condemning Mr. Parkes's scheme, advised a northern instead of an eastern entrance. It would appear that for the present the newly-constructed north entrance was satisfactory; but it might entail the eventual formation of a sand-spit, and necessitate periodical extension of the sheltering arm K (Fig. 1, Plate 4), in order to prevent sand from travelling round and blocking up the new entrance. Mr. Whyatt had been greatly interested in the breaking-test of cement briquettes; he had never found in his experience that the strength of briquettes diminished after they were taken out of water. He purposed carrying out a few experiments to see whether he obtained similar results.

Mr. CYRUS J. R. WILLIAMS observed that in discussing Madras Mr. harbour the vast changes which had taken place in ocean navigation since Mr. Parkes designed the original harbour must be borne in mind; for although in 1875 steamships were rapidly superseding sailing vessels, yet the masters of those steamships had come from the sailing vessels, bringing with them all the sailor's traditions and prejudices. Consequently, questions of easy access, good holding-ground, etc., were allowed to have more than their due share in the consideration of the lay-out of harbours. The old sailing-masters concerned themselves very little about how the cargo was to be got ashore, so long as the vessel bringing it to the port lay in safety. Sailing vessels stayed so long in port discharging that the

Mr. Williams. above consideration overshadowed all others, and the engineer had to lay out his works to accord with the views of the sea-captains. All this was now changed. The question of the ship's safety was solved by tying her securely against a quay-wall or jetty, or taking her into a quiet dock; and her stay in port was now a matter of days instead of weeks or months. Besides which, though at first glance it seemed a paradox, it was an indisputable fact that large vessels were as easily handled as small ones: they responded with

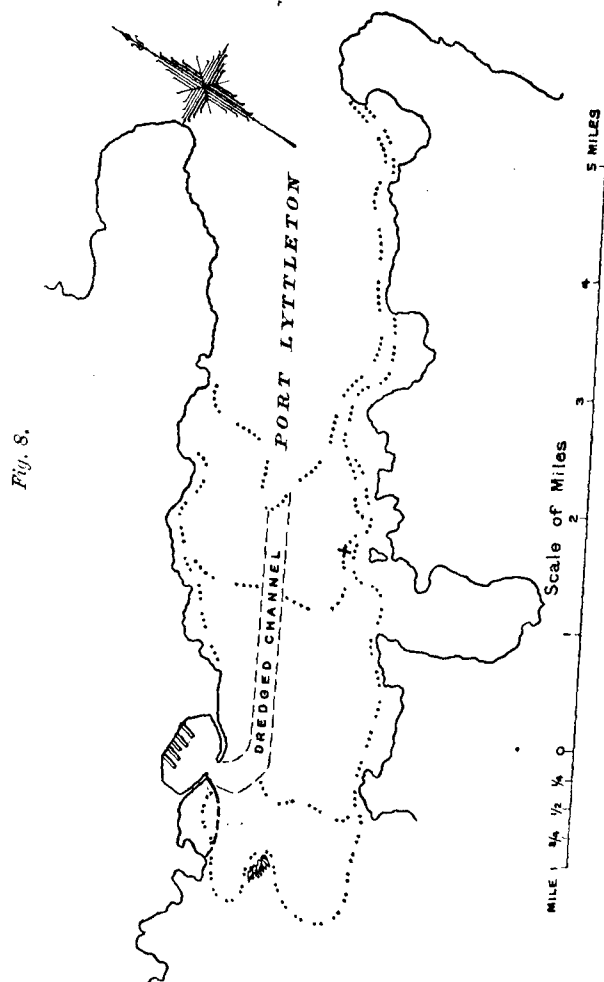
Fig. 7.



more certainty to the movements of their engines and rudders, as, on account of their great mass, they were less disturbed by wave-movements and winds. The lighterage customs in the eastern seas had probably also tended to encourage the assumption that a safe anchorage was a commercial port, whereas it was only one step towards it. Had Madras harbour remained uninjured by the seas it would still, with a range inside of 2 feet 7 inches downward, have been only an anchorage; and although lighterage could be conducted

—as it was on the Queensland coast under Flat Top Island, and Mr. Williams off Gisborne on the New Zealand coast—in such a range, it would never have been practicable, or at all events convenient, to berth vessels at quays or jetties in such circumstances. Again, littoral drift, that bugbear of the harbour-engineer, had lost its terrors since the introduction of suction dredging; indeed, as at Timaru on the east coast of the South Island of New Zealand (*Fig. 7*), and at Madras, it had almost become beneficial by assisting land-reclamation in such places as to form valuable adjuncts to the port. The 550,000 tons of sand referred to would not now be considered a serious item in connection with a harbour whose revenue was sufficient to bear the cost of working one modern dredger. In Lyttelton, for instance (*Fig. 8*), where Mr. Williams had had control of the harbour for the past 9 years, it had been necessary to remove annually 350,000 tons of soft clay from the entrance-channel, where there was no apparent drift; and the soft deposit could be accounted for only by the supposition that the soft clay bottom of the harbour was stirred up by the waves and naturally settled in the deeply-dredged portions where they had less effect. Until lately this deposit had been removed by a hopper-dredger of 850 tons hopper-capacity dumping the spoil; but as the channel was $1\frac{1}{2}$ mile in length, it took the dredger 18 months to work her way from one end to the other, and the result was that there was always a depth of 30 feet at one end of the channel and 25 or 26 feet at the other. The channel was now being maintained by a drag suction-dredger built by Messrs. Simons and Company, of Renfrew, from an outline design and specification prepared by Mr. Williams. This vessel dredged while under way, and carried 1,120 tons of a mixture of clay and water in her hoppers, the clay after settlement representing 60 to 70 per cent. of the total bulk. She made six complete trips in a day, the average time occupied in leaving the wharf, steaming to the dredging-ground, filling her hoppers, steaming back to the wharf, and pumping the spoil ashore from the hoppers, being 1 hour and 20 minutes. Such a dredger, while specially designed in this case for dealing with soft clay, could be modified so as to be equally successful in dealing with sand. He had had no experience in eastern ports, except the ports in connection with the Suez Canal, the only one he had visited being Colombo, but it would be difficult to convince him that, even with the cheap labour of the East, any system of lighterage could be as efficient as berthing vessels at quays or jetties; and there were indications in the Paper that this was being recognized at Madras, as there was a pronounced move in the direction of providing quays. He did not,

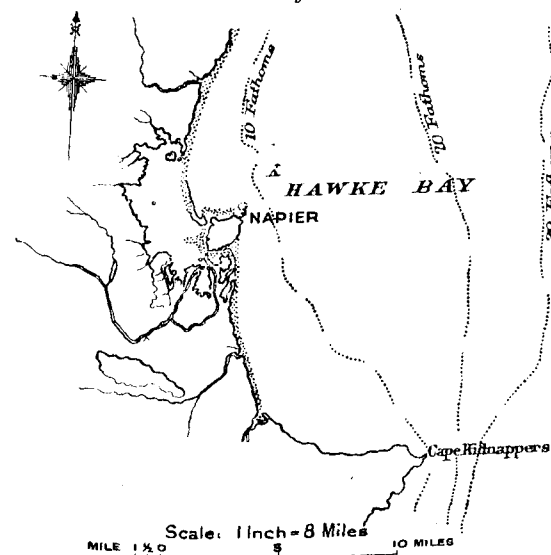
Williams. however, share the Author's satisfaction with the use that had been made of the area of sand accumulated to windward of the original harbour. The dock there might be in the future a source of embarrassment, as it appeared to him to be in the way of the most efficient use



of the harbour. Quay-walls surrounding a harbour or open dock, such as Madras harbour must now be considered, were neither the most economical nor the most efficient way of providing accommodation, and they had one very serious defect, namely, that if there was any wave-movement in the harbour, vessels lay very uneasily at such

breastwork wharves, moving inwards and outwards, to the great Mr. Williams' embarrassment of those conducting loading- or discharging-operations. When there was any wave-movement vessels should lie at their berths with bows or sterns pointing approximately towards the entrance. They would thus lie easily, moving a few inches fore and aft. If Madras harbour were supplied with a series of jetty-wharves with railway-lines, transit-sheds, and cart-ways, in accordance with modern practice elsewhere, the reclaimed land would be the natural situation for stores and marshalling railway-lines; and it might be desirable to fill up the small dock there. The engineering difficulties in connection with the

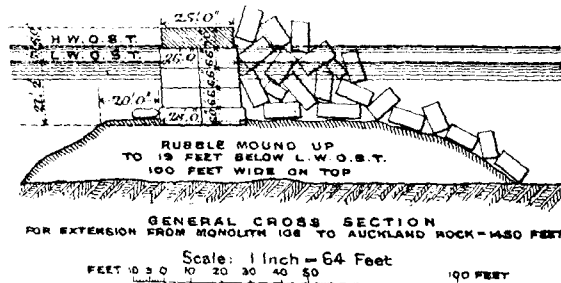
Fig. 9.



closing of the old entrance and the opening of the new one appeared to have been overcome satisfactorily, and without personal acquaintance with the harbour and the seas to be withstood, it would be presumptuous to criticize the question of the costs. However, if a 15-foot wave was the largest to be dealt with, the cost of the breakwaters seemed high, because at Napier (Fig. 9), on the east coast of the North Island of New Zealand, where the wave-stroke was that of the unrestricted rollers raised by south-easterly gales in the Southern Pacific Ocean, an efficient breakwater (Fig. 10), founded in 30 feet at low water and constructed of 30-ton concrete blocks on a rubble mound, protected by a wave-breaker of 30-ton

Mr. Williams. concrete blocks on the seaward side, was costing only £70 per lineal foot. On the whole, while he congratulated those concerned on the success of the Madras works executed so far, he could not

Fig. 10.



forbear to express the opinion that much remained to be done before the harbour could be considered efficient.

Mr. Wilson. Mr. F. J. WILSON, as an old friend of Madras harbour, whose professional connection with it in one capacity or another had aggregated about 10 years between 1891 and 1905, was much interested in the successful progress recorded in the Papers. The harbour, for which at one time few had a good word to say, had so far developed that Sir Francis Spring was now able to describe it as one of the most efficient harbours in the East. This efficiency was due largely to the shore facilities and other accommodation provided, and in some measure to the closing of the eastern entrance, which secured calmer water in the 196 acres of anchorage enclosed by the breakwaters. One ship-wharf had been constructed, and another quay was under construction, but it was still necessary to recommend commanders of vessels to go out to sea on the approach of a severe storm. Doubtless this would continue to be the case until ships could lie alongside quays in a basin of moderate width. It was the question of the merits of, or the need for, basin-quays at Madras which lay at the root of much of the discussion which took place in the nineties. If Madras required sheltered quays, then by constructing them in basin form in the south accretion, the need for still water in the harbour then existing became of less moment, and it only remained to deal with the question of shallowing at the eastern entrance. At that time there seemed to be a possibility of dealing with the matter by dredging, and the question whether outer works would be necessary in connection with this shallowing, and, if so, what form they should take, was somewhat uncertain until the effects of dredging had been seriously tried with up-to-date

plant. On the other hand, there was no doubt whatever that the Mr. Wilson. port was absolutely lacking in the most elementary forms of harbour-equipment, as might be judged from the descriptions in Sir Francis Spring's Paper. The need for a properly organized scheme, taking account of levels and future developments, was urgent, and the first point requiring decision was the form such developments should take. Mr. Wilson was the local Consulting Engineer to the harbour at the time, and, following the view expressed by Sir Alexander Rendel in 1889—that the harbour as it then was should be regarded merely as a satisfactory entrance to an inner harbour yet to be designed—he submitted in 1898 proposals for a 17-acre basin in the south accretion, to which the main body of the harbour-traffic would ultimately have been transferred. The alternative was to be content with a boat-basin and to develop the harbour-area much as was now being done. The basin proposal was carried by a small majority, which was not considered sufficient on so important a question. Sir Alexander Rendel therefore supported the proposal to make a ship-basin, though in a somewhat different form from that projected, and he also proposed outer works to carry the harbour-entrance farther east, should this become necessary. In February, 1902, when Mr. Wilson was at home on furlough, the Madras Government again addressed the Secretary of State for India, putting forward two proposals dealing with the harbour-entrance; and these being referred to the committee of that year (Admiral Sir George Nares, Sir William Matthews and Sir Charles Hartley), the recommendation was made in favour of the north-east entrance. This recommendation having been accepted by the Madras Government and by the Harbour Board, he was appointed, in 1903, to prepare the designs and estimates, and to carry out the works giving effect to them. His designs and estimates, including a 7-year programme of work, were sanctioned, and the works were started in 1904; but towards the end of 1905, after having organized the undertaking and completed all preliminary works, including the opening of quarries, the construction of a new block-ground, offices, and buildings, and starting block-construction, he left the works, now so satisfactorily completed, to take up the appointment of Chief Engineer in the Public Works Department. The credit for getting the entrance changed, assigned to him by Sir Francis Spring, should properly have been given to Mr. De Winton, who was the Chief Engineer and Secretary to Government, Public Works Department, at the time the matter was referred to the Committee of 1902, and was always a strong advocate of such an entrance. Mr. Wilson's share in that part of the improvements was

Mr. Wilson. confined to giving effect to the decision come to. This decision and the works entailed by it somewhat overshadowed for the time being the internal works and the future development, to which he had always attached great importance; but he did not take it that the decision involved a rejection of 'ultimate development in basin form, such as he proposed in 1898. He had never believed it reasonable to expect any form of mere entrance from the open ocean, on a coast subject to severe storms, to be sufficient to enable the present harbour to be made use of as a properly equipped inner harbour. If the plans of the best harbours of the world were considered, something would generally be found in the form of an outer harbour—which might be either natural or artificial—in direct communication with the ocean, and then an inner harbour in which the sufficient stillness of water and security for shipping in all weathers was beyond question. In drawing out his plans for the new entrance-works, which involved questions of railway-access, positions of new buildings, etc., he had set aside and fenced off an area for a future basin, with room for extensions southward. Now that the north-east entrance had become an accomplished fact, it enabled measures to be taken to make use of the present harbour-area for a certain amount of ship-quayage and wharfage; but he had always felt that however slowly development had to take place, the ultimate aim to be kept in mind should be works that would enable ships to lie alongside properly sheltered quays, with ample area for sheds and other equipment behind them, and such that it would not be necessary for ships to go to sea on the occurrence of a storm. Ship-quays in the present harbour, facing open water with a fetch of 3,000 feet or more, quite apart from the influence of ocean swell, were not in an ideal position; and although it might be claimed that they were more accessible, and therefore more suitable for a port of call, than basin quays, and that occasions when the weather would not permit of their being used would seldom occur, they would not serve for shelter during really bad weather. The mere knowledge that this was the case was to some extent a bar to their utility, for it was common enough for a storm-warning to be given without a storm following, and precautions ordered to meet such predictions were vexatious. The south accretion in Madras formed a favourable site for the construction of sheltered basins, and he would look for ultimate development in this direction.

Mr. Mitchell. Mr. MITCHELL, in reply, stated that fresh water was used for gauging the test briquettes. The local cement was manufactured by the dry process in a rotary plant supplied by Messrs. Smidth

and Company, of Copenhagen, the cylinder of which was 72 feet long and 6 feet in diameter. The calorific value of the fuel used in burning the clinker was 6,380 calories per pound, and its average analysis was:—

	Per Cent.
Volatile matter	27.20
Fixed carbon (by difference)	57.08
Ash	15.72
	100.00

The following detailed tests were submitted as typical of those made to ascertain what variation occurred in the tensile strength of briquettes when different periods elapsed between the time when they were taken from water and the time when they were tested.

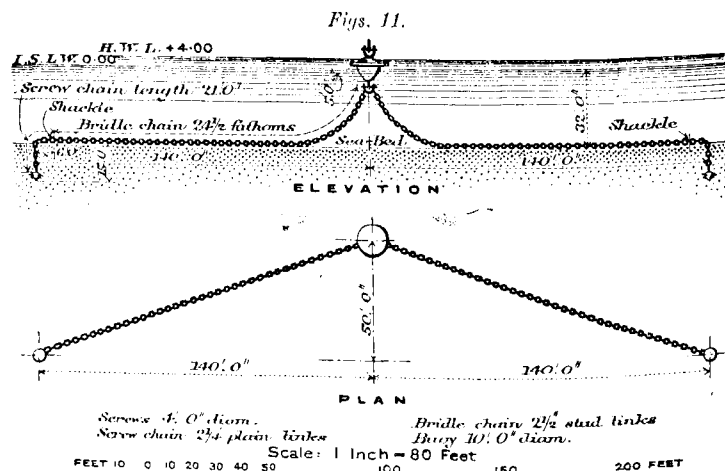
Age of 1-Inch by 1-Inch Briquettes when Tested.	Tensile Strength of Briquettes taken from Water:				
	1 Just before Testing.	2 3 Hours before Testing.	3 6 Hours before Testing.	4 12 Hours before Testing.	5 24 Hours before Testing.
	Lbs. per Sq. In.	Lbs. per Sq. In.	Lbs. per Sq. In.	Lbs. per Sq. In.	Lbs. per Sq. In.
7 Days	665 675	576 625	550	435 415	450 390
Average	670	600	595	425	420
28 Days	785 760	720 740	650 680	670 590	550 520
Average	772	730	665	630	535

The temperature of the water in which the briquettes were kept varied between 78° and 84° F. The minimum temperature of the air on the day on which the 7-day briquettes were exposed was 86° F., and on the day on which the 28-day briquettes were taken out of water 90° F. The following precautions were taken to reduce to a minimum the chances of error in manipulation:—

- (1) The same gauger was employed throughout the progress of the works (6 years).
- (2) All results were the average of two or more tests.
- (3) No two consecutively-made briquettes were ever used for the same test.

If twelve briquettes were required for four tests, the first, fifth and ninth in order of making were taken for the first test, the second, sixth and tenth for the second, and so on. He was of opinion that

Mr. Mitchell. the foregoing results, which were confirmed by ten similar tests, were not due to errors in manipulation, and was inclined to attribute the variations to internal stresses in the briquettes, set up by the outer portions of them drying more rapidly than the inner. In reply to Mr. Gedy's query, the mooring-chains were so



arranged that, if the buoys of a berth were 600 feet apart when slack, they would be 550 feet apart when a vessel was in the berth with her head and stern lines pulled in taut. Figs. 11 gave the necessary particulars for laying down such moorings.

Sir Francis Spring.

Sir FRANCIS SPRING, in reply, thought Mr. Reid Bell might be interested to hear that, around the sea-coast of the Madras Presidency, with its 30 millions of people, there were, besides Madras, sixteen ports of sorts—most of them as yet in their natural state—dealing with a registered tonnage of 8,000,000 tons in a year, of which less than 6 per cent. consisted of sailing craft, mostly of 200 tons or less. The passenger-traffic at these minor ports was about 300,000 in a year, and the value of the imports and exports 20 millions sterling. With regard to Mr. Bell's criticism about the design of the breakwaters, when the 600 lineal feet of breakwater was cut through for the formation of the new entrance, it was proved conclusively that in 30 years the granite rubble, whether underlying the wave-breakers or elsewhere, had not moved nor had it been ground smaller or globular. Probably not ten steamers out of the thousands that had used the port since the old screw-jetty mentioned by Mr. Carey was erected, could have lain alongside that jetty, even if it had extended a mile out to sea, whilst the value of the cargo dropped between it and lighters would

Sir Francis Spring.

probably have gone a long way towards paying for the modern harbour. Mr. Carey and some other correspondents were evidently obsessed by the belief that it was quite a common thing for steamers to have to run to sea on the occurrence of bad weather. Sir Francis knew of eight vessels which had done this in the last 8 years, and probably eight or ten vessels in a decade would be a fair average. With regard to Mr. Dyce Cay's remarks, the successive sections of the Madras breakwaters had always settled—that was, had pressed their rubble into the underlying sand—almost exactly 2 feet in the first year, whereas after that time practically no settlement has ever been observed, though constantly sought for, in 20 or 30 years. The depth in the fairway, where a vessel turning round the corner first entered the smooth water, was 36 to 42 feet at low water, and, on her starboard side as she entered, there was a distance of 800 to 1,000 feet between her and the 5-fathom line. Undoubtedly, towards the end, it was becoming risky for vessels to enter or leave by the old entrance (now closed) in a very heavy swell; but it could always be arranged to handle them at high water if danger seemed to be indicated. Moorings used to be screwed in former days, but, following an invention of Mr. A. L. Pogson, M. Inst. C.E., who was harbour-engineer at Madras for many years, the screws were always water-jetted, for removal or replacement. This water-jetting, in the Madras sand, in no way diminished their holding-power, and in any event the pull on them was limited to the buoy-chain's breaking-strength. Sixty tons made no impression on them. So far as it was possible to observe the waves on the piles of the jetties and on the walls of the harbour, the reduction in wave-height was not so great as was anticipated by Mr. Parkes with a 550-foot entrance and a 200-acre harbour. The two re-entrant pockets referred to by Mr. Larminie did not exist, the angles having been filled by the wave-breakers. The situation of the structure (now forming a quay) used for the closing section was partly explained in the description of the sinking of the first of the two skewback caissons, and had been governed partly by the exigencies of curves around which the titan cranes might travel. Moreover, its inside position gave room for a longer ship to lie alongside the new quay. The Board of Trustees of the port had always had on it the best available local mercantile-shipping and railway opinion. But there were disturbing factors, chiefly financial—the difficulty of obtaining money out of the public purse, or from the private investor—which rendered futile much of the advice tendered by those who were best informed. In reply to Mr. Olive's comments about the apparently haphazard manner in which the railway arrangements had grown up, it must be explained that just south

Sir Francis
Spring.

of the "timber pond" on the sand accretion there stretched a couple of miles of what was known as the "military zone," which was nearly as inviolable as a London engineer would find the precincts of Westminster Abbey to be. The Indian military authorities still maintained a historic but obsolete fort on the land behind the accreted strip in question, and so long as this was considered necessary by these authorities—who doubtless had adequate reasons, financial and other, for not being able or for not being willing to move—a belt of land must, they said, be maintained intact around it, and they were very jealous of any infringement thereon. Had it not been for this disability, the entire railway system of the harbour might have developed on better lines. It so happened, however, that only a very small portion of the imports, except coal, went away direct by rail, and also that very little of the exports arrived by rail for direct shipment. Both must, for the most part, go first into the town, there to be stored, manipulated, marked, etc., and no delay was due at present to defects in the harbour railway scheme—defects patent enough to him, and in gradual process of correction as funds became available. The remarks which he had made on the subject of wind-protection in his reply to the oral discussion, and also (the late) Mr. F. E. Robertson's apt remarks about cyclones, would serve for reply to Mr. Adam Scott's and other correspondents' questions on the subject of shelter from wind. Large vessels moored close alongside solid quays in narrow basins, especially if screened by high sheds, were of course better able to stand up through severe wind-storms than if they were moored or quayed in an open harbour. But from the first and always at Madras it had been a question of money, and of not placing too heavy a burden, in the form of dues, on goods and vessels using the port, which still suffered severely from competition with some of the sixteen smaller ports in the Presidency. These, having spent no capital to speak of, were able to offer cheaper facilities than Madras did, and under conditions quite good enough for at least most raw materials. Critics acquainted only with white men's countries could with difficulty realize how easily, smoothly, and cheaply work often got done in the East in the absence of what in the West would be looked on as essential equipment: and who was to say that one system was better than the other? He had been amused to see the puzzlement of an Australian timber-merchant at the sight of hundreds of enormous squares of timber being handled deftly by a swarm of little naked brown men, instead of needing, as in Australia, several hundred pounds' worth of equipment in cranes, teams, wagons, and sidings. The one and only true test in the long run

Sir Francis
Spring.

was the commercial test, "Does it pay?" If the Madras Port Authority could be sure of raising as much money as it needed at 4 per cent. it would probably do so, and get on quicker to the desired state of efficiency, trusting to the slow but sure growth of its trade to enable it to provide for its sinking-funds without having to impose such dues as were certain to drive its trade to cheaper rival ports. Mr. Cyrus Williams's remarks as to the altered aims of the shipmaster of to-day as compared with those of his fellows of a generation ago, were very much to the point, and ought to enlighten those who asked with undue persistence for unattainable shelter from winds. Mr. Williams referred also aptly to a suction dredger carrying out to sea a mixture of clay and water in her hoppers, instead of waiting for it to settle. Recently at a place near the outer arm at Madras a mass of fine deposit had accumulated—that was, deposit fine enough to be carried in suspension by the feeble local currents, instead of being wave-beaten like the heavier sand. Messrs. Simons and Company's dredger "Madras" worked for some weeks in this way, not waiting for the slurry to settle in her hoppers, but carrying out to sea a pea-soup kind of mixture several times a day, with excellent results. Referring to Mr. Wilson's comments, the ideal of an inner harbour for steamers was, of course, the right one. What more than all else had prevented its realization was first the attitude taken up by the military authorities in setting a higher value on such strategic considerations as attached to a fort entirely useless for all the purposes of a fort, as nowadays understood, than on the requirements of a steadily developing commercial seaport. This effectively, for the present, prevented all expansion in the only possible direction, namely, southward. But if at any future time Fort St. George were relegated to the melancholy limbo where the ghosts of bows, arrows, and catapults were to be found, and if at the same time an at present unattainable half-million or one million sterling became available to the Port Authority, it would be found that nothing had been done meanwhile to prejudice the question of deep-basin construction and more suitable railway-arrangements on the south accretion. For the advantage of the reinforced-concrete wharfing around the boat-basin was that it was capable of being lifted up, practically uninjured, for use elsewhere, so there was nothing to prevent the sinking of deep well foundations for the walls of a future inner harbour. If, however, he had waited for all this, instead of hammering away continually at the provision of every possible facility for the better handling of the trade of the port, everything would to-day be precisely as it stood 8 years ago. But

Sir Francis Spring.

there was another consideration, not perhaps realized by Mr. Wilson, which weighed largely with those now concerned with the future of the port, namely, the probable need, within a generation, for accommodation for ships of deeper draught, in view of the deepening of the Suez Canal, and perhaps also the construction of a ship-canal to get round the shallows of the Hooghly. In the later Paper which he had presented to The Institution on the subject of "Sand-Movement at Madras," the probable need of a future deeper harbour was adumbrated, and its probable site indicated. Should it ever be needed, the present harbour would not be deep enough, nor could its fairway and entrance well be kept deep enough, to serve as an entrance for vessels to quays adapted to serve the needs of the deeper-draught vessels of the future. The following information was given in response to the request of Mr. Buchanan, whose bold river-training work at Rangoon he had studied with great interest. The number and net registered tonnage of steamers entering Madras in 1911 and 1901 respectively were 558, with a total tonnage of 1,614,558 tons, and 153, of 1,220,310 tons. Two of the steamers of 1911 were over 5,000 tons, registering 11,588 tons for the two. None of those of 1901 were of over 5,000 tons register. No steamers in either year were of more than 28 feet draught. The tonnage of goods handled at the port in the 10 years ending the 31st March, 1912, was: imports, 4,889,146 tons, and exports, 1,295,385 tons. The receipts from goods in the same 10 years were Rs.92,08,902, or £613,927. Working-expenses, excluding interest and amortization of debt, came to Rs.43,82,450 (£292,163), or 47·6 per cent. The charges on shipping, as distinguished from those on goods, formed a separate fund, of which, in the same 10 years, the receipts totalled Rs.13,33,205 (£91,547), and the surplus, after meeting all working-expenses, made over to the Port Trust account amounted to Rs.4,58,500 (£30,570). The total value of the trade passing through the port, as given by the Imperial Customs Department, was £14,143,693 in 1911-12 and £9,239,520 in 1901-2, showing an increase in value averaging about 5·31 per cent. per annum. But 1911-12 was a very poor year, and its results were being greatly surpassed in 1912-13.

In conclusion, he desired to express his appreciation of the courtesy extended to his Paper by the members of The Institution, and his regret that he had not been able to be present at the meeting at which it was read. However, Mr. Mitchell, whose co-operation he desired again to acknowledge gratefully, appeared to have seen it through very effectively.

23 April, 1912.

ROBERT ELLIOTT-COOPER, Vice-President,
in the Chair.

It was resolved—That Messrs. E. R. Dolby, C. O. Grimshaw, B. M. Jenkin, E. W. Monkhouse, R. J. G. Read, L. S. Robertson, H. F. Rutter, A. W. Szlumper, and A. T. Walmisley be appointed to act as Scrutineers, in accordance with the By-Laws, of the Ballot for the election of the Council for the year 1912-13.

The Council reported that they had recently admitted as

Students.

RALPH PHILLIPS CLEARY.
HAROLD DREW.

MARTIN PICK.

The Scrutineers reported that the following Candidates had been duly elected as

Members.

GEORGE LEONARD ANDREWS, B.Sc.
(*Lond.*).
GODFREY THOMAS BRADLEY.
COLLINGWOOD ROSS DUGGAN.

ERNEST JOHN ELFORD.
HARRY ERLEGH FOOTNER.
JAMES HERON, B.E. (*Royal*).
SAMUEL FRANCIS SMITH.

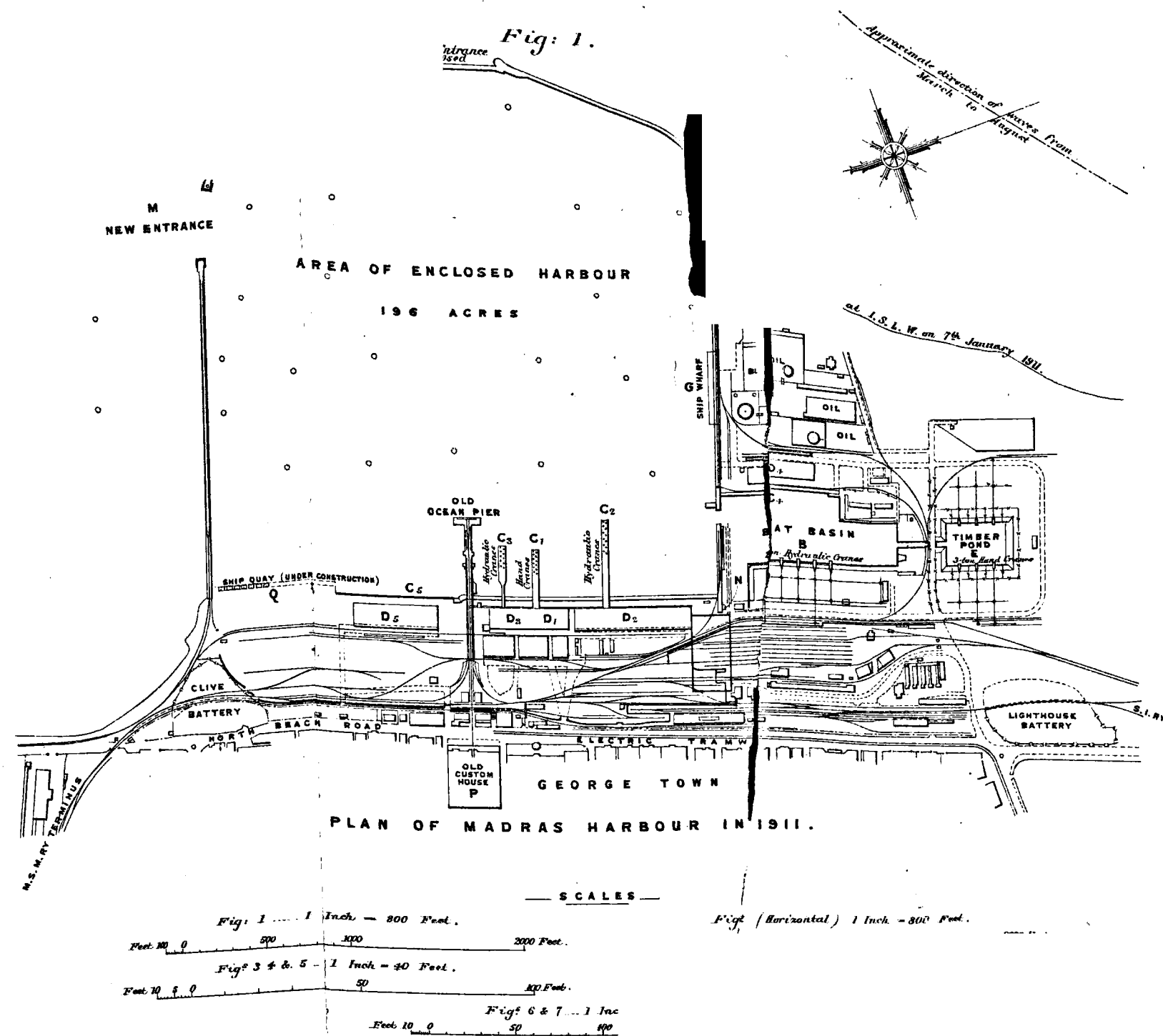
Associate Members.

FREDERICK JAMES AINSLEY, Stud. Inst.
C.E.
JAMES BACON, Jun., Stud. Inst. C.E.
WILLIAM FREDERICK CULLY.
OLIVER CARL DANIELL.
MARMADUKE STEPHEN DUFFITT.
BERTRAM WARREN ELLIOTT.
EDWARD JOSEPH FOTTRELL, B.Sc.
(*Leeds*).
HAROLD MARRIOT GELL, Stud. Inst.
C.E.
STEPHEN GLENNIE, Stud. Inst. C.E.

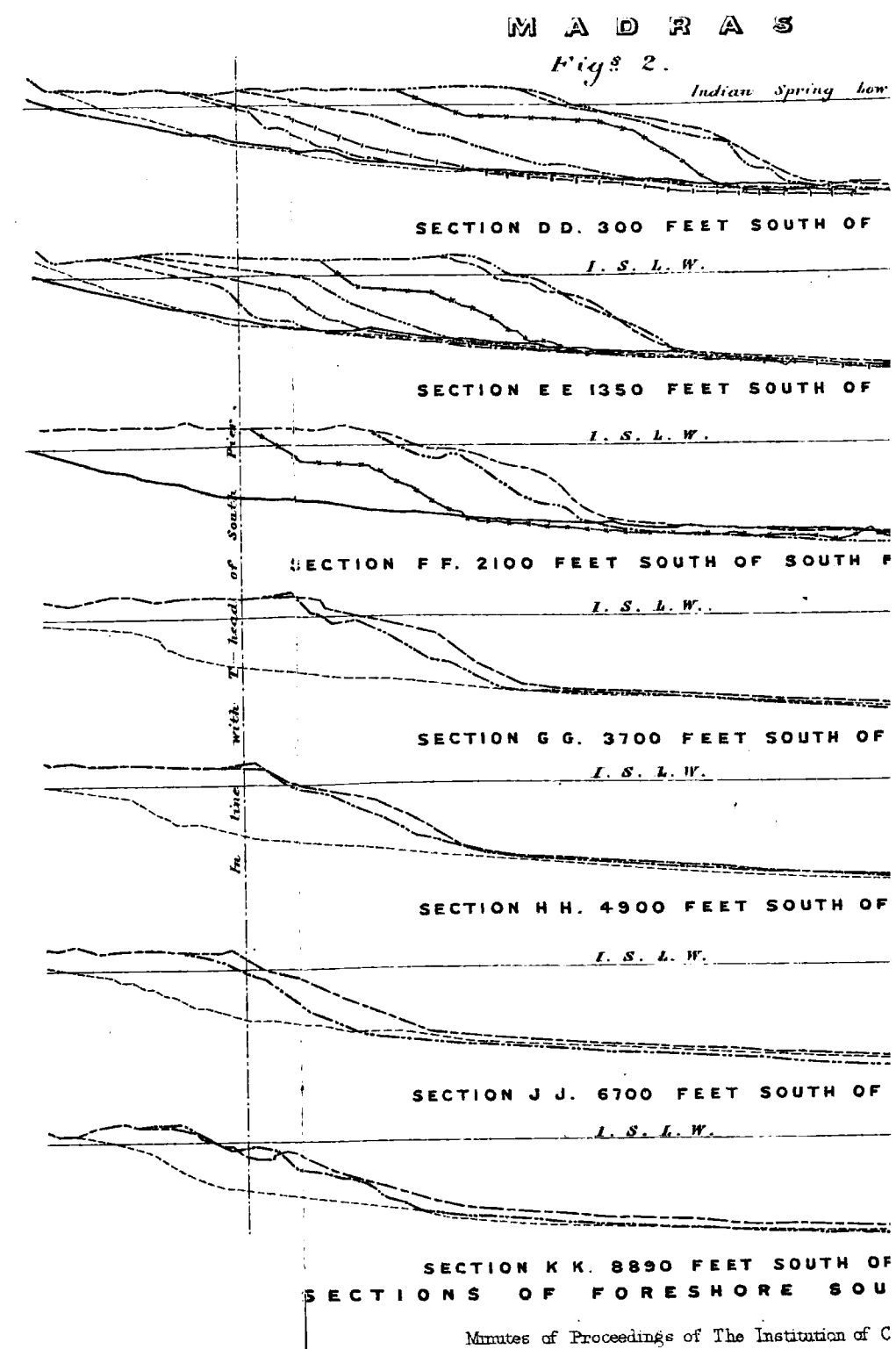
WILLIAM GRAHAM, B.Sc. (*Durham*),
Stud. Inst. C.E.
WILLIAM HOPE MASTERTON JAMESON,
B.Sc. (*Victoria*).
RONALD VIVIAN LIGHT, B.Sc. (Engi-
neering) (*Lond.*).
ALISTER MACKINNON, Stud. Inst. C.E.
JOHN MCGREGOR MORRIS, Stud. Inst.
C.E.
WILLIAM HOGARTH ROBERTSON NIMMO,
B.C.E. (*Melb.*).
CLIFFORD RAMIRO SHADDICK.
WILLIAM EDWARD WOODBRIDGE.

The discussion on the two Papers on Madras Harbour, by Sir Francis J. E. Spring and Mr. H. H. G. Mitchell, was continued and concluded.

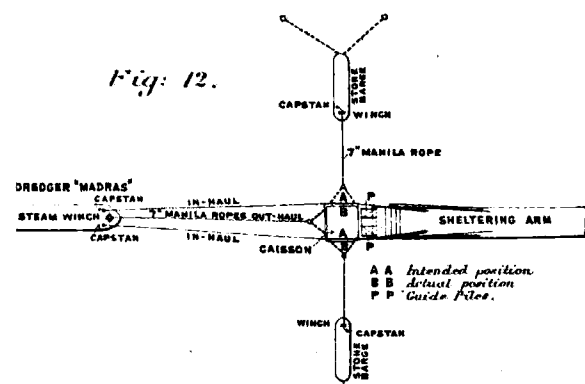
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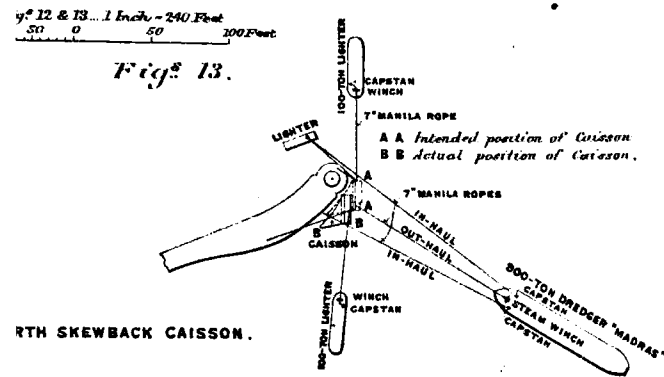
THOS KELL & SONS, LITH. 40 KING ST COVENT GARDEN.



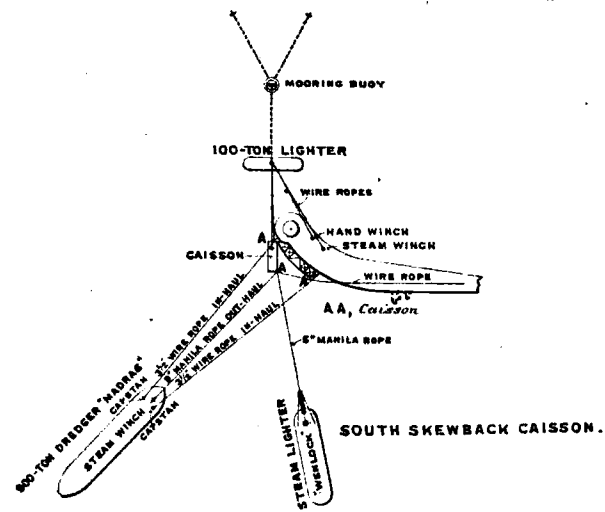
H A R B O U R .



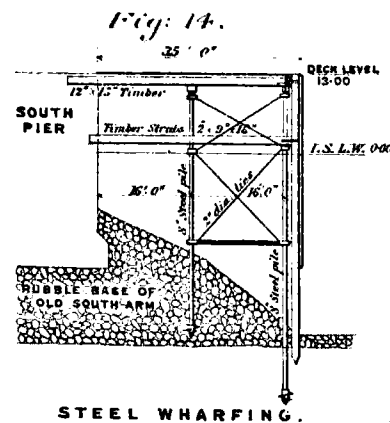
SINKING CAISSON AT NORTH PIER



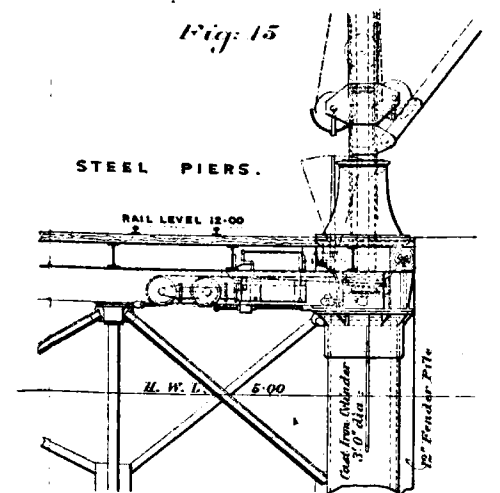
RTH SKEWBACK CAISSON.



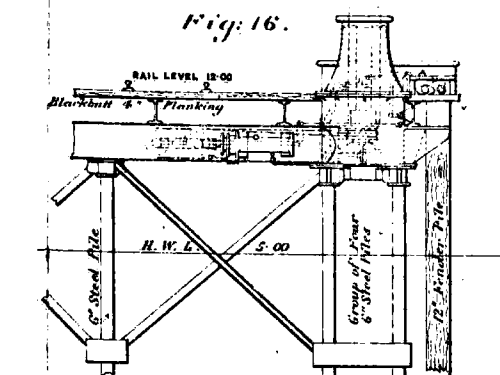
SINKING GEAR AT OLD ENTRANCE.



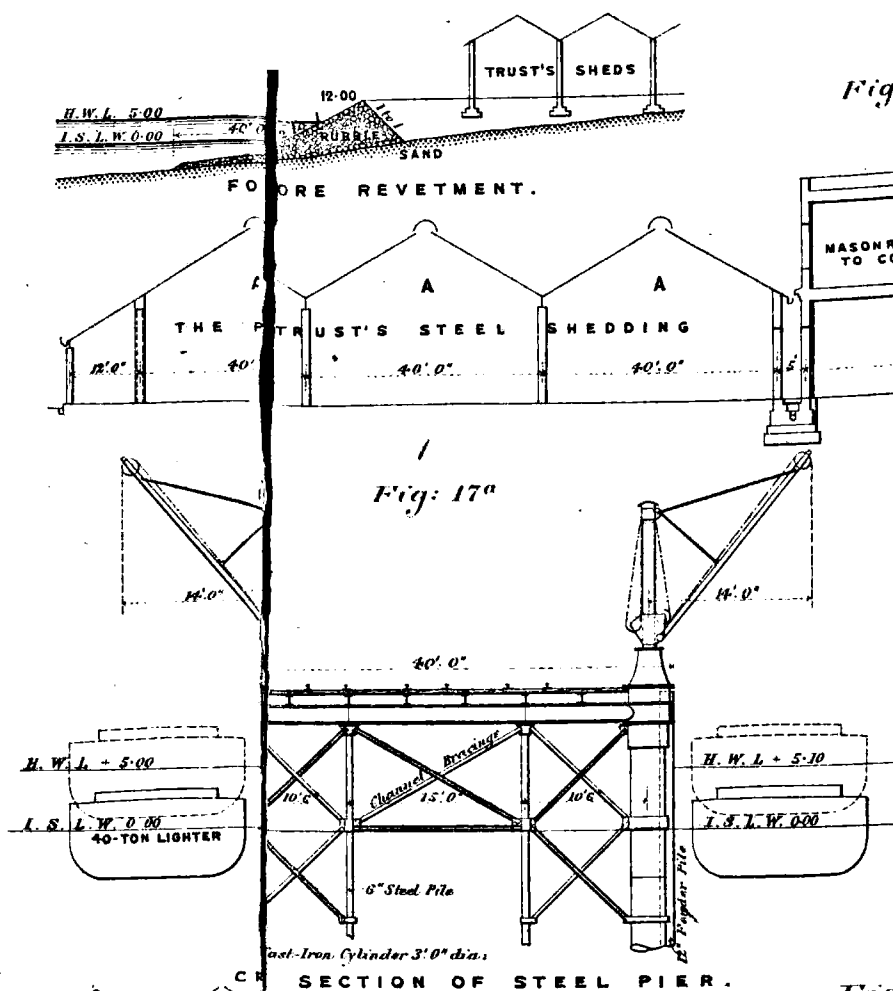
STEEL WHARFING



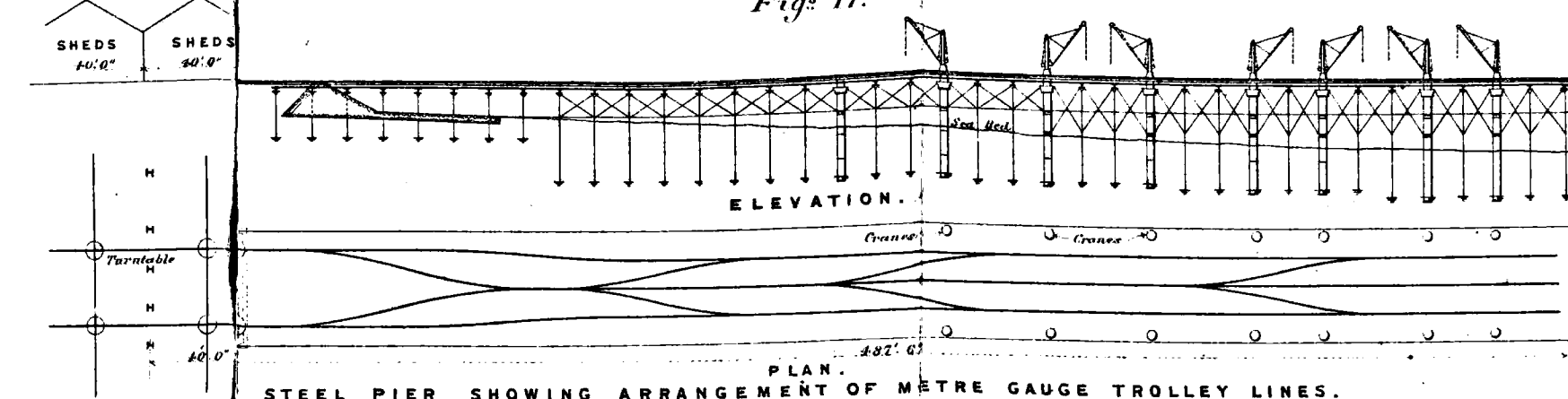
DETAILS OF CRANE SUPPORT ON CYLINDERS.



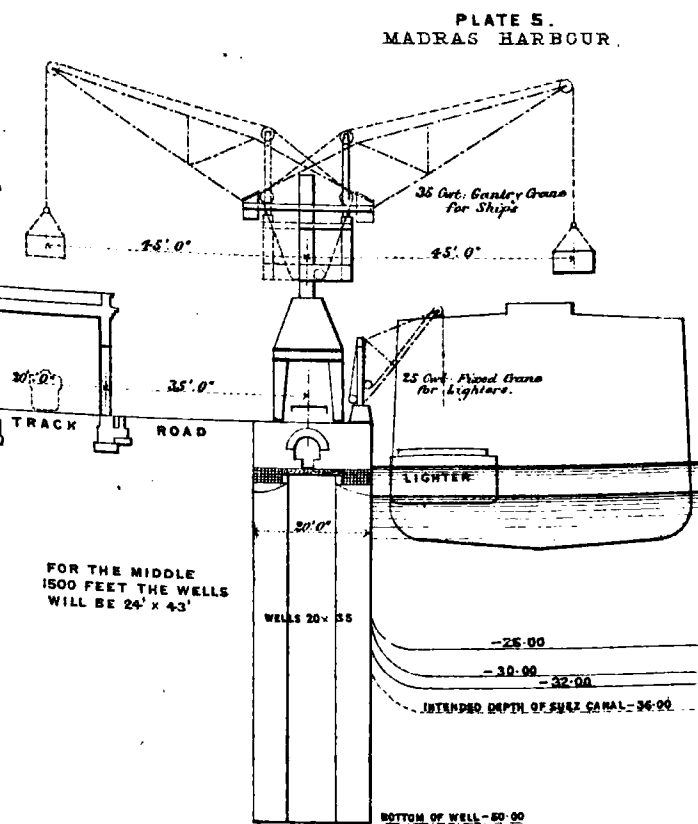
DETAILS OF CRANE SUPPORT ON PILES.



SECTION OF STEEL PIER



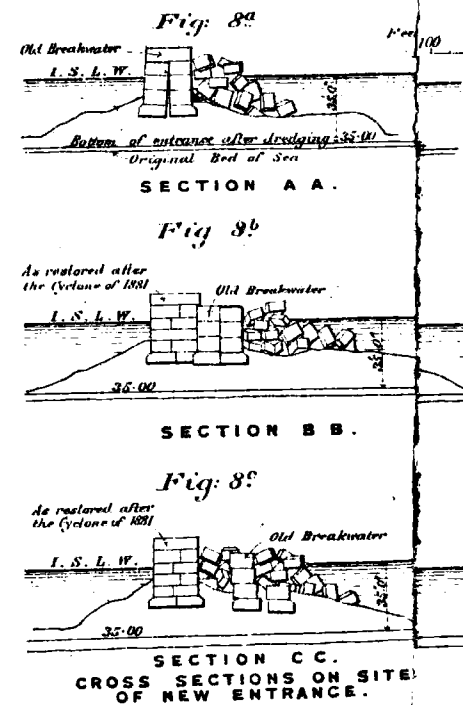
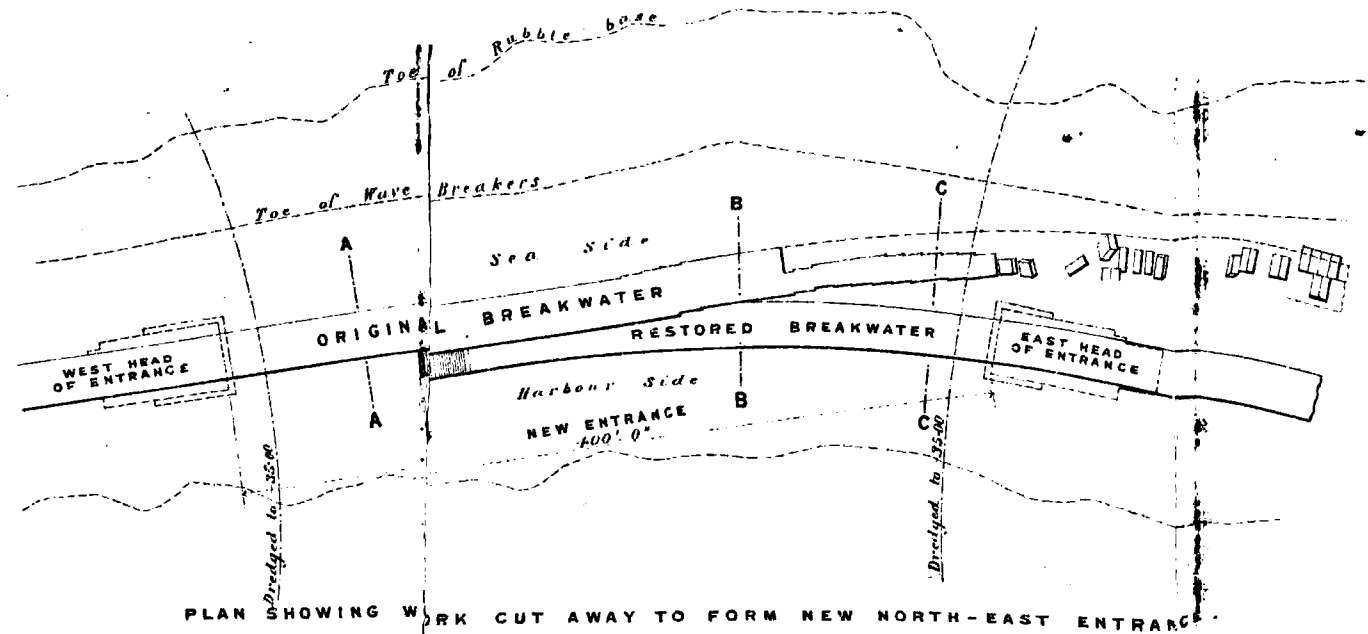
STEEL PIER SHOWING ARRANGEMENT OF METRE GAUGE TROLLEY LINES.



PROJECTED SHIP-QUAYS
SHOWING TRACKS, ROAD AND SHEDS.

Note: One Quarter of this scheme is now in hand.

Fig: 8.



THOS KELL & SON, LITH. 40 KING ST COVENT GARDEN

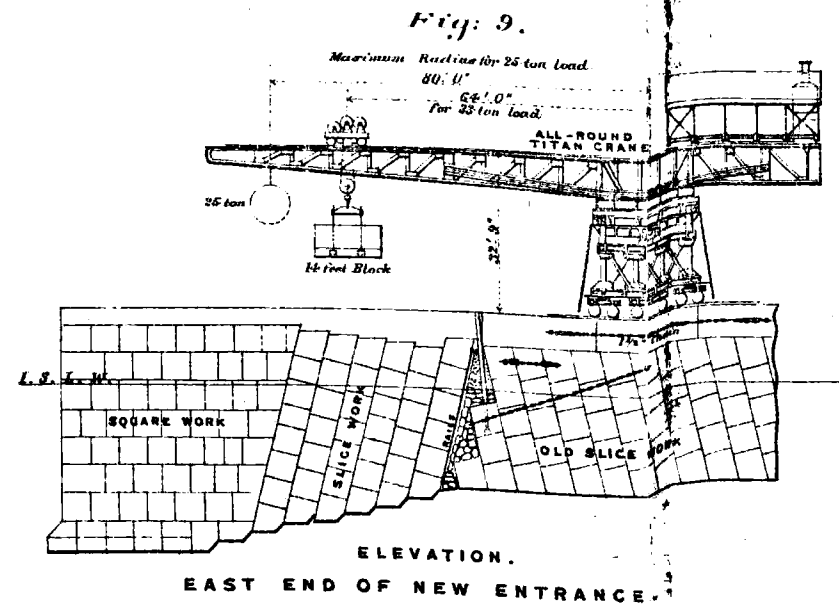


Fig: 10.

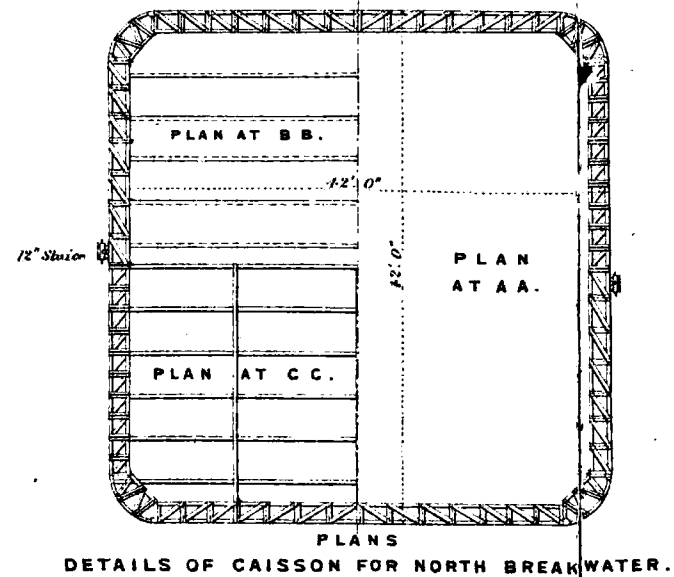
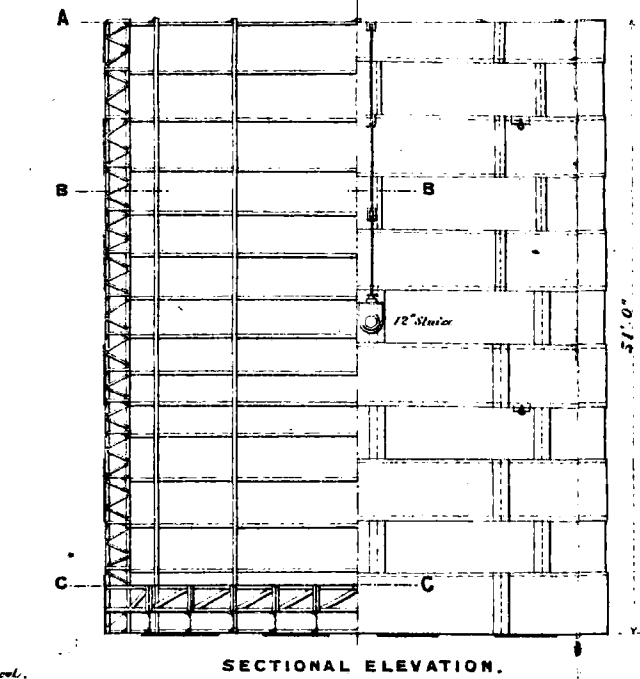


Fig: 11.

