Archives I—10,006—16-8-77.

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AMIL NADU ARCHIVES

VERNMENT OF TAMIL NADU

PUBLIC WORKS DEPARTMENT

G.O. No. / B.P. No.	Press. / Mis.
780, 781 & 782. W	
Dated 23.3.1882.	197 .

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GOVERNMENT OF MADRAS.

PUBLIC WORKS DEPARTMENT.

23rd March 1882, No. 780 W.

Buildings and Roads.
Civil Works.

Read the following papers :—

No. 182. From the Engineer-in-Chief, Madras Harbour Works, dated 9th March 1882.

No. 182-A. NOTE BY THE CHIEF ENGINEER.

In the annexed Report of the 9th March Mr. Parkes describes with clearness and precision the effects of the cyclone of the 12th November 1881 on the Madras Harbour Works, and although the whole of the sections cannot be completed for some little time, and may possibly, from the roughness of the sea, be delayed, there is apparently no reason on this account to defer the decision as to the further prosecution of the works.

2. As to the validity of the contentions put forward by Mr. Parkes in paragraphs 39 to 42 there can hardly be any doubt, and were his estimate for the requisite work to amount to even much more than his highest one of 18¼ lakhs, it would be both desirable and profitable to complete the harbour with the least practicable delay.

3. The total outlay to date, including the revetments north of the harbour, and excluding the esplanade and jetties, which are paid for from Port Funds, amounts to 57½ lakhs, but with even the large additions now proposed it would be a comparatively cheap harbour considering that it is entirely artificial, and that difficulties of an exceptional nature have had to be overcome.

4. The revised section which, by paragraph 30, Mr. Parkes proposes to give to seaward arms is almost identical in width with that of Sir John Coode's Columbo work, which, as will be remembered, was brought under the notice of Government (G.O., 8th June 1881, No. 1436 W.,) by the undersigned and the Master Attendant after they had visited that work early last year; and were there no other circumstances as revealed by the late storm to be taken into consideration, might be accepted as a satisfactory disposal of the matter.

5. In some respects the new section is stronger than that of the Columbo work—

(1) the vertical tenons *quantum valeat* counteract the tendency of the concrete blocks to slide on each other, and the proposed cramp between blocks Nos. 7 and 8 will give considerable cohesion to the whole ;

(2) the combined new blocks, *c* and *d*, form a better top to the rear face than in the Columbo work, and

(3) the toe blocks, *f*, if closely set in the form of a continuous apron should be a more efficient protection against the scour down the vertical face of the wall, which acted so seriously on the rubble base, than *pierres perdue* flooring.

6. It may be thought that stone tipped over the seaward face after positioning blocks *f*, would be beneficial as tending to afford a protection to the toe of these blocks, after the loosly packed rubble has been dragged outward by the action of the sea, but this is a detail which can easily be considered as the work advances.

7. It will be observed (paragraph 34) that Mr. Parkes does not intend to increase the section of the straight portions of the breakwaters which were uninjured, or to do more than to feed the foreshores with heavy granite blocks and cramp the upper concrete blocks together; although however these portions of the work escaped almost intact on the 12th November, and though they may continue to enjoy immunity from attack for a long period, it may be doubted whether the small work to them now proposed would suffice, or that, in case his present plan be accepted, at least the addition of a properly constructed apron with blocks *f*, would not be desirable for one-third or a half of their outer lengths.

8. The proposals now put forward rest, it will be observed, chiefly upon the following considerations:—

1*st*. That, as remarked in paragraph 33, "it is quite outside the limits of reasonable probability that we shall have to encounter a force of sea so much greater than that of the late storm as the strength of the new section would be greater than the old."

2*nd*. That although the rubble base has subsided on an average of 2 feet and has been scoured along the seaward faces and flattened out it has not been materially disturbed.

3*rd*. That the concrete blocks at base of the wall, Nos. 1, 2, 3, and 4, remain for all practical purposes unmoved, and are in many respects even better suited for building on than before, throughout not less than two-thirds of the total length of the damaged portion of the work.

9. The first of these contentions is clearly the one upon which all must depend, and as regards this it may fairly be asked whether the storm of the 12th November supplied a sufficiently crucial test of the forces which may be expected to be called into action in a cyclone of maximum intensity.

10. Though doubtless the seas were much heavier than might have been expected from the comparatively low recorded wind pressure at Madras, as also from other phenomena connected with the storm, many high authorities would be unprepared to accept the cyclone of the 12th November as having the required character; but even as regards this storm such as it was, it is now admitted (paragraph 12) that the action of the waves extended far lower than was apparently ever recorded by Engineers before in other parts of the world.

11. As observed by Mr. Parkes in paragraph 13, "This is an effect I should never have anticipated, and I can only account for it by the supposition that there is some peculiarity in the cyclone-raised disturbance to which the apparently heavier seas on the English coast have nothing analogous." He shows in fact that whereas it has been proved "by the general practice of Engineers at home that 15 feet below low water is safe, *foundations at a depth of* 22 *feet under water are not proof against a cyclone sea*" in Madras, and adds, in paragraph 22, that near the curved portions of the breakwaters, where the disturbance was greatest, "the original sandy bottom was scoured away 6 or 7 feet outside the rubble." The disturbance must thus have reached down to 35 feet below low water at least.

12. From the action of the waves during the storm the rubble in the base which had originally been heaped up from 3 to 4 feet above the bottom of the lowest seaward block (No. 1) was lowered by that amount, plus 2 feet which these blocks sunk on an average and in many places to the extent of undermining the block, the loose material being dragged outwards and the whole foreshore flattened. At the depth mentioned of 35 feet there seems to have been a general deepening of the sandy bed.

13. The mean level of the sea at Madras during the storm of the 12th November is shown to have been raised over 2 feet, and that sea movement reaches during abnormal disturbances to much greater depths than is commonly supposed is proved by the recorded fact that, on the banks of Newfoundland the agitation during storms has affected the bottom at a depth of over 80 fathoms. At St. Jean de Luz it has reached to 160 fathoms, and at Lands end the lobster straps are frequently filled with coarse sand and shingle during heavy ground swells at depth of 30 fathoms. Sir G. Airey mentions also that ground swells frequently break in a depth of 100 fathoms. It may in fact be inferred that we are in the presence of forces which cannot at present be sufficiently gauged, and the reasoning on which the monolithic system of reconstruction rests is incomplete. There is apparently insufficient ground for Mr. Parkes's contention (paragraph 24) that there is not the "slightest justification for reopening the worn out question of the relative merits of random and placed blocks, or of bonded and unbonded work."

14. On the contrary there would seem to be ample grounds for considering the question of adopting or rejecting the monolithic system for Madras as still open. With a bonded wall, such as that proposed, it needs but little imagination to infer what the effect would be of a succession of heavy seas (such as those shown in the plan facing page 2) precipitating themselves over the seaward arms, or how the impact communicated to the first attacked blocks would send a vibration and quiver in advance which must go far to loosen and weaken the stability of the mass—every succeeding blow shaking the structure from end to end. Even where the piers had a thickness of four blocks at the ends of the seaward arms, the impact was such as to ruin them quite as easily apparently as where there were only two blocks.

15. Again, it must be clear that the stability of a structure of this particular form must in great measure depend on whether the foundations are such as can safely withstand the scour which takes place down the face of the wall, or the disturbances due to the general cyclonic action before alluded to, which tend to drag out and flatten the material of the rubble base as during the late storm.

16. With a structure having its upper portion constructed of random blocks of sufficient size, the action being on the individual block, no general vibration can be communicated to the mass, and the seas must get broken up in a manner which is quite impossible with a structure on the monolithic system; the work could in fact hardly be destroyed, though individual blocks might be displaced.

17. The undersigned does not bring forward this as an original suggestion, as he was given to understand by Mr. Molesworth that, although possibly not for precisely the same reasons, the random block system was that which generally recommended itself to him. He will necessarily soon lay before the Government of India the results of the joint inspection of the works made lately by Lieutenant Stiffe and himself.

18. In regard to outlay, Mr. Parkes shows in his maximum estimate that about Rs. 3,20,330 and in his minimum Rs. 1,06,780 would be required for removing the broken blocks to enable him to clear the ground for his new structure, and admits (paragraph 29) that "the immense difficulty of clearing the ground of broken blocks" constitutes the "great objection" to the plan advocated by him.

19. While this trouble and expense would be saved by a system which would only aim at throwing in blocks at random when required to supplement present deficiencies and allow the sea to do the rest, it is believed that steam barges carrying shear legs could be designed on much the same principle as those used in placing the 370 ton blocks in the Dublin Quay Wall, which could be trusted to do the work economically and expeditiously.

20. With the almost ceaseless swell at Madras some difficulty may, it is true, be experienced in designing the vessels required having the needful steadiness, but with twin-barges and a proper system of guying the blocks this should disappear, or at least be sufficiently minimised: a system of tipping might also be adopted without necessarily using shear legs. The barges could be moored close to the seaward face of the work in depositing the blocks, and could be kept in reserve after completion of the Harbour for rectifying future damages—a matter of importance.

21. As more material would have to be used than in Mr. Parkes' scheme, it is not improbable that on the whole, even allowing for the savings adverted to, the expense would be greater; but without entering into detailed calculations, it cannot be supposed that the total could exceed at the outside 25 lakhs. This should include the extra apron of blocks previously alluded to for the straight portions, and also such extra dimensions to the rubble base and superstructure of blocks as may be

needed to counteract the excessive action on the portions near the curves, where the damage was greatest.

22. As regards the closure of the eastern entrance to the Harbour, while there can be little doubt that there is a greater disturbance of the surface within the enclosed area than was anticipated, Mr. Parkes' arguments against taking up the subject at present (paragraphs 43 to 45) appear to be conclusive.

23. In conclusion it may be hoped that, notwithstanding the inevitable delays attending the decision regarding a question of such magnitude, there may be no cessation in the preparation of the materials required for the completion of the work. Should the random system of reconstruction be eventually adopted, probably not less than 35 or 40 ton blocks of a special shape will have to be manufactured for the most exposed portions, but for the filling in of the lower parts the present 27 ton blocks, or such others as Mr. Parkes would require for the monolithic system, would amply suffice. There should thus be no necessity to hesitate in reference to manufacturing concrete blocks of the sizes required by Mr. Parkes, or of quarrying granite for feeding the foreshores.

24. A limit of 3 lakhs of rupees might with these objects be at once appropriated for 1882-83, subject to future increment if considered necessary. As to the immediate construction of new Titan cranes as required by Mr. Parkes, that must entirely depend on the decision arrived at by superior authority on the general subject of the restoration.

CHEPAUK,
13th March 1882.

(Signed) R. H. SANKEY, Colonel, R.E.,
Chief Engineer, P.W.D.

No. 183. ORDER THEREON, 23rd March 1882, No. 780 W.

ORDERED that the report above recorded and the Note by the Chief Engineer, Public Works Department, be forwarded to the Government of India for early orders, a copy being also sent to the Secretary of State.

(Here enter No. 781 W., dated 23rd March 1882.)

(True Extract.)

(Signed) R. H. SANKEY, Colonel, R.E.,
Secretary to Govt., P.W.D.

To the Engineer-in-Chief, Madras Harbour Works.
" Superintendent, Madras Harbour Works.
" Marine Department.

Exd. A. F. Goodall.
Spare Copies

BUILDINGS AND ROADS.
CIVIL WORKS.

Govt. of {1882} Madras.

PUBLIC WORKS.

To

THE ENGINEER-IN-CHIEF,
MADRAS HARBOUR WORKS,
&c., &c., &c.

Dated March, 23rd.

Issued

Recd. *Encl.*

G.O., 23rd March 1882, No. 780 W.

MARCH.

Nos. 182-183.

Madras Harbour Works.—Report by the Engineer-in-Chief of the — and Note by the Chief Engineer, Public Works Department, on the nature and extent of the damages sustained by the — and the estimated cost of the works, forwarded to the Government of India for early orders.

PUBLIC WORKS DEPARTMENT.

Buildings and Roads.
Civil Works.

No. 781 W.

No. 184.

FROM

THE SECRETARY TO THE GOVERNMENT OF MADRAS,
Public Works Department,

To

THE SECRETARY TO THE GOVERNMENT OF INDIA,
Public Works Department.

SIR,—In continuation of the correspondence quoted in the margin on the subject of the damage to the Madras Harbour Works by the storm of the 12th November 1881, I am now directed to forward, for the early orders of the Government of India, copy of a report by Mr. Parkes, the Engineer-in-Chief of the Harbour Works, on the extent of the damage, on the measures requisite for repairing it and providing against its recurrence, and on the estimated cost of the work. The report is accompanied by a Note by the Chief Engineer, Public Works Department.

Letter, No. 2955 W., of 25th Nov. 1881.

2. Should the Government of India, after taking the best professional advice available, concur in the proposals made by the Engineer-in-Chief, I am to request that the requisite authority for preparation of materials may be communicated by telegraph as requested in my letter, No. 505 W., dated 23rd February 1882.

3. The estimated cost of repairing the damage and providing supplementary strengthening works is set down at 18¼ lakhs, to which must be added a sum of Rs. 2,94,000 for compensation for damage to private property north of the Harbour and the acquisition of land in that direction still threatened.

I have the honor to be,

Sir,

Your most obedient servant,

Lieut.-Col., R.E.,
Ag. Under Secy. to Govt., P.W.D.

FORT ST. GEORGE,
23rd March 1882.

Exd. A. F. Goodall.
Spare Copies

BUILDINGS AND ROADS.
CIVIL WORKS.

Govt. of {1882} Madras.

PUBLIC WORKS.

To

THE SECRETARY TO THE
GOVERNMENT OF INDIA.

Dated March, 23*rd*.

Issued

Recd. *Encl.*

23*rd March* 1882, *No.* 781 *W.*

MARCH
No. 184.

MADRAS HARBOUR WORKS.—Report by the Engineer-in-Chief and Note by the Chief Engineer, Public Works Department, on the nature and extent of the damages sustained by, and the estimated cost of, the works.

From the Engineer-in-Chief, Madras Harbour Works, to the Secretary to Government, Public Works Department, dated Madras, 9th March 1882.

Madras Harbour.

I HAVE now the honor to submit to you my report on the damage to the above works caused by the storm of the 12th November 1881, and my proposals for their restoration.

2. It has been delayed longer than I could have wished, owing to the great difficulty of obtaining detailed measurements and sections, which require an exceptionally calm state of the sea. Upon the results shown by these depend in a great measure our conclusions as to the particular action of the sea which produced the damage. I have thought it desirable to delay the submission of my report until I had obtained such facts as were necessary, not only to form a basis for my own positive conclusions, but also to test beyond the possibility of doubt the correctness of the conclusions which have been put forward by others upon a more or less imperfect knowledge of the facts. I may here mention once for all that I have given careful consideration to various suggestions that have been made to account for the damage, but I do not think it necessary to notice these as a rule, but rather to submit my own conclusions, with the facts on which they are based.

3. PREVIOUS REPORTS.—I wish however to explain my position with regard to two documents of very great interest, the first being a report which was made only two days after the storm by the Chief Engineer of the Presidency, who with great promptitude availed himself, in company with the Master Attendant, of a specially favorable opportunity of taking what was necessarily a very general view of the state of the works. This report was forwarded "*with all reserve*" to the Secretary of State, and I had an opportunity of perusing it before I left London. If I were to comment upon the suggestions made in this report as to the particular action of the sea, it would give them a prominence which the author probably never intended they should possess.

4. The other document is a very excellent report made by Mr. Thorowgood on the 21st November, nine days after the storm, which is especially noteworthy as showing how much information can be obtained in a short time. But this information, though generally confirmed by subsequent observations, was not sufficiently complete to form a basis for practical conclusions, and what was then wanting had to be obtained with considerable difficulty afterwards. It is scarcely possible to make an intelligible statement of facts without conveying some suggestion of conclusions to be drawn from them, and in some cases such suggested conclusions fail to be confirmed by the facts subsequently ascertained. To a slight extent this is the case with Mr. Thorowgood's report, but it is no disparagement of its merits to ask that it may be considered as superseded, even if generally confirmed in its conclusions, by the present report, and in its facts by the plans and sections which will be submitted to Government, and will, I think, form a very interesting and instructive record.*

5. MR. THOROWGOOD.—I should mention that I had the advantage of five weeks' constant communication with Mr. Thorowgood before he left for England, and during that time, as further materials accumulated, we were able to form more definite conclusions, and those conclusions, independently formed by each of us, were in all essential matters the same. They included, subject to corrections suggested by the further surveys which have since been made, most of the recommendations which I am about to submit.

* These are still in progress. At the end of the present fine season so much as is complete will be submitted to Government.

6. The Storm.—The storm is thus described in the official Meteorological Report issued by the Government Astronomer on November 23rd 1881 :—

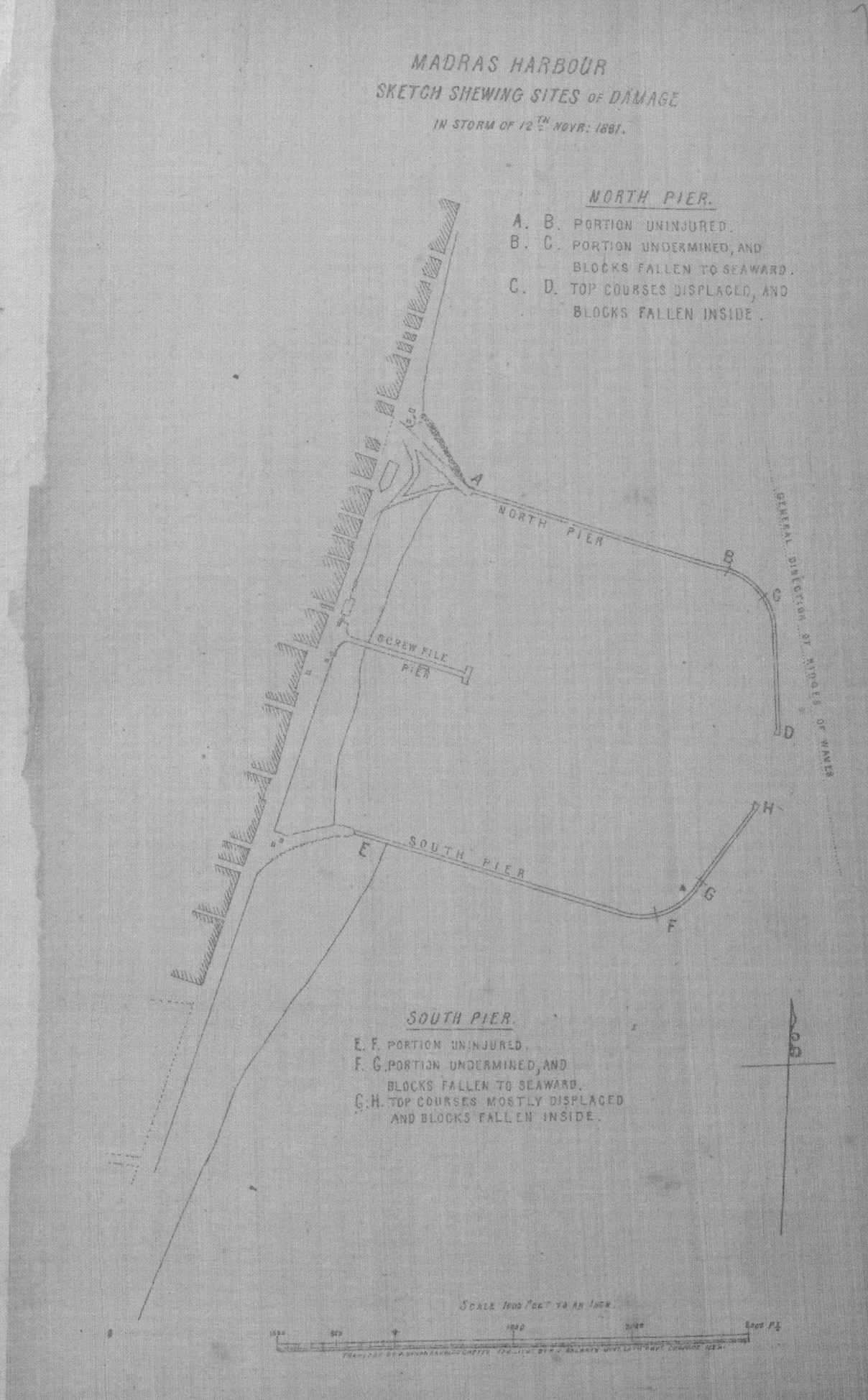
"A cyclone visited Madras on Saturday and Sunday the 12th and 13th instant. It appears to have exhausted its greatest force while crossing the Bay before reaching the coast of Southern India, which would account for the high and destructive sea, far beyond what might have been expected from the meteorological indications accompanying its progress. The centre of the storm must have struck the coast considerably southward of Madras. The lowest reduced reading of the barometer was 29·51 at 4 P.M. on Saturday; and the strongest wind was experienced between 11 P.M. and 2 A.M. on Sunday, during which time it averaged 32 miles per hour in velocity, equivalent to a pressure of about 5¼ lb. per square foot. Rain commenced at 1½ A.M. on Saturday and continued until 8 P.M., amounting in all to 8·19 inches—the twelfth heaviest fall on record at Madras since 1803. No single hour was extraordinarily excessive, but the persistence of both wind and rain was remarkable. The veering of the wind was as usual for cyclones southward of Madras. The records of the anemograph furnish the following mid-times for each principal point of the compass with the corresponding hourly velocities :—

N.W by W.	at	2½ P.M.	velocity 20 miles.	E.N.E.	at	1½ A.M.	velocity 33 miles.
N.W.	at	3½ P.M.	do. 29 do.	East	at	2½ A.M.	do. 25 do.
N.N.W.	at	6½ P.M.	do. 23 do.	E.S.E.	at	4½ A.M.	do. 18 do.
North	at	7¾ P.M.	do. 27 do.	S.E.	at	7½ A.M.	do. 14 do.
N.N.E.	at	8½ P.M.	do. 30 do.	S.S.E.	at	9½ A.M.	do. 14 do.
N.E.	at	10¾ P.M.	do. 31 do.	South	at	10½ A.M.	do. 13 do."

7. The Astronomer here alludes to the fact, to which I have myself frequently had occasion to advert, that there is no relation between the force and direction of the wind in the neighbourhood of a cyclone and those of the sea which may accompany it. The sea is raised, not by the wind which may happen to be blowing at the time at any given spot, but by an intense atmospheric disturbance at a distance, that is in the centre of the cyclone, and from the site of that atmospheric disturbance (which when the wind is from the north-west at any place will lie between north-east and east of that place) the sea disturbance will proceed, propagated by laws which, so far as we know, have no similarity whatever to those by which the atmospheric disturbance itself is propagated. On this occasion the maximum velocity of the wind at Madras was 33 miles per hour; on occasion of the great storm in May 1872 the velocity was 53 miles per hour; in May 1874 it was 49 miles per hour; while in May 1877, when the concrete block work of the north pier had advanced about 300 feet, the sea was nothing like so severe as in last November, though the velocity of the wind was 34 miles per hour.

8. The testimony of all observers is to the effect that the sea of 12th November must rank with those of the great historical cyclones, though there is a conflict of evidence as to whether it was actually as heavy or heavier. Mr. Chisholm, the Government Architect, a very intelligent and close observer, speaks confidently as to the recent sea being considerably heavier than that of 1872; but on the other hand, the officers of the Marine Department, who witnessed both storms, give the palm to that of 1872. A rough test is afforded by its action on the planking of the screw pile pier 17 feet above mean sea level. This was torn up in 1872, in 1874, and again in 1881, but it is uncertain whether on the last occasion the effect of the Harbour Works would be to reduce the waves at the site of the pier (as I have no doubt was the case over the area of the harbour generally), or to aggravate them by the confusion which would be caused by their rolling in over the piers as well as through the entrance. The end of the pier is just outside the line in which the first break of the waves occurred, and the height there was no doubt abnormally raised.

9. As compared with the force of sea in other places the evidence is also unsatisfactory. Mr. Bhoomya Saenna, Sub-Engineer, is the only person who could compare this sea with that raised by the south-west monsoon at Kurrachee. He considers the waves were not higher, but the succession of them was more rapid. The maximum height measured at Kurrachee was 15 feet. Mr. Chisholm estimated about the same height for the late storm at Madras,* and at both places independent testimony fixed the depth of solid water passing over the breakwaters at about 20 feet.



10. Mr. Thorowgood did not consider this sea to be so heavy to all appearance as those he had witnessed at the mouth of the Tyne, and he is confirmed by Mr. Underdown, the Foreman Diver, who was also engaged on the Tyne works.

11. I do not consider however that these comparisons are of much value. I have given them because they are sure to be made by others if not by myself, but my own experience is that the appearance of the sea gives very little indication of its real force.

12. EFFECTS OF SEA ON FOUNDATIONS.—When we come to compare results however we are led to a more definite conclusion. The best test for practical purposes of the force of sea is its power of undermining foundations. It is proved by the general practice of Engineers at home that a depth of 15 feet below low water is safe. At Alderney, where there is evidence of a power of sea greater in some respects than at any place I know, foundations at that depth have never been disturbed. At Wick, where a mass of concrete and masonry of 2,500 tons was moved bodily by the sea, and the height of the waves was estimated at 42 feet, foundations at 18 feet depth were untouched, and no action was found below 10 feet. The deepest foundations I have ever heard of as being undermined were 11 feet below low water at the Tyne, but at Madras the walls were in two places for a short length *undermined at 22 feet below low water.*†

13. This is an effect I should never have anticipated, and I can now only account for it by the supposition that there is some peculiarity in the cyclone-raised disturbance to which the apparently heavier seas on the English coast have nothing analogous. There is nothing improbable in the supposition of a difference in the effects produced on the underlying water by a very intense action within a limited area, and by a long continued surface friction over a large space. It is true that the North Atlantic storms are cyclonic in their movements, but the movements extend over a larger area, and have a less intensity, than those in the Bay of Bengal.

14. But however this may be, it is certain that the eight feet extra depth of foundation which I allowed, more for the sake of convenience and economy than for that of security, was really required for the latter purpose. Though the damage actually resulting from undermining on this occasion was not great, the whole length of the eastern face of the piers was *threatened*, and a rather heavier sea would have produced a serious amount of damage of a different kind from that which actually was produced. The most important lesson taught by this storm is that *foundations at a depth of* 22 *feet under water are not proof against a cyclone sea.*

15. EFFECTS OF SEA ON SUPERSTRUCTURE.—The great bulk of the damage however is of a totally different kind, and is due to the direct force of the waves on the superstructure. The results produced are precisely what might have been anticipated on a work of insufficient strength. The impact of the sea was delivered to all appearance just where it was expected, but it was stronger than any we had previously experienced on this description of work, and required a greater resistance than we had provided. The lesson has been very dearly bought, but it is precisely the same kind of lesson that has been taught in almost every case where works have been undertaken exposed to a sea of unknown force. It is only when a sea of nearly maximum force has been experienced that the final precautions are shown to be necessary.

16. I believe the damage produced by this storm on the Madras Harbour Works, the general nature of which is shown on the accompanying sketch, is greater in its extent than that of any similar disaster on record, but it must not be concluded that this is due to an unusual degree of weakness in the work. It is due rather to the fact that at Madras the maximum force of sea is not, as is practically the case on the coasts where most of our experience has been gained, an event of almost annual occurrence, but it occurs only at intervals of several years, and in one such interval of more than usual duration a great extent of work had been completed, and was

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* Other estimates give 30 feet, but I do not put any faith on such estimates made by unskilled persons, either in respect of this or any other storm with which they may be compared.

† It is of course well known that wave action extends and even moves rubble stone to a much greater depth than this, but the instances of such action have little bearing on practical engineering questions.

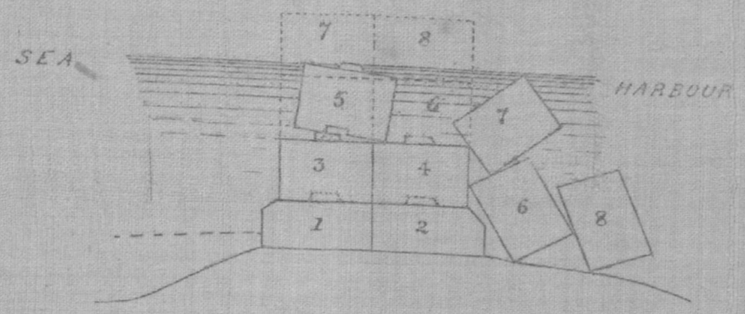
therefore exposed at once to the previously unknown destructive action of a sea of nearly maximum force.

17. The design of the work as executed at Madras was the result of a careful investigation into the causes of damage to previously executed works. Much material that appeared to be superfluous in them was dispensed with, but additional strength was given to the parts that were retained. The latest additions to the section were based on the experience gained at Kurrachee. At that place the first heavy sea showed where the greatest impact of the waves fell, and that part was strengthened in a way that has been quite successful in a subsequent experience of nine years at Kurrachee, and for five years was successful at Madras, but it failed under a sea of greater force than had previously been experienced at either place. To prevent a recurrence of the damage additional strength must be given to the vulnerable part. But it must be understood that all such precautions are necessarily tentative as to their sufficiency. We may feel confident as to their being right in principle, but the force of the sea cannot be estimated in figures, and we are unable to say, when a work has stood successfully, what margin of stability it possessed, or when it has failed, by how much the destructive force was in excess of its stability. The strength of an iron girder or the capacity of a water channel may be definitely calculated in figures, but the stability of a sea barrier is a question to be decided by precedent, guided by judgment and experience.

18. The experience gained at Kurrachee was to the effect that the heaviest blow of the sea was delivered on the tops of the blocks on the harbour side of the breakwater, tending to drive them out from the wall into the harbour. Several blocks were forced out in this way, but in no case was any block forced to seaward. The tendency was met by inserting a stone joggle which locked the top course to the course below, and prevented it from sliding. This precaution was quite successful at Kurrachee, and a contrivance for effecting the same object having been from the first adopted at Madras, the tendency was so completely met that no evidence of its existence was given by the action of the seas which preceded that of the 12th November last.

19. A knowledge of this tendency, however, forms a clue to enable us to trace the process of destruction of the Madras piers. The waves rising upon the sea face must have fallen with terrific force upon the top of the work on the harbour side, and the blocks were tilted off, probably two courses, and possibly, in some cases, three courses, being displaced at once. The sea wall then standing alone yielded to the lateral force of the waves, and generally one course, but sometimes two, and in one or two cases even three courses were driven after the blocks of the harbour wall. Generally speaking there is a course more remaining on the sea side than on the harbour side.

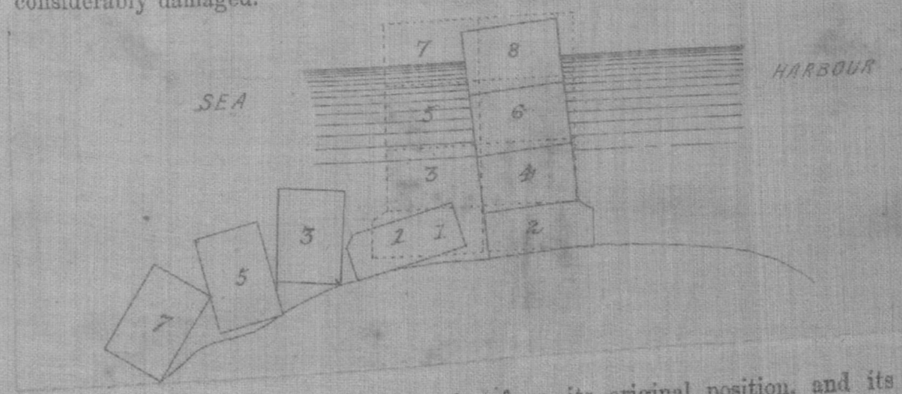
20. The following may be taken as a typical section of very much of the work in its present state. Parts of it



are necessarily hypothetical, but there is enough which is matter of actual observation to justify the assumption of the remainder. For a length of at least two-thirds of the damaged parts blocks 1 and 3 have been traced by the divers and found with slight exceptions to be undisturbed. For the greater part of this length block 5 may be traced from the surface and sometimes from below, generally more or less disturbed somewhat in the way shown. No. 7 is in some cases in its place, but it is then generally tilted by riding on the tenon on the top of No. 5 ; 6, generally 7, and 8 are represented by an apparently confused heap of blocks which effectually prevent access to 2 and 4. There is, however, sufficient evidence direct and indirect to negative the very improbable supposition of these having been undermined and thus caused the fall of the inner wall towards the harbour. This evidence is, first, that where the inner slope of the rubble is unencumbered with blocks it is found to be practically unchanged ; second, where the sea wall is gone and the harbour wall standing, as is the case for a short length in each pier, the harbour wall leans over to seaward ; third, at the spot at which, if anywhere, scour under the harbour wall might be expected, viz., at the extreme end of the north pier, the rubble is 4 feet above the foundations, and the wall is standing exceptionally well, the blocks corresponding to No. 6 being in place. There can therefore be, I think, no doubt that the failure began with No. 8 block, or more probably 6 and 8 together, and worked downwards and towards the harbour. The rubble foreshore on the sea side however presents a marked contrast to that on the harbour side. It is almost everywhere drawn away from the wall and lowered sometimes below the level of the foundation blocks.

21. The above description may be taken as a generalization of the effects produced upon about two-thirds of the damaged parts. It comprises the outer portions of the two piers, a length of 1,200 feet of the north and 900 feet of the south pier. The remaining third, comprising 400 feet of the north and 500 feet of the south pier, have been differently affected and the investigation is more difficult, as the blocks are thrown down on both sides of the piers, and a precise examination of the portions which remain standing is for the most part impracticable.

22. There is, however, one portion of the north pier, just at the commencement of the curve, which is accessible to the diver, and has been carefully examined. The following section, made from his description, will very clearly exhibit the action to which it has been subjected. In this case the harbour wall is standing, though considerably damaged.



No. 1 block is drawn out to seaward 4 feet from its original position, and its inner

end is lifted 9 inches from the rubble bed, the block itself being tilted towards the sea. The upper blocks are lying in confusion on the sea slope of the rubble. I do not see how it is possible to attribute these results to any other action than undermining of the foundation blocks. The portion of the pier where this is evident is a length of something under 100 feet, but it is probable that whenever the upper blocks have fallen to seaward it is due to the same cause, although the foundation blocks themselves are inaccessible. The action of the sea appears to have been exceptionally severe at this spot, for the original sandy bottom is scoured away 6 or 7 feet outside the rubble.

23. There is a portion of the south pier, also on the curve, which appears to have been acted upon in a very similar manner. At these two places the breakwaters form about the same angle, one on the right and the other on the left, with the prevailing line of the waves, and here the scouring action on the bottom appears to have been more violent than where the waves fell more directly on the face of the work.

24. Remedies.—The whole of the actual damage to the works is due to one or other of the above causes, and I think that if the original section were amended so as to give increased strength to the two weak places shown to exist, every confidence might be placed in its stability under even a much heavier sea than the recent one. The section as carried out was a perfectly good one to withstand a moderate sea, and the effects of the heavier sea show no grounds for any radical alteration. Such material as there was was good in quality and properly disposed, but there was not enough of it; or perhaps it would be more correct to say the principles of the design were good, but not carried far enough. There is not the slightest justification for re-opening the worn-out questions of the relative merits of random and placed blocks, or of bonded and unbonded work. Breakwaters of random blocks or of bonded masonry might have stood if very much more massive than those which have partially failed, but their security would have been due to their greater massiveness, not to the different principles of their construction.

25. Quality of Materials.—I have said that the materials were good. I am aware that a great deal has been said about the unsuitableness of laterite for the rubble base, and some doubts have been expressed about the quality of the concrete owing to many of the blocks having been broken. Now laterite is undoubtedly a *troublesome* material, and I am glad to think that no more of it will be required, but there is not the slightest ground for thinking that it contributed in any way to the late disaster. The trouble it occasions is that, being friable, it is very quickly compressed by the weight of the blocks laid upon it, so that to allow for subsidence the latter have to be set a higher level than is ultimately required. This is troublesome in execution, and it has the still greater evil of subjecting the blocks to excessive and irregular strains in the process of subsidence, in consequence of which many were broken. But when once consolidated, the laterite forms as good a bed as the granite rubble. This is proved by the comparison of the amount of settlement of the standing portions of the two piers, one being built on laterite and the other on granite. There is no appreciable difference between the two. It is right to add that the laterite was used, not from choice, but because it was not practicable to obtain the granite rubble in sufficient quantity to carry on the work at the speed for which all other parts of the work were organized. It would of course have been right to sacrifice speed of execution if ultimate stability were endangered, but after full consideration it was decided that this was not the case.

26. Breaking of Blocks.—The breaking of the blocks is undoubtedly a blemish, and though it occurred over both the granite and laterite bases, it occurred, I have no doubt, more over the latter for the reason I have given above, though it is impossible to determine the proportions accurately. The evil, however, is really greater in appearance than in reality, for the force which broke the blocks at the same time jammed them so closely together that the broken pieces are really as effective for the stability of the work as many unbroken blocks which have not been subjected to the same amount of pressure. I doubt whether it would have been

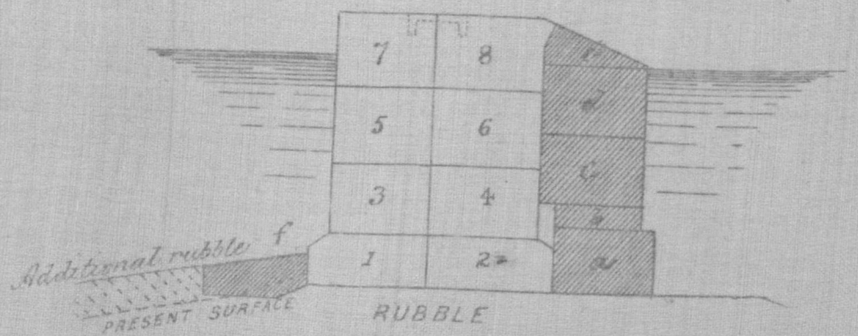
possible by any means entirely to prevent these breakages, but the number would have been reduced if it had been possible to keep the blocks longer before subjecting them to these severe strains. Be this as it may, however, the concrete is undoubtedly of excellent quality, as even the fractured surfaces of the broken blocks show. In the restoration of the work, as I shall presently point out, this evil will not recur. But so far there is no evidence to show that these breakages have contributed in any way to the failure of the work.

27. Subsidence.—Another point which has given rise to a good deal of remark is the subsidence of the structure, but in this I can see no evidence of weakness. It is quite certain that a rubble bank 20 feet high must consolidate under the weight of 30 feet of concrete, and it is equally certain that the effect of agitation of the water must be to cause the rubble to sink into the sandy bottom, but beyond involving the necessity of adding to the top if it sinks below the required level, there is really no harm done. We have the experience of years to show that subsidence does not involve loosening of the superstructure, but rather the contrary, while the sinking of the foundation to a still lower level is a substantial advantage. The portions of the piers standing entire have settled under the action of the storm about 9 inches at their outer ends, gradually diminishing to nothing near the shore, the amount of sinking being inversely proportioned to the length of time since they were built. The damaged portions, which of course are newer, have sunk about 2 feet, as far as can be ascertained. There may probably be a further subsidence, though its rate will decrease as time goes on, but it is, I repeat, a perfectly harmless process. The above are the settlements due to this particular storm. There had been previous settlements due mainly to the natural consolidation of the rubble base, generally amounting in the aggregate to from 2 to 3 feet, the maximum being near the south pier head, where it was 4 feet. The further settlement due to the storm is probably caused by subsidence into the sandy bottom.

28. Reconstruction.—In the scheme for reconstruction, then, we have especially to keep in view the two weak points, the foot of the outer wall and the top of the harbour wall. The required object may be attained either by breaking the force of the waves before they reach the weak points or by giving additional strength to the weak points themselves. The former principle has received full consideration. It appeared at first sight that the remains of the original piers would form a good outer barrier under shelter of which a new pier would be safe from damage. But further examination was not favorable to this idea. The shelter it would give in its present state is too irregular. In some parts it might be fairly efficient, but in others it would allow the sea to pass over it on to the new work with increased violence. To prevent this such places would have to be made up with new material, and this would lead to a serious amount of work, and I think a not very satisfactory result. Besides which there is a considerable proportion of the old work remaining, and the rubble base especially having been well consolidated would offer a better foundation than a new one, especially in not being liable to the immediate settlement which caused the fracture of the blocks. Two out of the four courses of blocks are also for the most part in a good state, and an uncertain proportion of the displaced blocks may be recovered and used again.

29. Preference was therefore given to the principle of rebuilding the piers on their original foundations, and making such additions as experience shows to be necessary. The one great objection to this is the immense difficulty of clearing the ground of fallen blocks. The magnitude of this difficulty can hardly be realised without inspection of the ruins. It will undoubtedly be a slow and costly operation, but all who are concerned in it are satisfied of its practicability, and the difficulty being simply a mechanical one, we may safely conclude that it will diminish with practice and experience.

30. I propose, therefore, that the work be rebuilt on the former lines and to the former section, but with the additions shown shaded on the accompanying sketch, to give increased strength to the two weak points.



The rubble base and blocks 1, 2, 3, and 4 are generally in a serviceable state. 5, 6, 7, and 8 are new blocks similar to the old ones, except that they will be 9 feet high instead of 8 feet, so as to make up for the 2 feet of subsidence. *a*, *c*, and *d* being of the same dimensions as the old blocks, the latter can be used so far as available; *b* is a thin block inserted for the purpose of bringing the top of *d* above water level, so that *e* may be set upon it in a bed of cement, thus making *d* and *e* together into one block of 36 tons weight. The top of *e* is sloped off to give an escape for the falling wave. If it were level like the top of 8, the effect would be simply to transfer the vulnerable point from the top of 8 to the top of *e*, as is shown by the fact that at the pier heads where the structure was increased to three and four blocks in width the one next the harbour still gave way.

31. Block *f* is intended to protect the toe of the outer wall from scour and ultimate undermining. It should be placed at as low a level as practicable, so as to avoid encroaching on the profile formed by the sea itself. It is a noticeable feature in the cross sections of the damaged parts of the piers that a scanty slope of rubble and severe damage to the superstructure do not go together. On the contrary, where the sea wall was actually undermined at the south pier, and the nearest approach to a clean breach was made, the rubble base happened to be particularly full. The evidence is at present not more than negative, but it is to the effect that a full foreshore is not an element of strength. The object of the footing, therefore, is simply to substitute a surface of concrete for one of loose rubble, preserving as nearly as possible the level and slope which the sea has formed. From the outer end of the block the slope will be continued in rubble. It may probably be desirable where the blocks are fallen to seaward not to disturb them, but rather add some more so as to make protective mounds of random blocks at those places.

32. Besides these actual additions to the section I propose to introduce two extra securities into the top course of the old section. It has always been an object, though hitherto unattainable, to connect the top blocks together, both longitudinally and transversely, so as to make all the portion of the section which is out of water into a monolithic mass; but it is impossible to do this in new work efficiently in consequence of the settlement to which the structure is liable. An unequal settlement would sever any attachments we could apply. Now, however, in rebuilding on an old foundation this difficulty will be much diminished. What settlement does occur will be more uniform, and slight inequalities in it may even be prevented by the adherence of the attachments. It is proposed, therefore, so to make the cross joints of the top blocks that they may be filled with cement, not during the progress of building, but on a suitable opportunity afterwards. It is also proposed to connect the two top blocks by an iron cramp made of a bent, worn-out rail with the ends turned down and cemented into the blocks. Thus each longitudinal row of blocks will become, so far as the cemented joints can be depended on, a monolith, and the two monoliths will be tied together at intervals of $4\frac{1}{2}$ feet. It cannot be anticipated that the monoliths will be absolutely continuous. Some of the cement joints will separate, but the majority will hold together, and the top of the breakwater will consist of much larger masses

than hitherto, which will lend support to one another in a way that the detached blocks could not do.

33. The section thus modified would have the following additional elements of stability over the old section:—First, it would have 50 per cent. greater width as a whole. Second, the vulnerable block No. 8 would be supported (*a*) by a buttress one-third heavier than itself, (*b*) by a tie to block No. 7, (*c*) by its longitudinal continuity afforded by the cemented joints. Third, the toe of the sea wall would be protected from undermining by an apron of concrete blocks. I must repeat that it is impossible to show the sufficiency of this by figures, as the force of sea is an indeterminable quantity. But I think it quite outside the limits of reasonable probability that we shall have to encounter a force of sea so much greater than that of the late storm, as the strength of the new section would be greater than that of the old.

34. Uninjured Portions.—I do not propose that the additions to the section should be applied to the portions of the piers which have stood uninjured. They have shown no sign of weakness beyond some scouring away of the foreshores at the foot of the sea walls. These should be fed with some heavy granite boulders. It would be desirable, however, now that the block work has settled down to a solid bearing, to tie the top blocks together with iron cramps in the same way as described for the new work. This would give additional resistance to block No. 8 in the event of the next heavy sea coming from a point more northerly or more southerly than the last, and the cost would be small, as there are a great number of rails which are of no value for any other purpose.

35. There is one further additional security which I would propose to apply to the curved portions of both piers. These have a special element of weakness in the fact that if there should be any leaning over to seaward, the upper course of blocks would open out like a fan. The late storm showed that there is a greater scouring force on the foreshore of the curves than elsewhere. I hope undermining from this cause will be effectually prevented by the precautions above recommended, but I would propose, as an additional precaution for the support of the superstructure, to form a groove longitudinally along the top of the sea wall about 12 inches deep all round the curves, in which a strong chain cable will be laid, strained up tight and then buried in concrete. The whole curve would thus be bound together.

36. I would beg to call attention to the fact that each one of the additions I have recommended is intended to meet some weak point disclosed by the action of the sea upon the work. I have made no attempt to meet theoretical objections that are not supported by the special experience of this particular occasion. My object has been to preserve what experience has shown to be good in the work, as well as to supplement what was shown to be insufficient, and I submit that it is by this process rather than by radical changes of plan, which would involve much experimental work, that ultimate success will be best assured.

37. Estimate.—In endeavouring to form an estimate of the cost of the works of restoration, I am met at the outset by elements of great doubt. About 43,000 cubic yards of concrete block work has been displaced. If the blocks were recoverable in an efficient state, they might be reset in position for about 4 lakhs of rupees, but it is quite certain that many are broken, and these will be more costly to remove than the unbroken ones, and will have to be replaced by new ones. To replace a broken block will cost altogether about three times as much as to reset a sound one. Others again, though unbroken, will probably be so jammed into the confused mass that they can only be removed by blasting them to pieces. Now it is quite impossible to form a reliable estimate of the proportion of blocks available for future use. One-fourth and three-fourths may be taken as the limits of uncertainty in the matter. As the work of restoration advances a more definite estimate may be formed, but for the present I am really unable to do more than give the minimum and maximum of what may fairly be taken as within the limits of reasonable probability. The Government will no doubt think it right to take the maximum estimate as the basis of its deliberations. I may be permitted to take the minimum as what I hope to see realized, though I am unable to pledge myself to it.

38. I have therefore divided my estimate into two parts: the first part is for the restoration of the work to its former state, exclusive of the small portions of the original design remaining incomplete, and the question of ultimately completing which should remain for the present in abeyance. The second part is for the additional works of strengthening recommended. The first part is also presented in two alternatives—a maximum and a minimum—the former amounting to a little under 9 lakhs, and the latter a little over 6 lakhs. The second part is based on the prices at which the work has hitherto been carried on, and may therefore be taken as reliable. Its total is a little over 9 lakhs. The total cost of placing the whole work in an efficient state may therefore be taken as lying between the limits of 15½ and 18½ lakhs, and I think three years will be required from the time of recommencing building operations for its completion.

39. The second part of the estimate (that for new works) is the amount which would have been added to the original estimate if we had had the data necessary for making provision against the force of a cyclone sea. The first part is the penalty paid for our ignorance on this point. But I may remark that this is not altogether without its equivalent. If the work had been carried out in the first instance in its stronger form, its completion would have been delayed by two years, and for those two years the harbour would have been in a less efficient state than it is now with the damaged piers.

40. Present efficiency of the Harbour.—Indeed the business of the harbour has proceeded with scarcely any change in consequence of the accident, and although steamers have the option of saving the payment of extra dues (levied according to the present admittedly inequitable system of charging on the register tonnage instead of on the cargoes landed and shipped) by anchoring outside, they invariably submit to the grievance and come in. The injury to the harbour is scarcely felt during fine weather, when the great bulk of the landing and shipping operations are carried on. Its evil effects will be felt in moderately rough weather, when more sea will come into the harbour, though even then the damaged piers will be better than none.

41. With the view of ascertaining what is the amount of benefit at present afforded by the harbour, I obtained, by the courtesy of the Collector of Customs and of the Agents of the principal lines of steamers, returns of the number of vessels of all classes which have visited the port for the three months following the accident to the harbour works, and of the number of tons of cargo actually landed and shipped within the harbour during the same time. The total register tonnage of sailing vessels was 13,302, and I have not ascertained what quantity of cargo was landed and shipped by these. They all lay outside the harbour. The register tonnage of steamers was 146,374 and the quantity of goods landed about 2[illegible]000 tons, and of those shipped 1[illegible],000 tons, making a total of 3[illegible]000. As the whole of this work was done at a rate of boat-hire less than that chargeable in the roads of half a rupee per ton, the sum of 18,000 rupees represents the proper earnings of the harbour during the first three months following the storm. I put the matter in this way rather than by giving the actual amount levied as dues on the register tonnage, because the latter does not represent the amount of business done in the harbour, and is in force only pending arrangements for a more direct and equitable mode of making the charge. The half rupee per ton also will be raised, when the harbour and the landing and shipping arrangements are more complete, to one rupee, and of course extended to the cargoes of sailing vessels.

42. I submit, therefore, that the Madras Harbour, even in its present damaged and incomplete state, is by no means an unprofitable undertaking. It is confessedly imperfect, and there are other points requiring consideration besides the restoration of the works, to one of which it is desirable to allude.

43. The experience gained since the harbour piers approached completion is to the effect that the entrance facing the eastward admits an amount of swell (particularly with easterly seas, which are more frequent than was supposed) which will render it desirable so to arrange the berthing of ships that they may lie with their heads towards the incoming swell, instead of towards the prevailing winds as had been at first intended. For the great majority of days in the year this can be done without

difficulty, but there are occasions (about 25 to 30 days as estimated by the officers of the Marine Department) when a ship cannot lie with her broadside directly or even obliquely exposed to the wind. On such occasions it becomes necessary to cast off the stern moorings and allow her head to swing to the wind. As the ship will then roll to the swell, landing and shipping cargoes will be more difficult, and sometimes even prevented. With a strong wind from one direction, and a heavy swell from another, the ship would roll very uneasily, and though it might be only in extreme cases that she would be in actual danger, such danger could only be avoided by sending her to sea. This in itself is no unforeseen contingency, but it is now suggested that there would be a difficulty in getting a ship clear from such an uneasy berth as that just described while subject to the combined influence of wind and swell. This difficulty could only be avoided by an earlier anticipation of the danger, and by taking the ship out of the harbour at an earlier period of threatening bad weather.

44. The officers of the Marine Department are of opinion that this evil can only be effectually cured by closing the present easterly entrance and making an opening facing southwards in the south pier. If I do not enter into the merits of this proposal, it is not because I question the reality of the evil, but because I think it premature to discuss a question upon which no practical action could in any case be taken for the three or four years that will be required for the restoration of the damaged portions of the piers. During those three or four years the harbour will be in daily use, and the bearing of this one particular evil upon the whole question of the development of the advantages afforded by the harbour will be more easily seen. It is not a question of a harbour or no harbour, but of a harbour affording a greater or less degree of shelter, and the value of the increased shelter will be more precisely ascertained by the experience of actual work. The proposal may then be put forward (if its desirability be confirmed by experience) as one giving an advantage directly comparable with the cost.

45. So far as carrying out the alteration is concerned, nothing would be gained by an immediate decision, nor do I think, even if the idea had been entertained from the beginning, any materially cheaper plan could have been devised—certainly none more expeditious—than that of advancing both piers to near their meeting point, using the interval between them as a temporary entrance, and then making the final opening in such a position as might appear most desirable by drawing back one of the Titans, removing the necessary length of blocks, and dredging away the rubble. The materials, of course, could be used for the final closing of the original entrance, which would be carried on by the other Titan from the side opposite to that in which the new opening would have been made. This process will still be available if the alteration be ultimately determined on.

46. Having now explained as clearly as I could my views with regard to the present state of the works and the best mode of restoration, it remains only for me to specify the immediate action required for carrying my recommendations into effect. An urgent indent should at once be made for two new Titan cranes, to be constructed with such modifications from the pattern of the former ones as is necessary for the altered circumstances of the work. I shall be prepared to furnish the details of these immediately on receiving instructions. Also 2,000 tons of Portland cement should be immediately ordered, 1,000 tons to be shipped by canal steamer, and 1,000 by sailing vessel. Other stores and materials will be required from England, for which indents will be duly submitted by the Superintendent.

47. In the mean time block-making should be proceeded with with the cement now in stock and such as may be procured from the local manufactory (formerly General Morgan's). The cramp irons described in paragraph 32 *ante* should be fixed in the uninjured portions of the piers, and the inequalities in the tops of the blocks levelled up with new concrete. This last is a small work which could not be carried on while there was a constant traffic on the piers, but may now be conveniently completed. The foreshores of the standing portions of the piers should also be made up after the cross sections have been taken to show exactly what is required.

48. I propose to submit a separate report on the question of the beach improvements and landing jetties which were sanctioned a year ago, and partially carried out, but the whole scheme must be reconsidered under the present changed conditions. These works are not charged to the Harbour Works Grant.

MADRAS HARBOUR.

ESTIMATE OF RESTORATION.

PART I.—REPAIRS OF DAMAGE.

				Rs.
Maximum—				
New Plant and Machinery				1,25,000
Resetting existing blocks of second course, both piers, 21,355 cubic yards, at				42,710
Removing broken blocks, 32,033 cubic yards, at	2	0	0	3,20,330
Replacing 32,033 cubic yards, at	10	0	0	3,45,956
Recovering whole blocks, 10,678 cubic yards, at	10	8	0	42,712
Resetting do., 10,678 cubic yards, at	4	0	0	21,356
	2	0	0	8,98,064
Credit by 32,033 cubic yards available as rubble, at	3	0	0	96,099
				8,01,965
Establishment (7½) and Contingencies (2½)				80,196
				8,82,161
Minimum—				
New Plant and Machinery				1,25,000
Resetting existing blocks of second course, both piers, 21,355 cubic yards, at				42,710
Removing broken blocks, 10,678 cubic yards, at	2	0	0	1,06,780
Replacing 10,678 cubic yards, at	10	0	0	1,15,322
Recovering whole blocks, 32,033 cubic yards, at	10	8	0	1,28,132
Resetting do., 32,033 cubic yards, at	4	0	0	64,066
	2	0	0	5,82,010
Credit by 10,678 cubic yards available as rubble, at	3	0	0	32,034
				5,49,976
Establishment (7½) and Contingencies (2½)				54,998
				6,04,974

ESTIMATE OF RESTORATION.

PART II.—SUPPLEMENTARY STRENGTHENING WORKS.

	Rs.	A.	P.	Rs.
North Pier—				
Buttress wall, 22,504 cubic yards, at	10	8	0	2,43,043
Apron outside, 4,000 cubic yards, at	12	9	0	51,600
* Extra rubble outside, 36,000 tons, at	2	0	0	72,000
* Do. inside, 20,952 tons, at	2	0	0	41,904
Two feet extra height, 3,111 cubic yards, at	10	8	0	33,598
Cementing joints of top course, 218 cubic yards cement mortar, at	30	0	0	6,540
Bending and fixing cramp irons				10,000
Chain round curve				1,500
Levelling top of blocks on standing portion				10,000
South Pier—				
Buttress wall, 17,735 cubic yards, at	10	8	0	1,91,538
Apron outside 3,200 cubic yards, at	12	9	0	41,280
* Extra rubble outside, 31,200 tons, at	2	0	0	62,400
* Do. inside, 16,512 tons, at	2	0	0	33,024
Two feet extra height, 2,400 cubic yards, at	10	8	0	25,920
Cementing joints of top course, 167 cubic yards cement mortar, at	30	0	0	5,010
Bending and fixing cramp irons				10,000
Chain round curve				1,500
Levelling top of blocks on standing portion				10,000
				8,50,857
Establishment 7½ per cent.				85,086
Contingencies 2½ „				
Total cost of New Works ...				9,35,943

* In execution these quantities will be reduced by the amount of broken blocks available as rubble (see Cr. in Part I.)

From the Engineer-in-Chief, Madras Harbour Works, to the Secretary to Government, Public Works Department, dated Madras, 9th March 1882.

Madras Harbour.

I HAVE now the honor to submit to you my report on the damage to the above works caused by the storm of the 12th November 1881, and my proposals for their restoration.

2. It has been delayed longer than I could have wished, owing to the great difficulty of obtaining detailed measurements and sections, which require an exceptionally calm state of the sea. Upon the results shown by these depend in a great measure our conclusions as to the particular action of the sea which produced the damage. I have thought it desirable to delay the submission of my report until I had obtained such facts as were necessary, not only to form a basis for my own positive conclusions, but also to test beyond the possibility of doubt the correctness of the conclusions which have been put forward by others upon a more or less imperfect knowledge of the facts. I may here mention once for all that I have given careful consideration to various suggestions that have been made to account for the damage, but I do not think it necessary to notice these as a rule, but rather to submit my own conclusions, with the facts on which they are based.

3. PREVIOUS REPORTS.—I wish however to explain my position with regard to two documents of very great interest, the first being a report which was made only two days after the storm by the Chief Engineer of the Presidency, who with great promptitude availed himself, in company with the Master Attendant, of a specially favorable opportunity of taking what was necessarily a very general view of the state of the works. This report was forwarded "*with all reserve*" to the Secretary of State, and I had an opportunity of perusing it before I left London. If I were to comment upon the suggestions made in this report as to the particular action of the sea, it would give them a prominence which the author probably never intended they should possess.

4. The other document is a very excellent report made by Mr. Thorowgood on the 21st November, nine days after the storm, which is especially noteworthy as showing how much information can be obtained in a short time. But this information, though generally confirmed by subsequent observations, was not sufficiently complete to form a basis for practical conclusions, and what was then wanting had to be obtained with considerable difficulty afterwards. It is scarcely possible to make an intelligible statement of facts without conveying some suggestion of conclusions to be drawn from them, and in some cases such suggested conclusions fail to be confirmed by the facts subsequently ascertained. To a slight extent this is the case with Mr. Thorowgood's report, but it is no disparagement of its merits to ask that it may be considered as superseded, even if generally confirmed in its conclusions, by the present report, and in its facts by the plans and sections which will be submitted to Government, and will, I think, form a very interesting and instructive record.*

5. MR. THOROWGOOD.—I should mention that I had the advantage of five weeks' constant communication with Mr. Thorowgood before he left for England, and during that time, as further materials accumulated, we were able to form more definite conclusions, and those conclusions, independently formed by each of us, were in all essential matters the same. They included, subject to corrections suggested by the further surveys which have since been made, most of the recommendations which I am about to submit.

* These are still in progress. At the end of the present fine season so much as is complete will be submitted to Government.

6. THE STORM.—The storm is thus described in the official Meteorological Report issued by the Government Astronomer on November 23rd 1881 :—

"A cyclone visited Madras on Saturday and Sunday the 12th and 13th instant. It appears to have exhausted its greatest force while crossing the Bay before reaching the coast of Southern India, which would account for the high and destructive sea, far beyond what might have been expected from the meteorological indications accompanying its progress. The centre of the storm must have struck the coast considerably southward of Madras. The lowest reduced reading of the barometer was 29·51 at 4 P.M. on Saturday; and the strongest wind was experienced between 11 P.M. and 2 A.M. on Sunday, during which time it averaged 32 miles per hour in velocity, equivalent to a pressure of about 5¼ lb. per square foot. Rain commenced at 1½ A.M. on Saturday and continued until 8 P.M., amounting in all to 8·19 inches—the twelfth heaviest fall on record at Madras since 1803. No single hour was extraordinarily excessive, but the persistence of both wind and rain was remarkable. The veering of the wind was as usual for cyclones southward of Madras. The records of the anemograph furnish the following mid-times for each principal point of the compass with the corresponding hourly velocities :—

N.W by W.	at	2½ P.M.	; velocity	20	miles.	E.N.E.	at	1¼ A.M.	; velocity 33 miles.
N.W.	at	3½ P.M.	; do.	29	do.	East	at	2½ A.M.	; do. 25 do.
N.N.W.	at	6½ P.M.	; do.	23	do.	E.S.E.	at	4½ A.M.	; do. 18 do.
North	at	7¾ P.M.	; do.	27	do.	S.E.	at	7½ A.M.	; do. 14 do.
N.N.E.	at	8½ P.M.	; do.	30	do.	S.S.E.	at	9½ A.M.	; do. 14 do.
N.E.	at	10¾ P.M.	; do.	31	do.	South	at	10½ A.M.	; do. 13 do."

7. The Astronomer here alludes to the fact, to which I have myself frequently had occasion to advert, that there is no relation between the force and direction of the wind in the neighbourhood of a cyclone and those of the sea which may accompany it. The sea is raised, not by the wind which may happen to be blowing at the time at any given spot, but by an intense atmospheric disturbance at a distance, that is in the centre of the cyclone, and from the site of that atmospheric disturbance (which when the wind is from the north-west at any place will lie between north-east and east of that place) the sea disturbance will proceed, propagated by laws which, so far as we know, have no similarity whatever to those by which the atmospheric disturbance itself is propagated. On this occasion the maximum velocity of the wind at Madras was 33 miles per hour; on occasion of the great storm in May 1872 the velocity was 53 miles per hour; in May 1874 it was 49 miles per hour; while in May 1877, when the concrete block work of the north pier had advanced about 300 feet, the sea was nothing like so severe as in last November, though the velocity of the wind was 34 miles per hour.

8. The testimony of all observers is to the effect that the sea of 12th November must rank with those of the great historical cyclones, though there is a conflict of evidence as to whether it was actually as heavy or heavier. Mr. Chisholm, the Government Architect, a very intelligent and close observer, speaks confidently as to the recent sea being considerably heavier than that of 1872; but on the other hand, the officers of the Marine Department, who witnessed both storms, give the palm to that of 1872. A rough test is afforded by its action on the planking of the screw pile pier 17 feet above mean sea level. This was torn up in 1872, in 1874, and again in 1881, but it is uncertain whether on the last occasion the effect of the Harbour Works would be to reduce the waves at the site of the pier (as I have no doubt was the case over the area of the harbour generally), or to aggravate them by the confusion which would be caused by their rolling in over the piers as well as through the entrance. The end of the pier is just outside the line in which the first break of the waves occurred, and the height there was no doubt abnormally raised.

9. As compared with the force of sea in other places the evidence is also unsatisfactory. Mr. Bhoomya Saenna, Sub-Engineer, is the only person who could compare this sea with that raised by the south-west monsoon at Kurrachee. He considers the waves were not higher, but the succession of them was more rapid. The maximum height measured at Kurrachee was 15 feet. Mr. Chisholm estimated about the same height for the late storm at Madras,* and at both places independent testimony fixed the depth of solid water passing over the breakwaters at about 20 feet.

10. Mr. Thorowgood did not consider this sea to be so heavy to all appearance as those he had witnessed at the mouth of the Tyne, and he is confirmed by Mr. Underdown, the Foreman Diver, who was also engaged on the Tyne works.

11. I do not consider however that these comparisons are of much value. I have given them because they are sure to be made by others if not by myself, but my own experience is that the appearance of the sea gives very little indication of its real force.

12. EFFECTS OF SEA ON FOUNDATIONS.—When we come to compare results however we are led to a more definite conclusion. The best test for practical purposes of the force of sea is its power of undermining foundations. It is proved by the general practice of Engineers at home that a depth of 15 feet below low water is safe. At Alderney, where there is evidence of a power of sea greater in some respects than at any place I know, foundations at that depth have never been disturbed. At Wick, where a mass of concrete and masonry of 2,500 tons was moved bodily by the sea, and the height of the waves was estimated at 42 feet, foundations at 18 feet depth were untouched, and no action was found below 10 feet. The deepest foundations I have ever heard of as being undermined were 11 feet below low water at the Tyne, but at Madras the walls were in two places for a short length *undermined at 22 feet below low water.*†

13. This is an effect I should never have anticipated, and I can now only account for it by the supposition that there is some peculiarity in the cyclone-raised disturbance to which the apparently heavier seas on the English coast have nothing analogous. There is nothing improbable in the supposition of a difference in the effects produced on the underlying water by a very intense action within a limited area, and by a long continued surface friction over a large space. It is true that the North Atlantic storms are cyclonic in their movements, but the movements extend over a larger area, and have a less intensity, than those in the Bay of Bengal.

14. But however this may be, it is certain that the eight feet extra depth of foundation which I allowed, more for the sake of convenience and economy than for that of security, was really required for the latter purpose. Though the damage actually resulting from undermining on this occasion was not great, the whole length of the eastern face of the piers was *threatened*, and a rather heavier sea would have produced a serious amount of damage of a different kind from that which actually was produced. The most important lesson taught by this storm is that *foundations at a depth of* 22 *feet under water are not proof against a cyclone sea.*

15. EFFECTS OF SEA ON SUPERSTRUCTURE.—The great bulk of the damage however is of a totally different kind, and is due to the direct force of the waves on the superstructure. The results produced are precisely what might have been anticipated on a work of insufficient strength. The impact of the sea was delivered to all appearance just where it was expected, but it was stronger than any we had previously experienced on this description of work, and required a greater resistance than we had provided. The lesson has been very dearly bought, but it is precisely the same kind of lesson that has been taught in almost every case where works have been undertaken exposed to a sea of unknown force. It is only when a sea of nearly maximum force has been experienced that the final precautions are shown to be necessary.

16. I believe the damage produced by this storm on the Madras Harbour Works, the general nature of which is shown on the accompanying sketch, is greater in its extent than that of any similar disaster on record, but it must not be concluded that this is due to an unusual degree of weakness in the work. It is due rather to the fact that at Madras the maximum force of sea is not, as is practically the case on the coasts where most of our experience has been gained, an event of almost annual occurrence, but it occurs only at intervals of several years, and in one such interval of more than usual duration a great extent of work had been completed, and was

* Other estimates give 30 feet, but I do not put any faith on such estimates made by unskilled persons, either in respect of this or any other storm with which they may be compared.

† It is of course well known that wave action extends and even moves rubble stone to a much greater depth than this, but the instances of such action have little bearing on practical engineering questions.

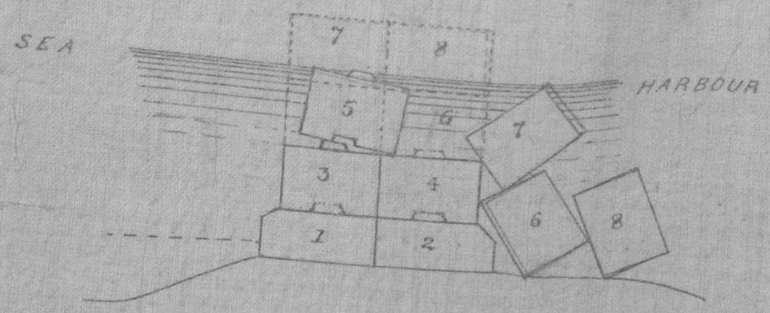
therefore exposed at once to the previously unknown destructive action of a sea of nearly maximum force.

17. The design of the work as executed at Madras was the result of a careful investigation into the causes of damage to previously executed works. Much material that appeared to be superfluous in them was dispensed with, but additional strength was given to the parts that were retained. The latest additions to the section were based on the experience gained at Kurrachee. At that place the first heavy sea showed where the greatest impact of the waves fell, and that part was strengthened in a way that has been quite successful in a subsequent experience of nine years at Kurrachee, and for five years was successful at Madras, but it failed under a sea of greater force than had previously been experienced at either place. To prevent a recurrence of the damage additional strength must be given to the vulnerable part. But it must be understood that all such precautions are necessarily tentative as to their sufficiency. We may feel confident as to their being right in principle, but the force of the sea cannot be estimated in figures, and we are unable to say, when a work has stood successfully, what margin of stability it possessed, or when it has failed, by how much the destructive force was in excess of its stability. The strength of an iron girder or the capacity of a water channel may be definitely calculated in figures, but the stability of a sea barrier is a question to be decided by precedent, guided by judgment and experience.

18. The experience gained at Kurrachee was to the effect that the heaviest blow of the sea was delivered on the tops of the blocks on the harbour side of the breakwater, tending to drive them out from the wall into the harbour. Several blocks were forced out in this way, but in no case was any block forced to seaward. The tendency was met by inserting a stone joggle which locked the top course to the course below, and prevented it from sliding. This precaution was quite successful at Kurrachee, and a contrivance for effecting the same object having been from the first adopted at Madras, the tendency was so completely met that no evidence of its existence was given by the action of the seas which preceded that of the 12th November last.

19. A knowledge of this tendency, however, forms a clue to enable us to trace the process of destruction of the Madras piers. The waves rising upon the sea face must have fallen with terrific force upon the top of the work on the harbour side, and the blocks were tilted off, probably two courses, and possibly, in some cases, three courses, being displaced at once. The sea wall then standing alone yielded to the lateral force of the waves, and generally one course, but sometimes two, and in one or two cases even three courses were driven after the blocks of the harbour wall. Generally speaking there is a course more remaining on the sea side than on the harbour side.

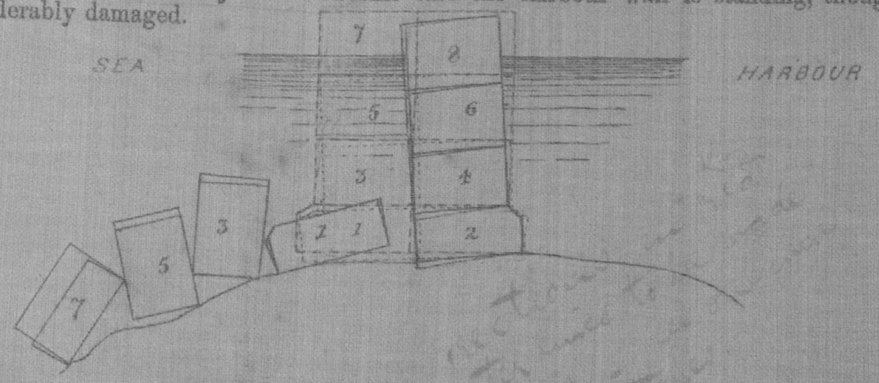
20. The following may be taken as a typical section of very much of the work in its present state. Parts of it



are necessarily hypothetical, but there is enough which is matter of actual observation to justify the assumption of the remainder. For a length of at least two-thirds of the damaged parts blocks 1 and 3 have been traced by the divers and found with slight exceptions to be undisturbed. For the greater part of this length block 5 may be traced from the surface and sometimes from below, generally more or less disturbed somewhat in the way shown. No. 7 is in some cases in its place, but it is then generally tilted by riding on the tenon on the top of No. 5; 6, generally 7, and 8 are represented by an apparently confused heap of blocks which effectually prevent access to 2 and 4. There is, however, sufficient evidence direct and indirect to negative the very improbable supposition of these having been undermined and thus caused the fall of the inner wall towards the harbour. This evidence is, first, that where the inner slope of the rubble is unencumbered with blocks it is found to be practically unchanged; second, where the sea wall is gone and the harbour wall standing, as is the case for a short length in each pier, the harbour wall leans over to seaward; third, at the spot at which, if anywhere, scour under the harbour wall might be expected, viz., at the extreme end of the north pier, the rubble is 4 feet above the foundations, and the wall is standing exceptionally well, the blocks corresponding to No. 6 being in place. There can therefore be, I think, no doubt that the failure began with No. 8 block, or more probably 6 and 8 together, and worked downwards and towards the harbour. The rubble foreshore on the sea side however presents a marked contrast to that on the harbour side. It is almost everywhere drawn away from the wall and lowered sometimes below the level of the foundation blocks.

21. The above description may be taken as a generalization of the effects produced upon about two-thirds of the damaged parts. It comprises the outer portions of the two piers, a length of 1,200 feet of the north and 900 feet of the south pier. The remaining third, comprising 400 feet of the north and 500 feet of the south pier, have been differently affected and the investigation is more difficult, as the blocks are thrown down on both sides of the piers, and a precise examination of the portions which remain standing is for the most part impracticable.

22. There is, however, one portion of the north pier, just at the commencement of the curve, which is accessible to the diver, and has been carefully examined. The following section, made from his description, will very clearly exhibit the action to which it has been subjected. In this case the harbour wall is standing, though considerably damaged.



No. 1 block is drawn out to seaward 4 feet from its original position, and its inner

end is lifted 9 inches from the rubble bed, the block itself being tilted towards the sea. The upper blocks are lying in confusion on the sea slope of the rubble. I do not see how it is possible to attribute these results to any other action than undermining of the foundation blocks. The portion of the pier where this is evident is a length of something under 100 feet, but it is probable that whenever the upper blocks have fallen to seaward it is due to the same cause, although the foundation blocks themselves are inaccessible. The action of the sea appears to have been exceptionally severe at this spot, for the original sandy bottom is scoured away 6 or 7 feet outside the rubble.

23. There is a portion of the south pier, also on the curve, which appears to have been acted upon in a very similar manner. At these two places the breakwaters form about the same angle, one on the right and the other on the left, with the prevailing line of the waves, and here the scouring action on the bottom appears to have been more violent than where the waves fell more directly on the face of the work.

24. Remedies.—The whole of the actual damage to the works is due to one or other of the above causes, and I think that if the original section were amended so as to give increased strength to the two weak places shown to exist, every confidence might be placed in its stability under even a much heavier sea than the recent one. The section as carried out was a perfectly good one to withstand a moderate sea, and the effects of the heavier sea show no grounds for any radical alteration. Such material as there was was good in quality and properly disposed, but there was not enough of it; or perhaps it would be more correct to say the principles of the design were good, but not carried far enough. There is not the slightest justification for re-opening the worn-out questions of the relative merits of random and placed blocks, or of bonded and unbonded work. Breakwaters of random blocks or of bonded masonry might have stood if very much more massive than those which have partially failed, but their security would have been due to their greater massiveness, not to the different principles of their construction.

25. Quality of Materials.—I have said that the materials were good. I am aware that a great deal has been said about the unsuitableness of laterite for the rubble base, and some doubts have been expressed about the quality of the concrete owing to many of the blocks having been broken. Now laterite is undoubtedly a *troublesome* material, and I am glad to think that no more of it will be required, but there is not the slightest ground for thinking that it contributed in any way to the late disaster. The trouble it occasions is that, being friable, it is very quickly compressed by the weight of the blocks laid upon it, so that to allow for subsidence the latter have to be set a higher level than is ultimately required. This is troublesome in execution, and it has the still greater evil of subjecting the blocks to excessive and irregular strains in the process of subsidence, in consequence of which many were broken. But when once consolidated, the laterite forms as good a bed as the granite rubble. This is proved by the comparison of the amount of settlement of the standing portions of the two piers, one being built on laterite and the other on granite. There is no appreciable difference between the two. It is right to add that the laterite was used, not from choice, but because it was not practicable to obtain the granite rubble in sufficient quantity to carry on the work at the speed for which all other parts of the work were organized. It would of course have been right to sacrifice speed of execution if ultimate stability were endangered, but after full consideration it was decided that this was not the case.

26. Breaking of Blocks.—The breaking of the blocks is undoubtedly a blemish, and though it occurred over both the granite and laterite bases, it occurred, I have no doubt, more over the latter for the reason I have given above, though it is impossible to determine the proportions accurately. The evil, however, is really greater in appearance than in reality, for the force which broke the blocks at the same time jammed them so closely together that the broken pieces are really as effective for the stability of the work as many unbroken blocks which have not been subjected to the same amount of pressure. I doubt whether it would have been

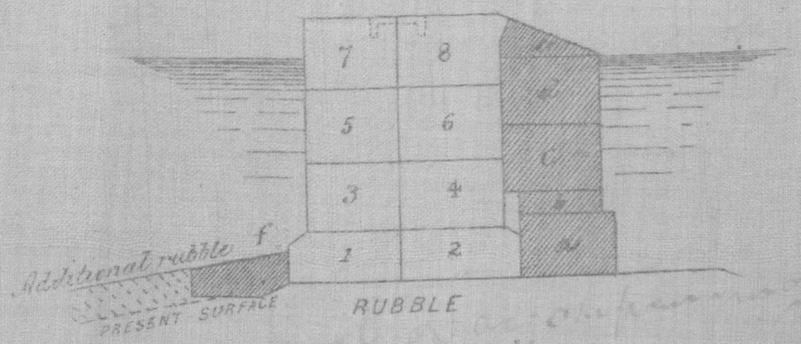
possible by any means entirely to prevent these breakages, but the number would have been reduced if it had been possible to keep the blocks longer before subjecting them to these severe strains. Be this as it may, however, the concrete is undoubtedly of excellent quality, as even the fractured surfaces of the broken blocks show. In the restoration of the work, as I shall presently point out, this evil will not recur. But so far there is no evidence to show that these breakages have contributed in any way to the failure of the work.

27. Subsidence.—Another point which has given rise to a good deal of remark is the subsidence of the structure, but in this I can see no evidence of weakness. It is quite certain that a rubble bank 20 feet high must consolidate under the weight of 30 feet of concrete, and it is equally certain that the effect of agitation of the water must be to cause the rubble to sink into the sandy bottom, but beyond involving the necessity of adding to the top if it sinks below the required level, there is really no harm done. We have the experience of years to show that subsidence does not involve loosening of the superstructure, but rather the contrary, while the sinking of the foundation to a still lower level is a substantial advantage. The portions of the piers standing entire have settled under the action of the storm about 9 inches at their outer ends, gradually diminishing to nothing near the shore, the amount of sinking being inversely proportioned to the length of time since they were built. The damaged portions, which of course are newer, have sunk about 2 feet, as far as can be ascertained. There may probably be a further subsidence, though its rate will decrease as time goes on, but it is, I repeat, a perfectly harmless process. The above are the settlements due to this particular storm. There had been previous settlements due mainly to the natural consolidation of the rubble base, generally amounting in the aggregate to from 2 to 3 feet, the maximum being near the south pier head, where it was 4 feet. The further settlement due to the storm is probably caused by subsidence into the sandy bottom.

28. Reconstruction.—In the scheme for reconstruction, then, we have especially to keep in view the two weak points, the foot of the outer wall and the top of the harbour wall. The required object may be attained either by breaking the force of the waves before they reach the weak points or by giving additional strength to the weak points themselves. The former principle has received full consideration. It appeared at first sight that the remains of the original piers would form a good outer barrier under shelter of which a new pier would be safe from damage. But further examination was not favorable to this idea. The shelter it would give in its present state is too irregular. In some parts it might be fairly efficient, but in others it would allow the sea to pass over it on to the new work with increased violence. To prevent this such places would have to be made up with new material, and this would lead to a serious amount of work, and I think a not very satisfactory result. Besides which there is a considerable proportion of the old work remaining, and the rubble base especially having been well consolidated would offer a better foundation than a new one, especially in not being liable to the immediate settlement which caused the fracture of the blocks. Two out of the four courses of blocks are also for the most part in a good state, and an uncertain proportion of the displaced blocks may be recovered and used again.

29. Preference was therefore given to the principle of rebuilding the piers on their original foundations, and making such additions as experience shows to be necessary. The one great objection to this is the immense difficulty of clearing the ground of fallen blocks. The magnitude of this difficulty can hardly be realised without inspection of the ruins. It will undoubtedly be a slow and costly operation, but all who are concerned in it are satisfied of its practicability, and the difficulty being simply a mechanical one, we may safely conclude that it will diminish with practice and experience.

30. I propose, therefore, that the work be rebuilt on the former lines and to the former section, but with the additions shown shaded on the accompanying sketch, to give increased strength to the two weak points.

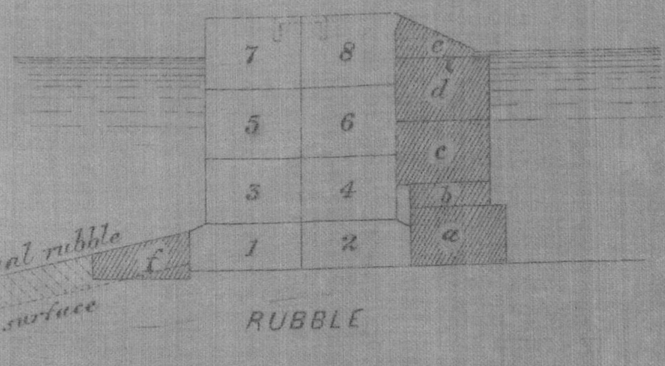


The rubble base and blocks 1, 2, 3, and 4 are generally in a serviceable state. 5, 6, 7, and 8 are new blocks similar to the old ones, except that they will be 9 feet high instead of 8 feet, so as to make up for the 2 feet of subsidence. *a*, *c*, and *d* being of the same dimensions as the old blocks, the latter can be used so far as available; *b* is a thin block inserted for the purpose of bringing the top of *d* above water level, so that *e* may be set upon it in a bed of cement, thus making *d* and *e* together into one block of 36 tons weight. The top of *e* is sloped off to give an escape for the falling wave. If it were level like the top of 8, the effect would be simply to transfer the vulnerable point from the top of 8 to the top of *e*, as is shown by the fact that at the pier heads where the structure was increased to three and four blocks in width the one next the harbour still gave way.

31. Block *f* is intended to protect the toe of the outer wall from scour and ultimate undermining. It should be placed at as low a level as practicable, so as to avoid encroaching on the profile formed by the sea itself. It is a noticeable feature in the cross sections of the damaged parts of the piers that a scanty slope of rubble and severe damage to the superstructure do not go together. On the contrary, where the sea wall was actually undermined at the south pier, and the nearest approach to a clean breach was made, the rubble base happened to be particularly full. The evidence is at present not more than negative, but it is to the effect that a full foreshore is not an element of strength. The object of the footing, therefore, is simply to substitute a surface of concrete for one of loose rubble, preserving as nearly as possible the level and slope which the sea has formed. From the outer end of the block the slope will be continued in rubble. It may probably be desirable where the blocks are fallen to seaward not to disturb them, but rather add some more so as to make protective mounds of random blocks at those places.

32. Besides these actual additions to the section I propose to introduce two extra securities into the top course of the old section. It has always been an object, though hitherto unattainable, to connect the top blocks together, both longitudinally and transversely, so as to make all the portion of the section which is out of water into a monolithic mass; but it is impossible to do this in new work efficiently in consequence of the settlement to which the structure is liable. An unequal settlement would sever any attachments we could apply. Now, however, in rebuilding on an old foundation this difficulty will be much diminished. What settlement does occur will be more uniform, and slight inequalities in it may even be prevented by the adherence of the attachments. It is proposed, therefore, so to make the cross joints of the top blocks that they may be filled with cement, not during the progress of building, but on a suitable opportunity afterwards. It is also proposed to connect the two top blocks by an iron cramp made of a bent, worn-out rail with the ends turned down and cemented into the blocks. Thus each longitudinal row of blocks will become, so far as the cemented joints can be depended on, a monolith, and the two monoliths will be tied together at intervals of $4\frac{1}{2}$ feet. It cannot be anticipated that the monoliths will be absolutely continuous. Some of the cement joints will separate, but the majority will hold together, and the top of the breakwater will consist of much larger masses

p. 8



To

THE SECRETARY TO THE GOVERNMENT OF INDIA,
PUBLIC WORKS DEPARTMENT.

Calcutta, 13*th March* 1882.

SIR,

I have the honor to report my return from Madras, having carried out the instructions conveyed in your No. 72 M of 8th February; and as Mr. Molesworth is of opinion it would be better I should prepare a separate report, I have the honor to submit the result of my enquiries as follows, premising that as the actual measurements, general plan, &c., of the present state of the piers will be dealt with by Mr. Molesworth, I do not think it necessary to enter into them in this report.

Plan of harbour.

2. In the first place, with reference to the suitability of the shape of the harbour for the purpose required, the plan appears to me judiciously designed. There is no great choice as to shape, and the only question I have heard raised is as to the position of the entrance. The Master Attendant at Madras is of opinion that the entrance should be about the centre of the north pier in 6 fathoms, instead of in its present position in the centre of the sea face, but has not, so far as I am aware, put forward the reasons which lead him to prefer this new position, or the objections to the present entrance, beyond stating it to be the opinion of all nautical men that the sea face must be closed, and that it is a source of weakness to the work. This latter hypothesis does not appear to me at all borne out by Captain Taylor's arguments. The current at Madras is never strong enough to do any harm to a mound of rubble stone, according to the information I received; but I shall return to the subjects of currents.

Mr. T. Stevenson, the eminent Harbour Engineer, lays down as an axiom that the entrance should always be fixed seaward of any other point. All harbours on the English coast that I am acquainted with are so constructed, and notably the great Amsterdam Harbour on the North Sea, a work designed by Sir John Hawkshaw for a similar situation on a straight sandy coast, is similar in shape and position of entrance to the Madras works.

Entrance.

3. The objection that the current sets across the present entrance, which is the only difficulty to ships entering, is common to all harbours similarly situated.

Currents.

4. There are no records of any systematic observations of the direction of the swell or of the currents, and their strengths at different seasons; and I would suggest that a series of observations on these points be at once set on foot, a special observer being employed for a whole year at least to make daily frequent exact observations, especially as the question of the best site for the entrance depends greatly on the first of these points.

Width of entrance.

5. The requisite smoothness inside the harbour may be probably obtained by contracting the entrance, and I believe this may be done without lessening the accessibility of the harbour. The Master Attendant is of opinion that 500

feet is the least admissible width, but, looking to the width of many other harbour entrances,* to the probability that when accustomed to a small entrance it will be found less formidable than anticipated, and also to the fact that from the first, without experience, no difficulty has been felt with the present opening of 550 feet, I believe 400 feet will be found a sufficient width, but the exact width should be settled after the observations suggested in para. 4 shall have been completed. With such a width, I believe no wave of a size to cause inconvenience would exist within the harbours except during heavy cyclones, when I believe heavy swell would roll in through any entrance.

	Feet.
* Portland	360
Sunderland	368
Aberdeen	378

Position of entrance.

6. As regards the position of the entrance, as the decision cannot be acted upon until plant has arrived from England, and the damaged walls have been repaired, there is time to consider carefully whether any alteration shall be made, after making careful observations on the set of the waves and swell through the year. I feel certain that an entrance at the side should not be so near the outer line of surf as the depth of six fathoms, proposed by the Master Attendant.

Piers or walls.

7. It is hardly necessary for me to do more than refer briefly to the design of the harbour walls. They consisted, in the normal section, of a base consisting of a rubble mound, 78 feet wide on top with slopes of 1 to 1, and raised to a height of 22½ feet below low-water line, on which stood two equal walls of concrete blocks, each 12 feet wide, touching each other but not connected or bonded together. Each wall consisted of a series of columns of four blocks each; each inclined slightly backward at a slope of 3 inches per foot, leaning against the next column behind, and pressed against by the next column in front. The upper blocks in each column were connected by tenons, made on the blocks, to the one next below it; but it was an essential feature of the design that there was no bond or connection laterally or longitudinally between the various columns. Each block measured 12 feet in depth of bed, 8 feet in height, by 4½ in thickness, excepting the foundation blocks which were 14 by 6 by 4½, and the normal height of the wall was 29 feet, which was increased by one block in depth near the head for a short distance only. Each block weighed about 27 tons, of which two tons were Portland cement, and they were, at times, set a month after completion. The specific gravity of the concrete was 2·3, so that the weight of a block under water is under 16 tons. The rubble mound was composed of stones of all sizes up to 2 or 3 cwt., deposited out of boats, and the north mound as far as the elbow was of laterite, while the southern one for the same distance is composed of gneiss: from thence to the ends both mounds are chiefly of laterite with a little gneiss mixed.

Comparative cost.

8. The work has been carried out most expeditiously and at an unprecedentedly low cost, being so far only £ 60 per running foot, as compared with the following:

	£	
Alderney	190	
Portland	120	lowest estimate.
Dover	360	
Holyhead	160	
Plymouth	300	
Marseilles	210	
Algiers	122	
Cherbourg	219	

The Colombo breakwater is said to have cost, so far, about Rs. 2,000, or £ 166 per foot. Even if the completion of the Madras works costs an additional 40 lakhs, an outside estimate, and occupies three years more, this great work will have been constructed at a very low rate and in a very short time.

Section.

9. A comparison shows that the cross section of the original design is slight compared with most other breakwaters, and in its prototype, the Kurrachee work, the vertical walls, which were of the same width, were only three blocks high. Moreover, the sea at Kurrachee strikes the pier at an angle of about 65 degrees with the line of the work, and gives only an oblique blow. The breakwater there has not received any damage since the monsoon of 1874.

Description of storm.

10. I would next offer some remarks on the character of the storm. The Master Attendant reports there was no wind to speak of, and that boatmen could have put off outside the harbour; further, that the wind set in at west, and that the cyclonic centre was to north-eastward of Madras, but that it afterwards 'recurved.'

It appears, however, from the records of the Meteorological Department, that the centre was southward of east from Madras, and that it reached the coast considerably south of Madras; the wind by the observatory anemometer being at first north-north-west, and only for a short time veering irregularly to north-west, and was never to the westward of north-west by west. The direction of the heavy sea at about east by north also clearly proves the centre to have been always to southward of the place. The strength of wind registered by the anemometer was 32 miles an hour, or a moderate gale of wind, as compared with 53 miles in the gale of 1872. The sea was getting up during the night of the 11th November, and the principal damage took place before noon of the 12th, but the greatest barometric depression, showing the nearest approach of the centre, was about 2 P. M., and the wind increased up to about 2 in the morning of the 13th, after which it rapidly decreased.

11. The storm was doubtless very severe out in the Bay, but there is no record at Madras of its having been actually encountered by any vessel. There is every reason to fear that the steamer *Lockyer* from Calcutta foundered in this cyclone. It appears not to have been of large diameter, and evidently decreased in intensity on approaching the coast, but the sea, originating on the advancing north side of the centre of the cyclone, and propelled by it on to the harbour works, was, there is no doubt, very high, and of destructive violence. A very competent observer, Mr. Chisholm, C. E., was of opinion the waves were much higher than in the storm of 1872, or in any cyclone he had seen at Madras. In fact, the waves inside the harbour, which, according to that gentleman, were much less than those outside, even after the works were breached, reached the platform of the iron pier, and did some slight damage to the planking. This is as high as any sea reported before the harbour was made.

Character of sea.

12. It is to be expected that the waves caused by a cyclone, the body of which passed to the southward, would be more severe than if the centre passed over the place itself. The sea is stated to have come in with great regularity from a direction a little northward of east, the line of breakers being parallel to the sea face of the north pier; it subsequently shifted slightly to a more southerly direction.

[illegible] anchor in the roads, was able to put to sea on the afternoon of the 12th, the wind being then to the westward of north. The P. and O. Co.'s steamer *Clyde*, which arrived from the southward the following day, had observed indications of a cyclone to the northward of her, and had slowed down to let it pass.

Depths, alteration of.

14. I have taken a few soundings, and made careful enquiry as to the depths inside and outside the harbour, and at its mouth, and found the depths somewhat in excess of those shown on the latest Marine survey—possibly owing to a difference of datum. No change has been recorded in the depth of the entrance since the construction of the piers, nor, from the few soundings I took, does there appear to be any deepening or scour acting on the sea bottom outside the entrance by the littoral currents. It appears these are too weak to act on the sandy bottom, and still less would they be able to displace the rubble mound.

Action of sea at bottom.

15. It is quite certain that the action of the sea waves or ground swell is felt to a depth far beyond what has been hitherto considered a maximum, namely, 12 to 15 feet, as the rubble base has been acted on both by being spread out into flatter slopes, and also by settling to some extent into the sand, probably by the action of the sea on the sand at the toe of the rubble mound, and by the vibration of the superstructure caused by the blow of the sea. As the top of the rubble base is 22 feet, and at the pier heads 28 feet, below low water, it is clear that the depth at which rubble can be moved by the oscillation of water caused by heavy storm waves must be greatly extended. There is also found a scooping out of the mound just outside the vertical wall, which is perhaps caused by the motion of translation of the wave being partly reflected downwards along the face of the wall.

Cotton's experiment.

16. The so-called breakwater of Sir Arthur Cotton was an insignificant affair. According to the records supplied by the Public Works Department, only 2,500 tons of stone were thrown into the sea in about 25 feet of water, forming a small heap of stones 76 feet by 55, rising to a height of 12 feet below the surface of the sea. It lies to southward of and just inside the line of the head of the screw pile jetty, and there is now not less than 19 feet over it in any part, but it cannot be said to have disappeared.

Present state.

17. For the purpose of describing the present state of the works, I shall refer to the straight portions of the piers extending straight seaward as the 'sides,' the straight parts on each side of the entrance facing the sea as the 'faces', and the curved portions connecting the sides and faces as the 'elbows.' Their condition since the storm is well and correctly detailed by Mr. Thorowgood in his report of 21st November 1882, paras. 8 to 19, and may be summarised as follows :

Northern pier, total length 3,866 feet, of this 2,240 feet, as far as the commencement of the elbow, are intact, except that for the last 200 feet the longitudinal joint has opened slightly. From the beginning of the elbow to the pier head, a distance of 1,626 feet, the damage is continuous and considerable. Practically the vertical wall has ceased to exist, and has been reduced to a heap of 'random' blocks; the lower or foundation tier remaining generally unmoved. In places, the second or even third, course is standing, but more or less displaced or settled down. It is noteworthy that the pier head, which was widened out to four blocks in width, has equally failed to resist the sea.

Of the southern breakwater, total length 3,970 feet, a length of 2,550 feet from the shore, or up to a point a little farther than the beginning of the curve, is uninjured, but the blocks of the remaining 1,420 feet as far as the end are little less displaced than in the northern pier.

18. The uninjured parts of both piers stand now at an equal height above the level of the sea, and, as regards the manner in which the fallen blocks lie, it is remarkable that round both elbows the blocks have fallen outwards as well as inwards in about equal proportions, while, in the faces or outer straight portions, they have generally been thrown over into the harbour, and the outer blocks have been the least disturbed. This peculiarity has been also found at Kurrachee, on occasions of damage during construction.

19. The rubble mound has not been much affected on the harbour side, but on the sea side it is drawn out into a long slope, uncovering and in places undermining the foundation blocks, and this action has been most marked at the elbows, where the blocks have fallen outwards. It has also, along the faces, been scooped out into a ditch near the foot of the wall, and has to some extent settled bodily down, owing probably to the sandy bottom yielding. It has been much washed down also along the still intact sides. At the pier heads, while the northern one is almost unaffected by undermining, except just at the corner for a few inches only, or no further than could be reached by the hand, the south head is reported much undermined, being attacked on two sides.

Causes of damage.

20. With reference to the causes of the damage to the different parts, the next point to which attention was invited, it appears that on the 'faces,' where the inner row of blocks is most injured, and has fallen into the harbour, the failure of the wall is principally due to the direct blow of the wave. This blow on the outer blocks has been transferred to the inner row of blocks, and as these were not tied to the outer blocks, they were driven inwards into the harbour. This is illustrated by the familiar experiment of three or more balls suspended, lightly touching each other; when, if one of the outer balls is moved out a short way and then allowed to fall back against the centre one, the blow is transferred to the outer ball on the other side, which will diverge to the same height from which the first ball fell, while the intermediate balls do not move. If this hypothesis be correct, it will account for the northern pier head failing in the same manner as the rest of the wall, although composed of four rows of blocks, part of the outer row only remaining in place.

21. The process has no doubt been assisted by the following actions which are referred to in many papers on the subject of sea walls :

(a).—The hydrostatic pressure of the water due to the difference of level on the two sides of the wall during the passage of a wave.

(b).—The action of air between the blocks compressed by the blow of the wave, and tending to force the blocks apart. This action has been intensified by the capping of concrete which has been laid on top of the blocks to form a bed for the permanent way, and which prevented the egress of the air upwards. The capping has been broken up, even over the parts of the pier which remain standing, in a manner suggesting such action.

(c).—The formation of a p...ial vacuum on the harbour side of the wall.

(d).—The dynamic blow of the actual weight of water falling nearly vertically on the top of the wall, chiefly on the inner line of blocks.

Downwards action.

22. If we assume that as part of the wave is thrown upwards with great force, so a similar action takes place also downwards, it would account for the hollow or trench scoured out on the sea side of the wall, and perhaps also for the depth at which the work has been affected.

Failure of elbows.

23. The failure of the 'elbows,' where the sea struck at an angle, and was perhaps intensified by 'interference,' appears to be principally due to the undermining of the wall by the lowering of the rubble mound on the sea side, as here the blocks have chiefly fallen outwards, and the rubble mound has been most severely acted on. The safety of the side walls is, I suggest, due to their meeting the blow end on, and to their being protected to some extent by the more seaward portions.

Quality of rubble base.

24. The fact of laterite having been used for the base has been criticised, and no doubt it would have been better had the harder stone been exclusively used. The reasons assigned for its use are the greater facilities for getting a large supply, and the fact that it was expected the rubble mound would not be moved by the sea. In future operations I would use the gneiss exclusively. If, however, the laterite had been one of the principal causes of the fall of the walls, it would naturally be expected the still standing north wall, which stands on laterite, would have settled more than the south wall which stands on gneiss, but this is not appreciably the case. In fact, the north side wall, considering it was somewhat more exposed, has stood equally well with the south wall.

Waves.

25. As regards the waves entering the harbour, Mr. Chisholm is decidedly of opinion they were much less than outside the harbour even after the damage had taken place. The tide gauge shews that the level of the water in the harbour was considerably raised, probably by the water continually poured in by the waves over the piers, so that it ceased to register the height on the scale. The rise amounted possibly to 2 or 3 feet, and gave rise to a current setting out of the harbour mouth of sufficient strength to carry wreckage out to sea. This, no doubt, made the waves in the harbour more hollow and dangerous.

As the height of the pier above the ordinary sea level is 18 feet, this would give the maximum height of wave in the harbour as near 16 feet above sea level.

Completion of works.

26. I have now to refer to the question of re-construction and completion, and I believe it to be proved that it will be undesirable to attempt to complete the work on the original principle of a vertical wall without any bond—even if it were completed with three walls instead of two for the whole length of the damaged part. The inner row would, I believe, be overthrown nearly as readily as it has been with two rows, and the experience of the north pier head indicates that the same result might follow, even with four walls or rows; further, the clearing away of the fallen blocks to make room for the foundations of a vertical wall would be expensive and tedious, and I would adopt the random block, or French system, leaving the whole of the material at present on the ground to form the nucleous of the new work.

Rubble base.

27. It will be necessary, in the first place, to complete the rubble base, and as this will be protected by the superposed random blocks from the action of the sea, I would raise it to a height of 35 feet from the bottom, instead of 22, widening it on top 10 feet on the outside beyond the present dimensions, and allow it to take its natural slope of 1 to 1. If left to itself, this would spread out into a long slope of 8 or 9 to 1; but if the large blocks are deposited on it at once, it will probably remain at about $1\frac{1}{2}$ to 1 after settlement. The toe of the rubble mound on the sea side should be protected by an apron of rubble extending 30 feet outside the mound and 2 to 3 feet thick.

Material.

28. I would use gneiss stone exclusively for the mound, and it should be, as far as possible, selected as to size at the quarries on the French system, the smaller stone being used in the centre of the mound and the larger for the outside. It can all be tipped from boats.

Random blocks.

29. The new blocks should be deposited close together, and as soon as possible after the mound has been completed to its full section, and they should extend to a depth of 25 feet below the sea level. If piled up to a height of 6 feet above high water, they would gradually settle down, and would for some time require fresh blocks to be added to fill up the section. They might be taken out on barges and deposited by a floating crane such as those used at Port Said, Alexandria, &c.

Protective blocks.

30. I would also deposit a row of blocks along the outer toe of the still standing side walls for their whole length as they stand, after completing the rubble mound, where it has been washed down, to its former section.

Size of blocks.

31. There is a convenience in adhering to the dimensions of the present blocks, owing to the formation of the block ground and travellers, which gives great facilities for making, storing and transporting the present pattern of block, but it might be considered whether the thickness should not be increased one foot, even if the breadth were diminished, so as to lessen the chance of fracture of blocks after being placed *in situ*, and I would not set any blocks in less time than four months after completion, to give them time to thoroughly harden, especially as, in the style of work proposed, they are subjected to more severe transverse strains than in a regular wall.

Resumption of work.

32. Whatever plan of re-construction be decided on, no time should be lost in resuming the tipping of granite rubble on the outside of the piers still standing to complete the section and secure the "sides" from chance of injury, and also the manufacture of blocks to the full extent of the storage capacity of the block grounds, which will be useful in any case.

Cost.

33. I have made a rough estimate of the cost as follows:

	Lakhs.
Plant	4
Protective blocks along side walls (1,250)	$2\frac{1}{2}$
Rubble mound completion, 450,000 tons at Rs. 2 ...	9
Random blocks, at 7 blocks per yard forward	14
Establishment and contingencies	$2\frac{1}{2}$
Total ...	32
Deduct blocks on hand and value of plant after completion ...	2
Net Total ...	30

and I think this would not be exceeded, but it would require more detailed calculations to arrive at any very exact result.

Breakwater.

34. It has been suggested ... be protected by a detached breakwater outside; but I think this, in addition to being very costly, would render the harbour very difficult to enter or leave, and if the required smoothness of water inside cannot, as I hope, be attained by narrowing the entrance, I would much prefer an entrance in 7 fathoms at the north-east angle, in which case the corresponding outer face should be prolonged a little beyond the line of the side walls.

35. I have much pleasure in recording the cordial help afforded by the officers of the Madras Government, and by Mr. Parkes and the officers of the Harbour Works.

I have the honor to be,

Sir,

Your most obedient Servant,

A. W. STIFFE,

Port Officer of Calcutta.

C A W

This may be kept with the Harbour file. Both the H.M. and this Govt have seen it

Att

2/13/82

RA

attach to the original C.S. in Mr Parkes' recent Report. C.P. 3

Madras Harbour Works Office,
13th March 1852.

My dear Colonel Sankey

The sketches for the Report were accurately made by Mr Parkes himself: they must be worth the Government printer or lithographer had
be worth the Government printer or lithographer
and I have no copies of them - I have a sketch
made (enclosed herewith) of the Section on p.8 from
another Section by Mr Parkes to a different scale,
but would prefer you to refer the lithographer to
Mr Parkes original as well - In the plan and the
other two sections I have tried to shew how they should
be corrected in red but here again I should prefer
you to refer to the originals & think it would be
better if they were done at the Revenue Survey
Col R. H Sankey R.E. C.B.

To L

For early correction of the sketches, and remarks as to the alleged inaccuracies.

R.S. 13/3.

CAW

Have we corrected the MSS as per list in MSS

If so we can have the Lecture corrected

Hamish to go letters back to the Beardmore whose remarks relate to Lee

AHS

As directed, the diagrams will be modified. The term is used as the alleged corrections indicated in red are in reality deviations from the original; the lithographed copies being faithful representations of Mr Parkes original diagrams in MSS

Mr Parkes' Diagrams

Shew me the originals and the lithographed copies. They seem to be identical. Mr Beardmore's corrections are therefore in reality corrections of Mr Parkes' drawings. Mr Baldry has altered the letter press, but he is under the circumstances doubtful whether he should strike off as noted.

Please see block 7 on page 4 (printed) It is in an impossible position. The centre of gravity falls go beyond the base

C W

Have Lectin
an/sale 5 alone
attend leaving
the rest as they
stand

Have this & the
verbal corrections
made as Quickly
as possible as
I take Mr Beardm
wants to despatch
Copies to England by
Tomorrow's mail

Atte

Rough Draft

Madras Harbour Works Office,
March 1882.

Copy

Rezas
Corrections to
be made in
original and all
spare copies and the
Para adverted to in the
My dear Colonel Lankey
letter to
Lankey

Para

With regard to the Letter press
of Mr Parkes' report:- In Para: 38 near the end
the total sum of the Estimate should read
"between the limits of 15½ and 18¼ lakhs," --
and in Para: 41 near the middle the sentence
with regard to the tonnage of steamers should read
"The Register tonnage of steamers was 146,374 and
"the quantity of goods landed about 22,000 tons,
"and of those shipped 11,000 tons, making a total
"of 33,000".
These are corrections Mr Parkes desired me to make
Yours sincerely
Frank F. B. Beardmore

Col R. H. Lankey R.E.
C.B.

breakwater. 34. It has been suggested ... detached breakwater outside ...

C 44

2b

C 440

Please have these Corrections made in all Copies of the Report at once

14-3 [illegible]

Very urgent

GOVT. OF MADRAS. } 1882. { P. W. DEPT.

No. 386. SECRETARY.

Chepauk, 27 March 1882.

OFFICE NOTE.

To Extract of para 3 from Note by the Chief Engineer PW Deptt on the Madras Harbour Works

The total outlay to date on the Madras Harbour Works including the pier tunnels mouth of the Harbour, and excluding the Esplanade and jetties, which are paid for from Port Funds, amounts to 58½ Lakhs."

To C. Please check the figures in the above Extract and return in the course of the day.

27.3.82

By W

No. 1299 dy 27th March 1882

TO DY. W.

PLEASE SEE STATEMENT WHIC
ACCOMPANIED THIS OFFICE LETTER NO.
238 W. DATED 24TH MARCH 1882 WHICH
SHOWS AN OUTLAY OF RS.59,22,208
INCLUDING RS.60,612 ON ACCOUNT OF
STOCK BALANCE TO END OF JANUARY
ON THE HARBOR WORKS EXCLUSIVE
OF THE OUTLAY DEBITED TO THE CIVIL
DEPARTMENT ON ACCOUNT OF THE BEACH
IMPROVEMENTS. SINCE SUBMITTING
THE ABOVE STATEMENT THE ACCOUNTS FOR
FEBRUARY (NOT YET AUDITED) HAVE
BEEN RECEIVED SHEWING AN OUTLAY OF
RS.59,44,667 TO END OF THAT MONTH.
THIS LAST OUTLAY INCLUDES RS.57,39
ON ACCOUNT OF STOCK AS ABOVE.

C.

file
draft
788 dy 23 Mar

C A W

Better defer
writing the P.W.D.
in type as I wish
have the orders
issued at once
by the H. A.

I have made
a few emendations
in my note, and
would wish to
see the proofs

21/3/82.

Ja 11 7

Kindly say
what is to be done
with the 50 Copies
of Report which
the Harbour Works
office returned to
us. They were
intended for Mrs
Parkes?

R. F.

17-3

C A N

Return to Mr
Bundrose as
no further attention
of the Secretary is
desirable

Attd

1713

I think that the immediate
course should be forward
the Report of C. E. Scott &
S.S. for consideration of Board
Landing offices at Cape
Town &c. &c. of S. A.
Requesting in which to be
given an early answer to be
taken here. Mr Kingdon
has a covering letter if
necessary. Write for S.S.
& consider whether answer
can be received after next
Post & another letter sent
home. Enclose this report,
advise how disposed &
form an independent
judgment on the position
& cause the work
adopted, & decide
if opinion that to be carried

Cir 13.3.82

pass them by
& go direct to

For orders

In circulating Lieut
Mr Parkes's Report on
the restoration of Table
Harbour works and
my professional note
thereon I should wish
in any early instructions
as to be further dis-
posal of these documents
(1) Should be directed
be that the S of S or
the S of S to address
(2) Would be disposed
be any time more to
a forwarding letter
despatch accompa
by a request that
intimation be sent
by telegram date
the incorporation of
materials as to

in the closing paras
of my note?

Adm

13.5.82

Adm

The Lds. of A. for Secy

[illegible] 14/5/82

In sending on this Estimate
for the Capital Ship
I wish to call their Lds.
attention to the approximate cost of
the alterations in the certain
Docking &c in the
of the Basin for the
the Hartlepool. Dr. Litchfield
re Material &c

JB

78
787 y
562

The Hon W Ward Castle

Draft order and
despatch for approval

Orders have been given
to put the Chief Engineers
note in type at once
and if the annexed
despatch be passed by
the Lds. the whole
should be in readiness
for despatch in 2 or 3
days

Adm

24/5/82

GOVT. OF MADRAS. } 1882 { P.W. DEPT.

Madras ~~Fort St. George~~, 16 March 1882.

OFFICE NOTE.

To

The Chief Assistant
Govt Secretariat Dept.

The 50 copies of Mr Parker's Report were returned with a demi-official letter to Col: Sankey explaining what is further required in them. I did not see the letter in question

Ep Coates
Manager
Pr. Mch 1882

OF 187 .

Pl. see
Shown the
50 Copies of Report.
Please say what is
to be done with them

CMO
RS
Mr Brackenbury 17/3
In charge of Govt Press when
such will they are published
please with Mr Parker's

Copied 29 Sept 82

Abt

173

W

Papers inclosed

R.A.

17-3

Remarked

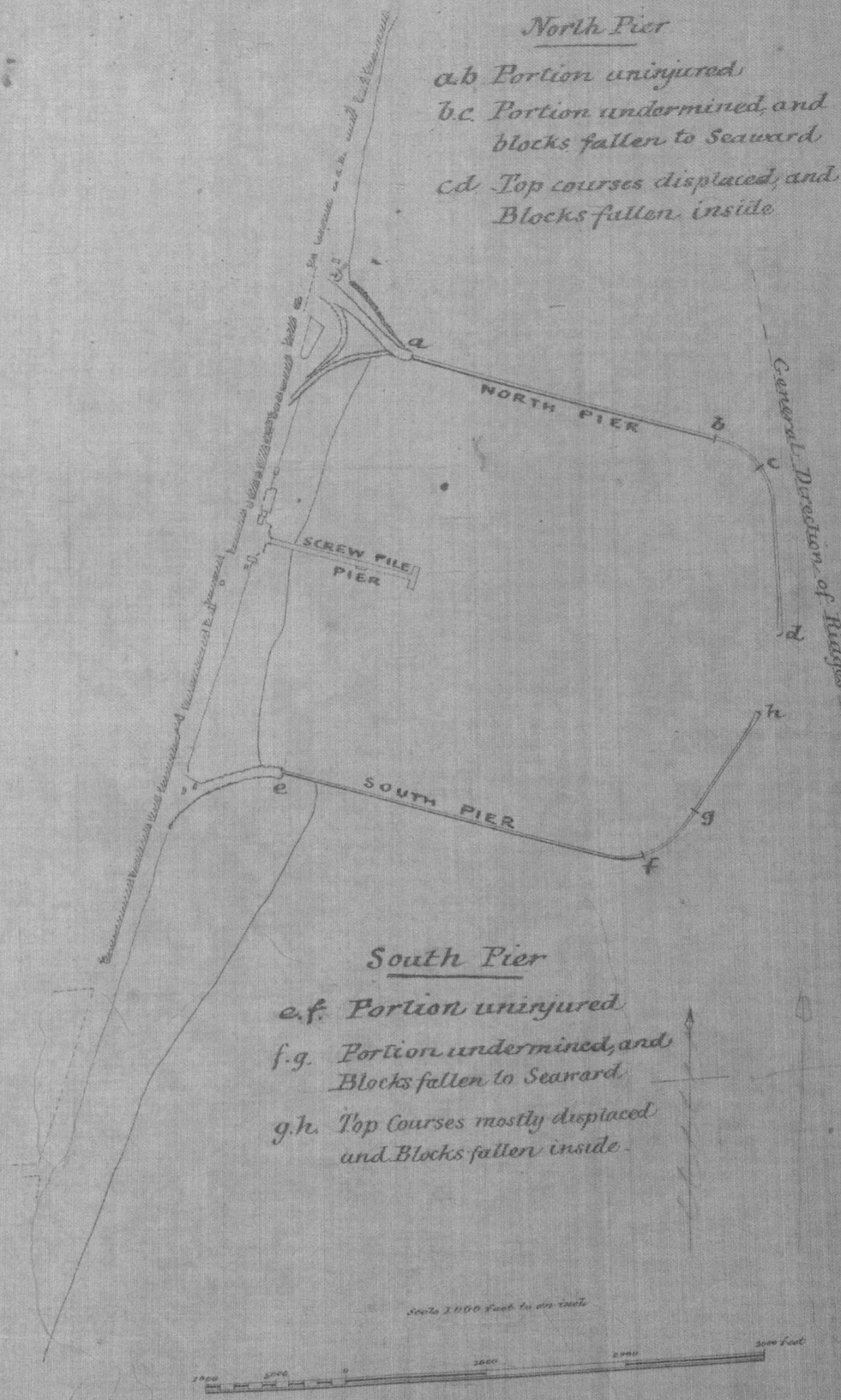
Abt

17.9.82

37

Madras Harbour

Sketch shewing Sites of Damage in Storm of 12 Novr 1881



Madras Harbour

Estimate of Restoration

Part I. Repairs of damage

	Rupees
Maximum	
New Plant and machinery	1,25,000
Resetting existing blocks of second course both piers 21,355 cubic yards at Rs 2	42,710
Removing broken blocks 32,033 cubic yards at Rs 10	3,20,330
Replacing 32,033 " " " Rs 10.8	3,45,956
Recovering whole blocks 10,678 cubic yards at Rs 4	42,712
Resetting do 10,678 " " " Rs 2	21,356
	8,98,064
Credit by 32,033 cubic yards available as Rubble at Rs 3	96,099
	8,01,965
Establishment (7½) and contingencies (2½) Rupees	80,196
	8,82,161
Minimum	
New Plant and machinery	1,25,000
Resetting existing blocks of second course both piers 21,355 cubic yards at Rs 2	42,710
Removing broken blocks 10,678 cubic yards at Rs 10	1,06,780
Replacing 10,678 " " " Rs 10.8	1,15,322
Recovering rubble blocks 32,033 cubic yards at Rs 4	1,28,132
Resetting do 32,033 " " " Rs 2	64,066
	5,82,010
Credit by 10,678 cubic yards available as Rubble at Rs 3	32,034
	5,49,976
Establishment (7½) and contingencies (2½) Rupees	54,997
	6,04,974

Madras Harbour

Estimate of Restoration

Part II. Supplementary Strengthening Works

North Pier		
Buttress Wall 22504 Cbyards at Rs 10·8		2,43,043
Apron outside 4000 " " " Rs 12·9		51,600
+ Extra rubble outside 36,000 tons Rs 2		72,000
+ do inside 20,952 " Rs 2		41,904
Two feet extra height 3111 Cbyds Rs 10·8		33,598
Cementing joints of top course 218 cubic yards cement mortar Rs 30		6,540
Bending & fixing cramp irons		10,000
Clearing round curves		1,500
Levelling top & blocks on standing portion		10,000
South Pier		
Buttress Wall 17735 Cbyards at Rs 10·8		1,91,538
Apron outside 3,200 " " " Rs 12·9		41,280
× Extra rubble outside 31,200 tons at Rs 2		62,400
× Do inside 16,572 " " Rs 2		33,024
Two feet extra height 2400 Cbyds Rs 10·8		25,920
Cementing joints of top course 167 cubic yards cement mortar at Rs 30		5,010
Bending and fixing Cramp irons		10,000
Clearing round curves		1,500
Levelling top of blocks on standing portion		10,000
		8,50,857
Establishment 7½ per cent }		85,086
Contingencies 2½ " " }		
Total cost of New Works Required		9,35,943

× In execution these quantities will be reduced by the amount of broken blocks available as Rubble. (See Cl in Part I).

P3 30

Madras Harbour

From the Engineer in Chief
Madras Harbour Works

To the Secretary to Government
Public Works Department
Madras

Madras
March 1882

Sir,

I have now the honor to submit to you my report on the damage to the above works caused by the storm of the 12th November last, and my proposals for their restoration.

2. My report has been delayed longer than I could have wished owing to the great difficulty in obtaining detailed measurements and sections, which require an

/

exceptionally calm state of the
sea - Upon the results shewn
by these depend in a great measure
our conclusions as to the particular
action of the sea which produced
the damage. I have ~~do~~ thought it
desirable to delay the submission of my report until I had
it ~~of importance~~ obtained such facts
as were necessary not only to form a basis
for my own positive conclusions, but also to
test ~~shew~~ beyond the possibility of doubt
the correctness of the conclusions which
by others upon a matter of
~~may~~ have been put forward ~~now~~
imperfect knowledge of the facts. I
may here mention once for all that
I have given careful consideration to
various suggestions that have been made
~~forward~~ to account for the damage,
but I do not think it necessary
to notice these as a rule, but rather to
~~I do not think~~ submit my own
conclusions with the facts on which they are based.

Previous Reports

3. I wish however to explain my
position with regard to two documents
of very great interest, the first being
a report which was made only two
days after the storm by the Chief

Engineer of the Presidency who with great promptitude availed himself in company with the Master Attendant of a specially favorable opportunity of taking what was necessarily a very general view of the state of the works. This report was forwarded "~~to~~ with all reserve" to the Secretary of State, and I had an opportunity of perusing it before I left London. If I were to comment upon the suggestions made in this report, as to the ~~actual~~ particular action of these which the author probably never intended they should possess.

4. The other document is a very excellent report made by Mr. Thorowgood on the 21st November, 9 days after the storm which is especially noteworthy as shewing how much information can be obtained in a short time. But this information though generally confirmed by subsequent observations was not sufficiently complete to form a basis for practical conclusions and what was then wanting had to be obtained with considerable difficulty

afterwards. ~~Chief Engineer~~ ~~Report like that of the~~ ~~which is scarcely~~ ~~suggests some conclusions confirmed by subsequent~~ ~~investigation~~ It is scarcely possible to make an intelligible statement of facts without conveying some suggestion of conclusions to be drawn from them, and in some cases such suggested conclusions fail to be confirmed by ~~subsequent investigation~~ the facts subsequently ascertained. To a slight extent this is the case with Mr. Thorowgood's report, but it is no disparagement of its merits to ask that it may be considered as superseded, ~~in the~~ ~~its facts and~~ its conclusions by the present report, and by the plans and sections which will be submitted to Government and will I think form a very interesting and instructive record*.

Mr. Thorowgood 5. I should mention that I had the advantage of five weeks constant communication with Mr. Thorowgood before he left for England, and during that time, as further materials accumulated, we were able to form more definite conclusions, and those conclusions

*Note. These are still in progress - at the end of the present fine season so much as is complete will be submitted to Government. 4

each set
independently formed, were in all
essential matters the same. They
included, subject to corrections suggested
by the further surveys which have since
been made, most of the recommen=
=dations which I am about to submit.

The storm 6. The storm is thus described
in the official meteorological report
issued by the Government Astronomer
as November 23rd 1881.

"A cyclone visited Madras

METEOROLOGICAL RESULTS.

Meteorological Results from the Madras Observatory Register for the Week ending 18th November 1881.

1881.		Barometer reduced to 32°.	Thermometers. Corrected Daily Means. Dry.	Thermometers. Corrected Daily Means. Wet.	Thermometers. Observed Extremes. Max.	Thermometers. Observed Extremes. Min.	Maximum Solar Heat in Vacuo.	Humidity.	Wind. Prevailing Direction.	Wind. Daily Velocity.	Depth of Rain.	Clear Sky.	General Weather.
		Inches.	°	°	°	°	°	Cts.	Points.	Miles.	Inches	Cts.	
Nov. 12th	Sat. ..	29·583	68·9	66·9	77·0	65·6	78·0	90	N.N.W.	530	8·19	0	A moderate cyclone: (*see* note).
13th	Sun. ..	29·797	72·2	68·2	78·2	69·5	136·4	81	S.E.	285	..	43	Stormy before sunrise; fine after.
14th	Mon. ..	29·854	77·3	73·8	83·3	71·1	142·2	84	E.S.E.	81	0·12	37	Showers before sunrise; passing clouds.
15th	Tues. ..	29·879	77·9	74·4	86·2	74·0	143·4	84	E.N.E.	71	0·06	33	Cloudy.
16th	Wed. ..	29·860	79·6	75·4	89·4	74·1	152·5	81	N.N.E.	52	..	77	Fine with passing clouds.
17th	Thurs. ..	29·846	80·1	75·6	90·8	73·8	152·2	80	N.N.E.	46	..	60	Do.
18th	Friday ..	29·820	80·4	75·9	89·0	75·0	155·4	80	S.E. by E.	58	..	57	Do.
Mean of the week.		29·806	76·6	72·9	84·8	71·9	137·2	83	E.S.E.	160	8·37	44	

The Standard Barometer and Thermometers are read at 10 A.M., 4 P.M., and 10 P.M., and the daily means are obtained by the application of hourly corrections, deduced from twenty years' observations. The cistern of the Barometer is twenty-two feet above the level of the sea, and the receiver of the Rain Gauge is three feet from the ground. The wind and rain registered are for the current Civil Day—from midnight to midnight. The total quantity of rain collected since January 1st is 34·2 inches, the average due for the same period being 38·8 inches.

A cyclone visited Madras on Saturday and Sunday the 12th and 13th instant. It appears to have exhausted its greatest force while crossing the Bay before reaching the coast of Southern India, which would account for the high and destructive sea, far beyond what might have been expected from the meteorological indications accompanying its progress. The centre of the storm must have struck the coast considerably southward of Madras. The lowest reduced reading of the barometer was 29·51 at 4 P.M. on Saturday; and the strongest wind was experienced between 11 P.M. and 2 A.M. on Sunday, during which time it averaged 32 miles per hour in velocity, equivalent to a pressure of about 5¼ lb. per square foot. Rain commenced at 1½ A.M. on Saturday and continued until 8 P.M., amounting in all to 8·19 inches—the twelfth heaviest fall on record at Madras since 1803. No single hour was extraordinarily excessive, but the persistence of both wind and rain was remarkable. The veering of the wind was as usual for cyclones southward of Madras. The records of the anemograph furnish the following mid-times for each principal point of the compass with the corresponding hourly velocities:—

N.W by W.	at	2½ P.M.;	velocity	20	miles.		
N.W.	at	3½ P.M.;	do.	29	do.		
N.N.W.	at	6½ P.M.;	do.	23	do.		
North	at	7¾ P.M.;	do.	27	do.		
N.N.E.	at	8¾ P.M.;	do.	30	do.		
N.E.	at	10¾ P.M.;	do.	31	do.		
E.N.E.	at	1¼ A.M.;	velocity	33	miles.		
East	at	2¼ A.M.;	do.	25	do.		
E.S.E.	at	4½ A.M.;	do.	18	do.		
S.E.	at	7½ A.M.;	do.	14	do.		
S.S.E.	at	9½ A.M.;	do.	14	do.		
South	at	10½ A.M.;	do.	13	do.		

N. R. POGSON,
Government Astronomer.

MADRAS: PRINTED AND PUBLISHED BY E. KEYS, AT THE GOVERNMENT PRESS, FORT ST. GEORGE.

89 07

7. The Astronomer has alluded to the fact, to which I have myself frequently had occasion to advert, that there is no relation between the force and direction of the wind in the neighbourhood of a cyclone and those of the sea which may accompany it. The sea is raised not by the wind which may happen to be blowing at the time at any given spot but by an intense atmospheric disturbance at a distance, that is in the centre of the cyclone, and from the site of that atmospheric disturbance (which when the wind i from the N.W. at any place will lie between N. E and E of that place) the sea disturbance will proceed, propagated by laws which, so far as we know, have no similarity whatever to those by which the atmospheric disturbance itself is propagated. On this occasion the maximum velocity of the wind at Madras was 33 miles per hour; on occasion of the great storm in May 1872 the velocity was 53 miles per hour; in May 1874 it was 49 miles per hour; while in May 1877 when the concrete block work of the North Pier had advanced

and a portion of the timber shelter
about 300 feet & the sea was nothing
like so severe as in last November, though
the velocity of the wind was 34 miles
per hour.

8. The testimony of all observers
is to the effect that the sea of 12th Nov
~~on the last occasion~~ must rank with those of
the great historical cyclones, though
there is a conflict of evidence as to
whether it was actually as heavy or
heavier. Mr. Christobus the Government
Architect, a very intelligent and close
observer, speaks confidently as to the
recent sea being considerably heavier
than that of 1872, but on the other hand
the Officers of the Marine Department
who witnessed both storms give the
palm to that of 1872. A proof test
is afforded by its action on the planking
of the screw pile pier 17 feet above
mean sea level. This was torn up
in 1872, in 1874, and again in 1881,
but it is uncertain whether on the
last occasion the effect of the
Harbour works would be to reduce

the waves at the site of the pier (as I have no doubt was the case over the area of the harbour generally) or to aggravate them by the confusion which would be caused by their ~~fole~~ rolling in over the piers as well as through the entrance - The end of the pier is just outside the line of breaks. the first breach of the waves occurs, and the height there was no doubt abnormally raised -

9. As compared with the force of sea in other places the evidence is also unsatisfactory - Mr Bhoomya Saxena Sub. Engineer, is the only person who could compare this sea with that raised by the South West Monsoon at Kurrachee. He considers the waves were not higher but the succession of them was more rapid. The maximum height measured at Kurrachee was 15 feet. Mr Chisholm estimated, the late storm at about the same height for Madras* and at both places independent testimony priced the depth of solid water passing over the Breakwaters at about 20 feet.

10. Mr Norwood did not consider

* note
Other estimates give 30 feet, but I do not put any faith on them such estimates made by unskilled persons either in respect of this or any other storms with which they may be compared

this sea to be so heavy, to all appearance as those he had witnessed at the mouth of the Tyne, and he is confirmed by Mr. Underdown, the foreman diver, who was also engaged on the Tyne works.

11. I do not consider however that these comparisons are of much value. I have given them because they are sure to be made by others if not by myself, but my own experience is that the appearance of the sea gives a very little indication of its real force-

Effects of Sea on foundations

12. When we come to compare results, however, we are led to a more definite conclusion. The best test for practical purposes of the force of sea is its power of undermining foundations. It is proved by the general practice of Engineers at home that a depth of 15 feet below Low Water is safe. At Alderney where there is a evidence of the power of the sea is greater in some respects than at any place I know, foundations at that depth have never been disturbed. At Wick where a

of Concrete and Masonry

a mass of 2500 tons was moved bodily by the Sea, foundations and 18 feet depths were untouched, and no action was found below 10 feet. The deepest foundations I have ever heard of as being undermined were 11 feet below low water at the Tyne, but at Madras the walls were in two places for a short length undermined at 22 feet below low Water.* and the height of the wave was estimated at 42 feet

13. This is an effect I should never have anticipated, and I can now only account for it by the supposition that there is some peculiarity in the Cyclone raised disturbance which the apparently heavier seas on the English Coast have nothing analogous. There is nothing improbable in the supposition of a difference in the effects produced by a very intense action within a limited area, and by a long continued surface friction over a large area. It is true that the North Atlantic Storms are cyclonic in their movements, but the movements extend over a larger area and from within a

* It is of course well known that wave action at Cuddy's & a much greater depth than this, and even worse results (and the instances of such action have been quoted in Engineering Questions - but the latter being a practical

less intensity than those in the Bay of Bengal-

14. But however this may be, it is certain that the eight feet extra depths of foundations which I allowed, more for the sake of convenience and economy than for that of security, was really required for the latter purpose though the damage actually resulting from undermining on this occasion was not great, the whole lengths of the Eastern face of the piers was threatened, and a rather heavier sea would have produced a serious amount of damage of a different kind from that which actually was produced. This is the most important lesson taught by this storm - that foundations at a depth of 22 feet under water are not proof against a cyclone sea.

Effects of Sea on Superstructure

15. The great bulk of the damage however is of a totally different kind, and is due to the direct force of the waves on the superstructure. The

12
Sketch sent to Lithographic dept 6/3/82

results produced are precisely what might have been anticipated on a work of insufficient strength. The impact of the sea was delivered to all appearance just where it was expected, but it was stronger than any we had previously experienced in this description of work, and required a greater resistance than we had provided.

The lesson has been very dearly bought, but it is precisely the same kind of lesson that has been taught in almost every case where works have been undertaken exposed to a sea of unknown force. It is only when a sea of nearly maximum force has been experienced that the final precautions are shown to be necessary.

16. I believe the damage produced by this storm on the Madras Harbour Works is greater in its extent than that of any similar disaster on record, but the same nature of which is shown in the accompanying sketch it must not be concluded that this is due to an unusual degree of weakness in the work. It is due rather to the

fact that at Madras the maximum
force of sea is not, as is practically
the case on the coasts where most of
our experience has been gained, an
event of almost annual occurrence,
but it occurs only at intervals of several
years, and in one such interval of more
than usual duration a great extent
of work had been completed, and was
therefore exposed at once to the previously unknown
destructive action of a sea of nearly
maximum force.

17. The design of the work as executed at Madras
was the result of a careful investigation
into the causes of damage to previously
executed works. Much material that
appeared to be superfluous in them was dispensed
with, but additional strength was given
to the parts that were retained. ~~What~~
~~may be termed the finish of the section~~
The latest additions to the section
were based on the experience gained
at Kurrachee. At that place the
first heavy sea showed where the
greatest impact of the waves fell
and that part was strengthened in a

way that has been quite successful in a subsequent experience of 9 years at Kurrachee, and for five years was successful at Madras, but it failed under a sea of greater force than had previously been experienced at either place. To prevent a recurrence of the damage additional strength must be given to the vulnerable part. But it must be understood that all such precautions are necessarily tentative as to their sufficiency. We may feel confident as to their being right in principle, but the force of the sea cannot be estimated in figures, and we are unable to say, when a work has stood successfully, what margin of stability it possessed, or, when it has failed, by how much the destructive force was in excess of its stability. The strength of an iron girder or the capacity of a water channel may be definitely calculated in figures, but the stability of a sea barrier is a question to be decided by precedent, guided by judgment and experience.

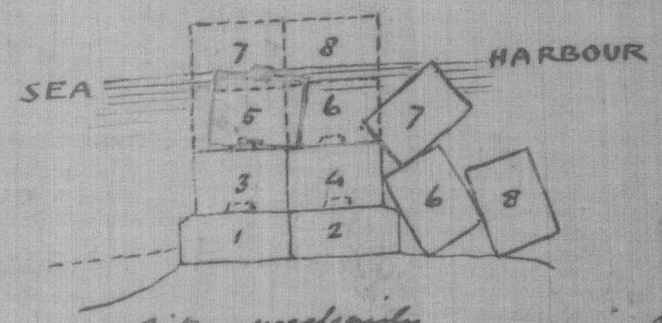
18. The experience gained at Kurrachee was to the effect that the heaviest blow

tops of the
of the Sea was delivered on the blocks
on the Harbour side of the Breakwater
tending to drive them out from the
wall into the harbour. Several blocks
were forced out in this way, but in
no case was any block forced to
seaward. The tendency was met
by inserting a stone joggle which locked
the top course to the course below and
prevented it from sliding. This precaution
was quite successful at Kurrachee
and a similar one, having been
from the first
adopted at Madras, the tendency
so completely met that
was not afterwards in evidence of
its existence was given by the action
of the seas which preceded that of
the 12th November last.

19. A knowledge of this tendency forms
making us to know
a clue to the process of destruction
of the Madras Piers. The waves rising
sea face must have fallen
upon the face of the ~~wall~~ with terrific
force upon the top of the work on the
harbour side, and the blocks were tilted
off, probably two courses and possibly in
some cases three courses being displaced

at once. The sea wall then standing alone yielded to the lateral force of the waves, and generally one course, but sometimes two, and in one or two cases even three courses were driven after the blocks of the harbour wall. Generally speaking there is a course more remaining on the sea side than on the harbour side.

20. The following may be taken as a typical section of very much of the work in its present state. Parts

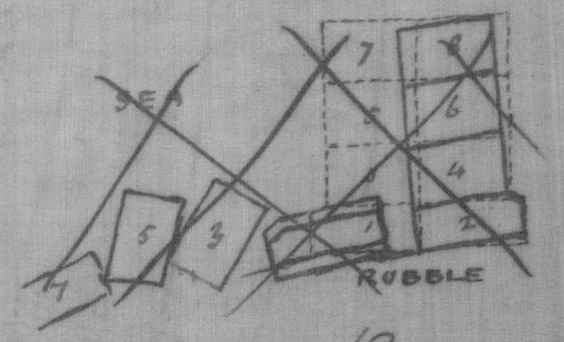


of it are necessarily ~~of the section are of course~~ hypothetical, but there is enough which is matter of actual observation to justify the assumption of the remainder. For a length of at least two thirds of the damaged part blocks ✱1 and 3 have been traced by the divers and found, with slight variations, to be undisturbed. For the greater part of this length block 5 may be traced from the surface and sometimes from below, generally more or less disturbed somewhat in the way shown. No 7 is in

it is then
sometimes cases in its place but generally
tilted by riding on the ~~centre~~ terron on
the top of No 5. 6, generally 7, and 8 are represented
by an apparently confused heap of blocks
which effectually prevent access to 2 and 4.
There is however sufficient evidence direct and
indirect to negative the very improbable
supposition of these having been undermined
and thus caused the fall of the ~~harbour~~ inner wall
towards the harbour. This evidence is 1°
that where the inner slope of the rubble
is unencumbered with blocks it is found
to be practically unchanged. 2° Where the
sea wall is gone and the harbour wall
standing as is the case for a short length
in each pier, the harbour wall leans over
to seaward. 3° at the spot at which
if anywhere scour under the harbour
wall might be expected viz at the extreme
end of the North Pier, the rubble is 4 feet
above the foundation, and the wall is
standing exceptionally well, the blocks
corresponding to No 6 being in place.
There can therefore be little or no doubt
that the failure began with No 8 block
or nine rubbles 6 and 8 together
and worked downwards and towards the
Harbour. The rubble foreshore on the sea side
a marked contrast to that on the Harbour side. It
is almost everywhere drawn away from the
wall and lowered sometimes below the level of the
foundation blocks. 1181

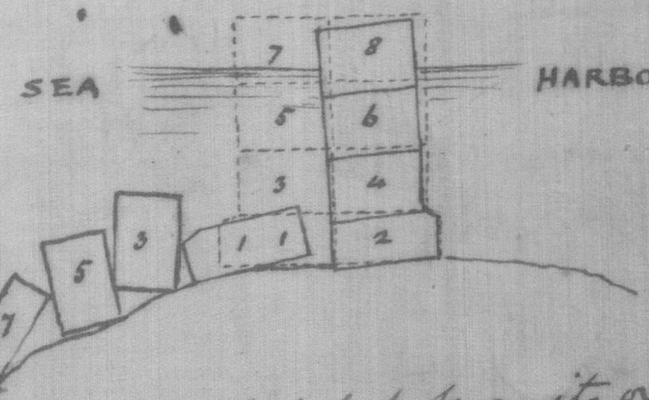
21. The above description may be taken as a generalization of the effects produced upon about two thirds of the damaged parts of the ~~Outer~~ piers. It comprises the outer portions of the two piers, a length of 1200 feet of the North and 900 feet of the South Pier. The remaining third comprising 400 feet of the North and 500 feet of the South Pier have been differently affected and the ~~result~~ investigation is more difficult, as the blocks are thrown down on both sides of the piers, and a process examination of the portions which remain standing is for the most part impracticable.

22. There is however one portion of the North Pier, just at the commencement of the curve which is accessible to the diver, and having been carefully examined the following section, made from his description will very clearly exhibit the action to which it has been subjected. In this case the



19

harbour wall is standing though consid=
=erably damaged. No 1 block is drawn



out to seaward 4 feet from its original position, and its inner end is lifted 9 inches from the rubble bed, the block itself being tilted towards the sea. The upper blocks are lying in confusion on the sea slope of the rubble - I do not see how it is possible to attribute these results to any other action than undermining of the foundation blocks, ~~though it may have been aided~~ The portion of the pier where this is evident is a length of something under 100 feet, but it is probable that wherever the upper blocks have fallen to seaward it is due to the same cause although the foundation blocks themselves are inaccessible - ~~The action of the sea appears to have been exceptionally severe at this spot for the length of about 100 feet and~~ The action of the sea appears original sandy bottom is scoured away 6 or 7 feet outside the rubble - (20)

23
~~24~~. There is a portion of the South Pier, also on the Curve, which appears to have been acted upon in a very similar manner - At these two places the Breakwater forms about the same angle, one on the right, and the other on the left, with the prevailing line of the waves, and here the scouring action on the bottom appears to have been more violent than where ~~it was more directly opposed~~ the waves fell more directly on the face of the work.

Remedies

24

~~B~~. The whole of the actual damage to the works is due to one or other of the above causes, and I think that if ~~such~~ the original section were amended so as to give increased strength to the two weak places shewn to exist every confidence might be placed in its stability under even a much heavier sea than the recent one. The section as carried out was a perfectly good one to withstand a moderate sea, and the effects of the heavier sea shew no grounds for any radical alteration. Such material as there was was good in quality and properly disposed, but there was not enough of it; or perhaps it would be more correct to say the principles of the design were good, but not carried far enough. There is not the slightest justification for reopening the worn out questions of the relative merits of random and ~~or~~ placed blocks, or of bonded and ~~or~~ unbonded work. ~~Section~~ Breakwaters of random blocks or of bonded masonry might have stood if very much more massive than those

which have partially failed, but their security would have been less & their greater massiveness, not to the different principles of their construction -

Quality of Materials

25
~~24~~. I have said that the materials were good. I am aware that a great deal has been said about the unsuitableness of Coleute for the rubble base, and some doubts have been expressed about the quality of the concrete owing to many of the blocks having been broken. Now Coleute is undoubtedly a troublesome material and I am glad to think that no more of it will be required, but there is not the slightest ground for thinking that it contributed in any way to the late disaster. The trouble it occasions is that, being friable, it is very quickly compressed by the weight of the blocks laid upon it, so that, to allow for subsidence the latter have to be set a higher level than is ultimately required. ~~to allow for subsidence~~ This is troublesome as

execution, and it has the still greater evil of subjecting the blocks to excessive and irregular strains in the process of subsidence, in consequence of which many were broken. But when once consolidated the Catenta forms as good a bed as the granite rubble. This is proved by the comparison of the amount of settlement of the standing portions of the two piers, one being built on Catenta, and the other on granite. There is no appreciable difference between the two. It is right to add that the Catenta was used, not from choice, but because it was not practicable to obtain the granite rubble in sufficient quantity to carry on the work at the speed for which all other parts of the work were organized. It would of course have been right to sacrifice speed of execution if ultimate stability were endangered, but after full consideration it was decided that this was not the case.

Breaking of Blocks

~~25~~ 26. The breaking of the blocks is undoubtedly a blemish, and though it occurred on both the granite and Catenta bases, it occurred I have no doubt more often the latter for the reason I have given above, though it is impossible to determine the proportion accurately. The evil however is really greater in appearance than in reality, for the force which broke the blocks at the same time jammed them so closely together that the broken pieces

are really as effective for the stability of the work as many unbroken blocks which have not been subjected to the same amount of pressure. I doubt whether it would have been possible by any means entirely to prevent these breakages, but the number would have been reduced if it had been possible to keep the blocks longer before subjecting them to this severe strain. Be this as it may, however, the concrete is undoubtedly of excellent quality as even the fractured surfaces of the broken blocks shew. In the restoration of the work, as I shall point out presently ~~here~~, this evil will not recur. ~~There~~ But so far there is no evidence to shew ~~is however no reason to suppose~~ that these breakages have contributed in any way to the failure of the work. ~~which has~~

Subsidence

27. ~~26~~. Another point which has given rise to a good deal of remark is the ~~settlement~~ subsidence of the structure, but in this I can see no evidence of weakness. It is quite certain, ~~that a weight of 30 feet of concrete~~ that on a rubble bank ~~must~~ 20 feet high must consolidate under the weight of 30 feet of concrete, and it is equally certain that the effect of agitation of

the water must be to cause the rubble to sink into the sandy bottom, but beyond involving the necessity of adding to the top if it sinks, there is really no harm done. We have the experience of years to shew that subsidence does not involve loosening of the superstructure, but rather the contrary; while the sinking of the foundation to a still lower level is a substantial advantage. The portions of the piers standing entire have settled under the action of the storm about 9 inches at their outer ends gradually diminishing to nothing (the amount of sinking being apparently proportioned to the weight) near the stone. The damaged portions (which of course are newer than the rest) have sunk about 2 feet, as far as can be ascertained. There may probably be a further subsidence, though it will decrease as time goes on, but it is perfectly harmless process. The above settlements due to this particular storm, There had been previous settlements due mainly to the natural consolidation of the rubble base, generally amounting in the aggregate to from 2 to 3 feet, the maximum being near the South Pier head, where it was 4 feet. The further settlement due to the storm is probably caused by subsidence into the sandy bottom.

x of time since they were built

25

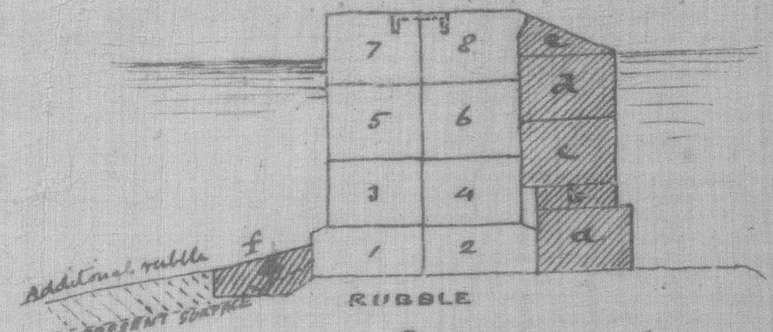
Reconstruction.

28 In the scheme for reconstruction then, ~~this~~ we have especially to keep in view the two weak points, the foot of the outer wall and the top of the Harbour wall. The required object may be attained either by breaking the force of the waves before they reach the weak points or by giving additional strength to the weak points themselves. The former principle has received full consideration. It appeared at first sight that the remains of the original piers would form a good outer barrier under shelter of which a new pier would be safe from damage. But further examination was not favorable to this idea. The shelter it would give in its present state is too irregular. In some parts it might be fairly efficient, but in others it would allow the sea to pass over it or to the new work with increased violence. To prevent this such places would have to be made up with new material, and this would lead to a serious amount of work and I think a not very satisfactory result. Besides which there is a ~~very~~ considerable proportion of the old work remaining, and the rubble base especially having been

well consolidated would offer a better foundation than a new one especially in ~~Two out~~ not being liable to the immediate settlement which causes the fracture of the blocks. Two out of the four corners of blocks are also for the most part in a good state, and an uncertain proportion of the displaced blocks may be recovered and used again.

29. Preference was therefore given to the principle of rebuilding the piers on their original foundations and making such additions as experience shews to be necessary. The one great objection to this is the immense difficulty of clearing the ground of fallen blocks. The magnitude of this difficulty can hardly be realized without inspection of the ruins. It will undoubtedly be a slow and costly operation, but I think all who are concerned in it are satisfied of its practicability, and the difficulty being simply a mechanical one we may safely conclude that it will diminish with practice and experience.

30 ~~29~~. I propose therefore that the work be rebuilt on the former lines and to the former section, but with the additions shaded shewn on the accompanying sketch, to give increased strength to the two



weak points. The rubble base and blocks 1, 2, 3 and 4 ~~are~~ are generally in a serviceable state. 5, 6, 7 and 8 are new blocks similar to the old ones except that they will be 9 feet high instead of 8 feet, so as to make up for the two feet of subsidence. a c and d being of the same dimensions as the old blocks the latter can be used so far as available; b is a thin block inserted for the purpose of bringing the top of d above water level, so that c may be set upon it in a bed of cement, thus making d and e together into one block of 36 tons weight. The top of e is sloped off to give an escape for the falling wave. If it were level like the top of 8 ~~is~~ the effect would be simply to transfer the vulnerable point from the top of 8 to the top of e, as is shown by the fact that at the pier heads where the

structure was increased to three and four blocks in width, the one next the harbour still gave way -

31. ~~32.~~ Block f is intended to protect the toe of the outer wall from scour and ultimate undermining. It ~~is intended to~~ should be placed at as low a level as practicable so as to avoid encroaching on the profile formed by the sea itself. It is a noticeable feature in the cross sections of the damaged part of the pier that a scanty slope of rubble and coeur damaged the superstructure do not go together. On the contrary where the sea wall was actually undermined, ~~at bottle pier~~ at the South Pier, and the nearest approach to a clean breach was made, the rubble base happened to be particularly full. The evidence is at present not more than negative, but it is to the effect that a full foreshore is not an element of strength. The ~~foot~~ seat of the footing therefore is simply to substitute for a surface of concrete as many as possible for one of loose rubble, preserving the level and slope which the sea has formed. From the outer end of the block the slope will be continued in rubble. It may probably be desirable where the blocks are fallen (29) to seaward not to disturb them, but rather add some more so as to make protection mounds of random blocks at those places.

P33 66

32 ~~In addition~~ Besides these actual additions to the section I propose to introduce two extra ~~additional~~ securities into the top course of the old section - It has always been an object, though hitherto unattainable, to connect the top blocks together, both longitudinally and transversely, so as to make all the portion of the section which is out of water into a monolithic mass, but ~~hitherto~~ it has been impossible to do this in an efficient manner in consequence of the settlement to which the newly built structure an unequal settlement would cover any attachments we can possibly is liable. Now however in rebuilding on an old foundation this difficulty will be much diminished. ~~no longer exist~~. What settlement does occur will be more uniform, and slight inequalities in it may even be prevented by the adherence of the attachments - It is proposed therefore to make the end joints of the top blocks that they may be filled with cement, ~~at a suitable time~~ not during the progress of building, but on a suitable opportunity afterwards. It is also proposed to connect the two top blocks by an iron cramp made of

with the ends turned down and
a bent worn out rail, cemented into the
blocks - Thus each longitudinal row of blocks will
become so far as the cemented joints can
be depended on, a monolith, and the two
monoliths will be tied together at intervals
of 4½ feet - It cannot be anticipated
that the monolith will be absolutely
continuous. Some of the cement joints
will separate, but the majority will
hold together, and the top of the breakwater
will consist of much layer masses than
hitherto, which will lend support to one
another in a way that the detached
blocks could not do. ~~in the event of~~

33 - The section thus modified would have
the following additional elements of stability
over the old section. 1° It would have 50
per cent greater width as a whole 2° The
vulnerable block No 8 would be supported
(a) by a buttress one third heavier than itself
~~with a very sufficient bolt in the joint of~~
~~direction of the block~~ ~~to resist by reason of~~
~~the it would have~~
~~to displace it~~, (b) by a tie to block No 7
(C) by its longitudinal continuity afforded by
the cemented joints - 3rd The toe of the
sea wall would be protected from undermining
by concrete blocks - I must repeat that

it is impossible to shew the sufficiency of this by figures as the force of sea is an indeterminable quantity- But I think it quite outside the limits of reasonable probability that we shall have to encounter a force of sea so much greater than that of the late storm as the strength of the new section would be greater than that of the old-

Uninjured Portions

3¾4. I do not propose that the additions to the section should be applied to the portions of the piers which have stood uninjured- They have shewn no sign of weakness beyond some scouring away of the foreshores at the foot of the Sea Walls. These should be fed with some heavy granite boulders- It would be desirable however now that the Work has settled down to a solid bearing to tie the top blocks together with iron cramps in the same way as described for the new work. This would give additional resistance to Block No 8 in the event of the next heavy sea coming from a point more Northerly or more Southerly than the last

and the cost would be small as there are a great number of rails which are of no value for any other purpose.

35 ~~34~~. There is one further additional security which I would propose to apply to the curved portions of both piers. These have a special element of weakness in the fact that if there should be any leaning over to seaward, the upper courses of blocks would open out like a fan. The late storm showed that there is ~~such a tendency, and also~~ a greater scouring force at the forefeet of the curves than elsewhere, ~~which will aggravate it. I hope this~~ I hope undermining from this cause will be effectually prevented by the precautions ~~of block~~ above recommended but I will propose an additional precaution for the support of the substructure ~~for the purpose~~ to form a groove longitudinally along the top of the sea wall ~~blocks~~ about 12 inches deep all round the curves, in which a strong chain cable will be laid, strained up tight and then buried in concrete. The whole curve would thus be bound together.

36. I would beg to call attention to the fact that each one of the additions I have

recommended is intended to meet some weak point disclosed by the action of the sea upon the work. I have made no attempt to ~~satisfy~~ meet theoretical objections that are not supported by the special experience of this particular occasion. ~~I have~~ My object has been to preserve what experience has shewn to be good in the work as well as to supplement what ~~of~~ was shewn to be insufficient, and I submit that it is by this process rather than by radical change of plan, which ~~would probably~~ would involve much experimental work, that ultimate success will be best assured.

37. ~~With respect to the cost of the new~~
works recommended an Estimate of detail
is appended the total of which amounts
to ~~£~~ Rupees . This I believe
will suffice to bring the work back to the
state in which it was before the storm
but with the additional security of the
stronger ~~works~~ construction.

Estimate 37 In endeavouring to form an Estimate
of the cost of the works of restoration, I
am met at the outset by elements of
great doubt. About 43,000 cubic yards

If concrete block work has been displaced -
If the blocks were recoverable in an efficient
state they might be ~~replaced~~ reset in position for about
4 fifths, if ripes, but it is quite certain that many
are broken, and will be more costly to
remove than the unbroken ones, and will have to be replaced
by new ones. To replace a broken block
will cost altogether about three times as much as
to ~~replace~~ reset a sound one. Now it is quite
impossible to form a reliable estimate
of the proportion of blocks available for future
use - One fourth and three fourths may
be taken as the limits of uncertainty in the
matter - As the work of restoration advances
a more definite estimate may be formed,
but for the present I am really unable
to do more than give the minimum
and maximum of what may fairly
be taken as within the limits of reasonable
probability - The Government will no doubt
think it right to take the maximum estimate
as the basis of its deliberations - I may be
permitted to take the minimum as what
I hope to see realized, though I am unable
to pledge myself to it -

30. I have therefore divided my estimate

d
Others again though unbroken will probably be so jammed into the confused mass that they can only be removed by destroying them to pieces.

into two parts, the first part ~~is~~ is for the restoration of the work to its former state (exclusive of the small portion of the original design remaining incomplete, and the question of completing which should remain for the present in abeyance) the second part is for the additional works of strengthening recommended. The first part is also presented in ~~two forms~~ two alternatives—a maximum and a minimum ~~Thousand~~ the former amounting to a little under 9 lacs, and the latter a little over ~~one~~ 6 lacs. The second part is based on the prices at which the work has hitherto been carried on, and may therefore be taken as reliable. Its total is a little over 9 lacs. The total cost of placing the whole work in an efficient state may therefore be taken as lying between the limits of 15¼ and 18 lacs, and I think 3 years will be required from the time of recommencing drilling operations for its completion—

38. The second part of the estimate (that for new works) is the amount which would have been added to the original estimate if we had had the ~~materials~~ data necessary for making provision against the forces of a cyclone sea. The first part is the penalty paid for our ignorance in this point. But I may remark

that this is not altogether without its equivalent. If the work had been carried out in the first instance in its stronger form, its completion would have been delayed by two years, and for those two years the harbour would have been in a less efficient state than it is now with the damaged piers.

Present efficiency of the Harbour

39. Indeed the business of the harbour has proceeded with scarcely any change in consequence of the accident, and although steamers have the option of saving the payment of extra dues (& accordingly) by anchoring outside, they invariably submit to the grievance and come in. The injury to the harbour is scarcely felt during fine weather when the great bulk of the trade landing and shipping operations are carried on. Its evil effects will be felt in moderately rough weather, when more sea will come into the harbour, though even then the damaged piers will be better than none.

40. With the view of ascertaining what is the amount of benefit at present afforded by the Harbours, I obtained by the courtesy of the Collector of Customs and of the Agents of the principal lines of steamers, returns of the number of vessels ~~of~~ all classes which have visited the port ~~since~~ for the three months following the accident to the Harbour works, and of the number of tons of cargo actually landed and shipped within the harbour during the same time. The total ~~tons~~ register tonnage of sailing vessels was 13,302, and I have not ascertained what quantity of cargo was landed and shipped by them. ~~It would be near~~ ~~alike~~ They all lay outside the harbour. The register tonnage of steamers was 146,374 and the quantity of goods landed about 24,000 tons, and of those shipped 12,000 tons making a total of 36,000. As the whole of this work was done at a

rate of boat hire less than that
charged in the roads of half a
rupee per ton, this sum of 18,000 rupees
represents the ~~actual~~ proper earnings of
the harbour during the first three
months following the storm. ~~The~~
I put the matter in this way rather
than by giving the actual amount levied
as dues as the register tonnage because
the latter does not represent the amount
of trading done in the harbour, and is
in force only pending the arrangements
for a more direct and equitable mode
of making the charge. The half rupee
per ton also will be raised when the
harbour ~~works~~ and the landing and
shipping arrangements are more complete
to one rupee and of course extended
to the cargoes of sailing vessels.

41. I submit therefore that the Madras
Harbour even in its present damaged
and incomplete state is by no means
an unprofitable undertaking. It is
confessedly imperfect, and there are
other points requiring consideration besides
the restoration of the works, to one of
which it is desirable to allude

42. The experience gained since the Harbour piers approached completion is to the effect that the Entrance facing the Eastward admits an amount of swell (particularly with Easterly seas, which are more frequent than was supposed) which will render it desirable so to arrange the berthing of ships that they may lie with their heads towards the incoming swell, instead of towards the prevailing winds as had been at first intended - For the great majority of days in the year this can be done without difficulty, but there are occasions (about 25 to 30 days in the year as stated by the Officials of the Marine Department) when a ship cannot lie with her broadside directly or even obliquely exposed to the wind - ~~the the bow head is to spread it~~ ~~will to pass become the more frequently~~ On such occasions it becomes necessary to cast off the stern moorings and allow her head to swing to the wind - ~~to the bow~~ ~~It should be noted that~~ As the ship will then roll to the Swell, landing and shipping

Capes will be more difficult, and sometimes even prevented. With a strong wind from one direction and a heavy swell from another the ship would roll very uneasily, and though it might be only in extreme cases that she would be in actual danger such danger could only be avoided by sending her to Sea. This in itself is no unforeseen contingency, but it is now suggested that there would be a difficulty in getting a ship clear from such an uneasy berth as that just described while subject to the combined influence of wind and swell. This difficulty could only be avoided by an earlier anticipation of the danger, and by taking the ship out of the harbour at an earlier period of threatening bad weather.

~~It must not be supposed that I underrate the evil, or question the ultimate necessity of meeting it because~~ I say that it is one which cannot under existing circumstances be cured by immediate Engineering measures, though well worthy of

43. The Officers of the Marine Department are of opinion that this evil can only be effectually cured by closing the present Easterly entrance and making an opening facing Southwards in the South Pier. If I do not enter into the merits of this proposal it is not because I question the reality of the evil, but because I think it premature to discuss a question upon which no practical action could in any case be taken for the 3 or 4 years ~~during~~ that will be required for the restoration of the damaged portions of the Pier. During the 3 or 4 years the Harbour will be in daily use, and the bearing of this one particular evil upon the whole question of the development of the advantages afforded by the Harbour will be more easily seen. It is not a question of a harbour or no harbour, but of a harbour affording a greater or less degree of shelter and the value of the increased shelter will be more precisely ascertained by the experience of actual work. The proposal may then be ~~renewed~~ put forward (if

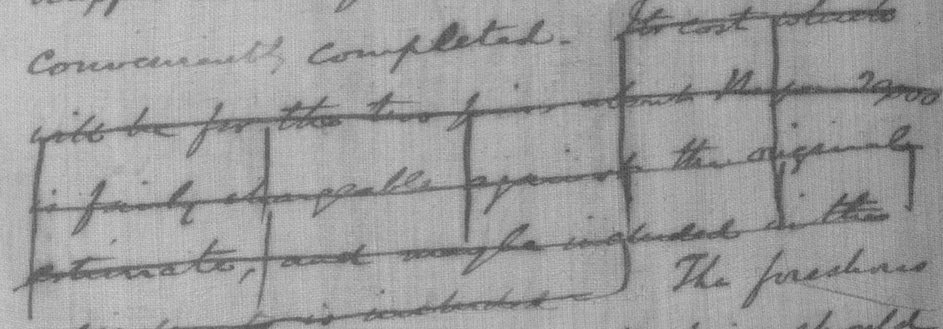
its desirability be confirmed by
experience) as one giving an advantage
directly comparable with the ~~expenditure~~ cost
44. So far as carrying out the alteration
is concerned, nothing would be gained
by an immediate decision, nor do I
think even if the idea had been
entertained from the beginning any
materially cheaper plan could be have
been devised, than that of advancing
both piers to near their meeting point
using the interval between them as a
temporary entrance, and then making
the final opening in such a position
as might appear most desirable by
removing the necessary length of blocks,
and dredging away the rubble. The
materials of course could be used for
the final closing of the original entrance,
which would by be carried across from the
side opposite to that in which the new
opening would have been made. This
process will still be available if the
alteration be ultimately determined on.

45. Having now explained as clearly
as I could my views with regard to the

present state of the works and the best mode of restoration it remains only for me to specify the immediate action required for carrying my recommendations into effect. An urgent indent should at once be made for two new Titan Cranes to be constructed with such modifications from the pattern of the former ones as is necessary for the altered circumstances of the work. I shall be prepared to furnish the details of these immediately on receiving instructions. Also 2000 tons of Portland Cement should be immediately shipped aboard, 1000 tons to be shipped by Canal Steamer, and 1000 by sailing vessel. Other stores and materials will be required from England for which indent will be duly submitted by the Superintendent.

46. In the mean time blockmaking should be proceeded with with the cement now in stock, and such as may be procured from the local manufactory (formerly Egan & Morgan's) - The cramps described in para 32 ante ~~items~~ should be picked in the unimpeded

independent in the
portions of the piers, and the tops of the
blocks levelled up with new Concrete.
This last is a small work which could not
be carried on while there was a constant
traffic on the piers, but may now be
conveniently completed. It cost about May 29/00
will be for the two piers
is fairly chargeable upon the original
estimate, and may be included in the
adjustment is included



The foundations
of the standing portions of the piers should
also be made up after the cofferdams
have been taken to show exactly what
is required

47. I propose to submit a separate
report on the question of the harbour
improvements and landing jetties which
were sanctioned a year ago, and partially
carried out, but the whole scheme
must be reconsidered under the present
changed conditions. These works are
not charged to the Harbour Works Grant.

I have the honour to be
Sir
your most obedient servant

P. & C. No 1422

E-2

Rec'd 6 Mar 82

Note by the Chief Engineer

In the annexed Report of the 9th March Mr Parker describes with clearness and precision the effect of the cyclone of the 12th November 1881 on the Madras Harbour Work and although the whole of the sections cannot be completed for some little time - and may possibly from the roughness of the sea be delayed, there is apparently no reason on this account to defer the decision as to the further prosecution of the Works.

2 As to the validity of the contentions put forward by Mr Parker in para 39 to 42 there can hardly be any doubt, and were his estimate for the requisite work to amount to even much more than his highest one of 18¼ Lakhs, it would be both

desirable and profitable to complete the Harbour with the least practicable delay.

3. The total outlay to date including the reclamement north of the Harbour and excluding the esplanade and jetties, which are paid for from Port Fund, amounts to 58(½) Lakhs; but with even the large additions now proposed it would be a comparatively cheap Harbour considering that it is entirely artificial, and that difficulties of an Exceptional nature have had to be overcome.

4. The revised section which by para 30 Mr Parkes proposes to give to seaward arms is almost identical in width with that of Sir John Coode's Columbo Work, which as will be remembered was brought under the notice of Government (GO 8th June 1881 No 1436 of

by the undersigned and the Master Attendant after they had visited that work early last year; and were there no other circumstances (as revealed by the late storms) to be taken into consideration might be accepted as a satisfactory disposal of the matter.

5. In some respects the new section is stronger than that of the Columbo Work:

(1) the vertical tenons, quantum valeat counteract the tendency of the concrete blocks to slide on each other, and the proposed cramp between blocks No 7 & 8 will give considerable cohesion to the whole.

(2) the combined upper blocks, c and d, form a better top to the rear face than in the Columbo Work, and

(3) the toe blocks, f, if closely set in the form of a continuous apron should be a more efficient

protection against any ~~seaward~~ scour down the vertical face of the wall, and which acted so seriously on the rubble base of the pierre perdue

6. It may be thought that stone tipped over the seaward face after positioning blocks of, would be beneficial as tending to afford a protection to the toe of these blocks, after being dragged outward by the action of the sea, but this is a detail which can easily be considered as the work advances.

7. It will be observed (para 34) that Mr. Parkes does not intend to increase the section of the straight portions of the breakwater which were uninjured, or to do more than to feed the foreshores with heavy granite blocks and cramp the upper concrete blocks together; although however these portions of the work escaped almost intact on the 13th November, and though

they may continue to enjoy immunity from attack for a long period it may be doubted whether the small work to them now proposed would suffice in case his present plan be accepted or that at least the addition of a properly constructed apron with blocks of, would not be desirable for one third or a half of their outer lengths.

8. The proposals now put forward rest, it will be observed chiefly upon the following considerations:—

1st that as remarked in para 33 "it is quite outside the limits of "reasonable probability that we "shall have to encounter a force "of sea so much greater than that "of the late storm as the strength "of the new section would be greater "than the old."

2nd that although the rubble base has subsided on an average of

2 feet and has been scoured along the seaward faces it has not been materially disturbed.

3 that the concrete blocks at base of the wall Nos 1, 2, 3 & 4 remain for all practical purposes removed, and are in many respects even better suited for building on than before thought not less than two thirds of the total length of the damaged portion of the work.

9. The first of these contentions is clearly the one upon which all must depend, and as regards this it may fairly be asked whether the storm of the 12th November supplied a sufficiently crucial test of the forces which may be expected to be called into action in a cyclone of maximum intensity -

10. Though doubtless the seas were much heavier than might have been expected from the comparatively low recorded wind pressure at Madras, as also from other phenomena connected with the storm, many high authorities would be ~~t~~ unprepared to accept the cyclone of the 12th November as having the required character; but even as regards this storm such as it was, it is now admitted (para 12) that the action of the waves extended far lower than was apparently ever recorded by Engineers before in other parts of the world.

11. As observed by Mr Parkes in para 13 "this is an effect I should "never have anticipated, and I can "only account for it by the supposition "that there is some peculiarity in "the cyclone-raised disturbance

"to which the apparently heavier seas
"on the English Coast have nothing
"analagous." He shews in fact
that whereas it has been proved
"by the general practice of Engineers
"at home that 15 feet below low
"water is safe, foundations at a
"depth of 22 feet under water are
"not proof against a cyclone sea"
in Madras, and adds in para 22
that near the curved portion of
the breakwaters where the disturbance
was greatest "the original sandy
"bottom was scoured away 6 or 7
"feet outside the rubble." The
disturbance must thus have reached
down to 35 feet below low water
at least

12. From the action of the waves during
the storm the rubble in the base
which had originally been heaped

X. In a foot note to para 13 enter

In general bed of the Sea at Madras during the storm of the 12th November is shewn to have been raised over 2 feet and that Sea movement reaches during abnormal disturbances to and depths there is commonly disclosed is proved by the recorded fact that on the banks of Newfoundland the agitation during storms has affected the bottom at a depth of over 80 fathoms — At St. Jean de Luz it has reached to 160 fathoms and at Lands End the lobster traps are frequently filled with coarse sand and shingle during heavy ground swells at depths of 30 fathoms — Sir G. Airey mentions also that mud swells frequently break in a depth of 100 fathoms

"to which the apparently hea
"on the English Coast he

up from 3 to 4 feet above the bottom
of the lowest seaward block (No 1)
was lowered by that amount, and
in many places to the extent of
undermining the block, the loose
material being dragged outwards
and the whole foreshore flattened.
At the depths mentioned of 35 feet
there seems to have been a general
deepening of the sandy bed.

13. It may thus be inferred that
we are in the presence of forces which
cannot at present be sufficiently gauged
and the reasoning on which the more-
-lattic system of reconstruction rests
is incomplete. There is apparently
insufficient ground for Mr Sarkes's
contention (para 24) that "there is
"not the slightest justification for
"reopening the worn out question of
"the relative merits of random

"blocks
and placed A, or of bonded and
"unbonded work."

14. On the contrary there would
seem to be ample grounds for considering
the question of adopting or rejecting
the monolithic system for Madras
as still open - With a bonded wall
such as that proposed it needs but
little imagination to infer what
the effect would be of a succession of
heavy seas (such as those shown in
the plan facing page 2.) precipitating
themselves over the seaward arms or
how the impact communicated to the
first attacked block would send
a vibration and quiver in advance
which must go far to loosen and
weaken the stability of the mass -
every succeeding blow shaking the
structure from end to end - Every where
the first head a tendency to form blocks the impact was
such as to rupture it must as largely abruptly as upon the open face
15. Again it must be clear that the
stability of a structure of this particular
form must in great measure depend
on whether the foundations are such
as can safely withstand the scour
which takes place down the face of
the wall & the disturbances due to
the General Cyclonic action before alluded to which
tend to drag out and flatten the
material of the rubble base as during
the late storm -

16. With a structure having its upper
portion constructed of random blocks
of sufficient size, the action being on
the individual block no general
vibration can be communicated to
the mass, and the pens must get broken
up in a manner which is quite im-
-possible with a structure on the
monolithic system; the work could
in fact never be destroyed, though

individual C blocks might be displaced.

17. The undersigned does not bring forward this as an original suggestion as he was given to understand by Mr Molesworth that although possibly not for precisely the same reasons, the random block system was that which generally recommended itself to him. He will necessarily soon lay before the Government of India the results of the joint inspection of the works made lately by Lieutenant Stuffe and himself.

18. In regard to outlay Mr Sarkes shews in his maximum estimate that about Rs 3,20,330 and in his minimum Rs 1,06,780 would be required for removing the broken blocks to enable him to clear the ground for his new structure, and admit

(para 19) that "the imminent difficulty "of clearing the ground of broken "blocks" constitutes the "great "objection" to the plan advocated by him.

19. While this trouble and expence would be saved by a system which would only aim at throwing in blocks at random when required to supplement present deficiencies and allow the sea to do the rest, it is believed that steam barges, carrying derricks could be designed on much the same principle as those used in placing the 370 ton blocks in the Dublin Quay wall, which could be trusted to do the work economically and expeditiously.

20. With the almost ceaseless swell at Madras some difficulty may, it is true, be experienced in designing

the refels required having the needful steadiness, but with twin barges and a proper system of gauging the blocks this should disappear, or at least be sufficiently minimised. The barges could be moved close to the seaward face of the work in depositing the blocks, and could be kept in reserve after completion of the Harbour for rectifying future damages.

31. As more material would have to be used than in Mr Parkes scheme it is not improbable that on the whole, even allowing for the saving adverted to, the Expense would be greater but even without entering into detailed calculations it cannot be supposed that the total could exceed at the outside 25 Lakhs.

This should include the Extra apron of blocks previously alluded to for the straight portions and also such Extra dimensions to the rubble base and superstructure of blocks as may be needed to counteract the Excessive action on the portions near the curves, where the damage was greatest.

32. As regards the closure of the eastern entrance to the Harbour while there can be little doubt that there is a greater disturbance of the surface within the enclosed area than was anticipated, Mr Parkes' argument against taking up the subject at present (paras 43 to 45) appear to be conclusive.

33. In conclusion it may be hoped that notwithstanding the inevitable delays attending the decision

regarding a question of such magnitude there may be no cessation in the preparation of the material required for the completion of the work - Should the random system of reconstruction be eventually adopted probably not less than 35 or 40 ton block of a special shape will have to be manufactured for the most exposed portions, but for the filling in of the first or lower parts the present 27 ton blocks or such others as Mr Parkes would require for the monolithic system would amply suffice - There should thus be no necessity to hesitate in reference to manufacturing concrete blocks of the sizes required by Mr Parkes or of quarrying granite for facing the foreshore -

24. A limit of 3 Lakhs of Rupees might with these objects be at once appropriated for 1882-83 subject to future increment if considered necessary. As to the immediate construction of new Titan cranes as required by Mr Parkes that must entirely depend on the decision arrived at by superior authority on the general subject of the restoration -

Chepâk
13th March 1882

A A Tanner Colonel R.E.
Chief Engineer, P.W. Dept

No. 780 W.

P. W. Department.

Proceedings of the Madras Government
Under date the 23rd May 1882
Read the following:-

From the Engr.-in-Chief,
Madras Harbour Works N.C. No 99 dated 9th March 82
Note by the Chief Engineer " " 13— do —

Ordered that the report above recorded and the Note by the Chief Engineer P.W. Dept. be forwarded to the Government of India for early orders. A copy being also sent to the Secretary of State.

(True Abstract No 781 W. dated 23-5-82)

To

The Secy. to the Govt of India, P.W.D.

Sir,

In continuation of the correspondence quoted in

Urgent
Send for in Abstract
Send for in Abstract

Engr in Chief. In N. Works
Supt. In N. Works
Marine dept
Despatched 29-3-82.

Cir. 13-3-82

Letter № 2955 W of
25th November 81.

in the margin on the
subject of the damage
to the Madras Harbour
works by the Storm of
the 12th November 81, Sanc-
tion directed to for-
ward for the early
orders of the Government
of India copy of a Report
by Mr. Parkes the Engineer-
-in-Chief of the Harbour
works on the extent
of the damage, on the
measures requisite for
repairing, and providing
against its recurrence,
and the estimated cost
of the work. The Report
is accompanied by a
note by the Chief. Engr
P. W. Dept.

Should the Govt
of India, after taking
the best professional
advice available, concur
in

Cir. 1.

914

in the proposals made
by the Engineer-in-Chief.
I am to request that
the requisite authority
for preparation of ma-
-terials may be com-
-municated by telegraph
as requested in my letter
№ 505 W of 23rd Feby 82.

The estimated cost
of repairing the damage
and providing supple-
-mentary strengthening
works is set down at
18¼ lakhs, to which
must be added a sum
of Rs 2,94,000 for
compensation for damage
to private property both
of the Harbour and the
acquisition of land in
that direction still
threatened.

R. S.

24/3/82

× to be filled in
when papers are available

Desd
13/4/82

Ans A

95

P.W. Department

No. 14/782 W. dy 23d March 82.

To,

The Most Honorable the

Secy of State for India -

My Lord Marquis,

In our Despatch

No. V.

No. 74 W dated 23d Feby 1881

2928

we promised a further

report on the condition

of the Madras Harbour

Works as soon as the

requisite survey and

soundings had been taken.

These have now been

completed - and Mr.

Parkes has submitted

to depart on the nature
and extent of the damage
sustained by the work,
the remedial measures
which he proposes to
adopt, and the estimated
cost of the work.

We have laid the papers
before the Government of
India for such orders as
they may consider necessary
after taking the best
professional advice
available - and we have
now the honor to forward
copies of the correspondence
for your Lordship's information.

R.S.

Attt

24/3/82