Sir Bruce
Mr Gelson
Ackd

MINISTRY OF TRANSPORT
DIVISIONAL ROAD ENGINEER (SOUTH-WESTERN)
GOVERNMENT BUILDINGS, ALPHINGTON ROAD
EXETER, DEVON EX2 8NF
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M. Beckett.
a model report, good sense
+ particularly good language
Mrs G. Weir
M. Ratcliffe.
will be interested

10th July, 1969.

Dear Teddy.

When sorting out the bookcases in my new office, I came across the enclosed copy of a very old report by J. Wolfe Barry which I thought you might like to retain in your own or the firm's archives. I found the report terribly interesting.

As you may know, I have at last been allowed to leave St. Christopher House and sample the countryside. I must say I am enjoying it.

I send my best wishes to Marjorie and yourself.

Yours sincerely,

William

(W. Downie)

W. E. Gelson, Esq., M.Sc., A.C.G.I., F.I.C.E.,
Sir Bruce White, Wolfe Barry & Partners,
1, Lygon Place,
Westminster, S.W.1.

REPORT ON THE FAILURE

OF THE

EMPRESS DOCK NORTH WALL

BY

J. Wolfe Barry.

1888.

23, Delahay Street,

Westminster,

October 22nd 1888.

To Philip Hedger Esqre

Secretary of the Southampton Dock Coy.

Dear Sir,

In accordance with the request of your Directors, I have visited the new Deep Water Dock at Southampton and have examined the wall which has given way, the nature of the soil on which it rested, and which it supportes. I have studied the mode in which the wall was built and the manner in which other portions of

the dock walls are being executed. I have also had access to the various drawings & and documents which bear on the subject — I now beg to report on the three subjects enumerated in your letter of the 2nd inst.

(1.) "As to the cause of the failure of the wall."

The first movement of the wall was, I understand, very slight and had taken place to the extent of a few inches before it was noticed. The rate of movement, which was slow at first, rapidly increased to several inches in 12 hours, and at last the wall moved forward with great rapidity till at the central part of the length of 400 feet

which gave way, the maximum amount of displacement from its original position was about 23 feet, at which distance it came to rest. The wall was partially pulled down when I saw it, and a high bank of debris was in front of it. I could not therefore plumb the wall, but I am informed that it maintained its vertical position almost unimpaired by the movement, and the photographs which I have seen confirm this statement.

The wall which is made of concrete consisting of good gravel and portland cement in the pro-portions of 8 to 1, is 51 feet high from its base to the coping, has a thickness of 30 feet

in width at its base, and of 24 feet at Dock Bottom. The thickness at the top is 10 feet, and there are 4 steps or offsetts at the back of the wall, each 2 feet wide. The face of the wall is curved and the back is vertical. The base of the wall rested on a slight incline upwards from back to front of 6 inches, equal to a slope of 1 in 60.

The nature of the soil behind the wall was as follows, reckoning from the base of the wall upwards. About 23 feet of clay was left vertically behind the wall which was erected in a timbered trench, and I am informed that great care was exercised

to ensure that the concrete was tight against the front and back faces of the clay. Above this level there was a further depth of about 3 feet of clay, then 4 feet of gravel, then 8 feet of soft mud. All these layers of soil were in their natural order of stratification. Above the level of 23 feet from the base of the wall, the clay gravel and mud had been more or less removed and replaced by earth filling as will now be described.

The earth filling was executed as follows. — Immediately behind the wall from a point 23 feet above the base, the clay gravel and mud were sloped backwards at an angle of about

1 vertical to 1 horizontal to a point half way of the thickness of the mud, at which level the mud was removed for a distance horizontally from the back of the wall of about 22 feet. Beyond that distance the mud was left with a slope of about 2 to 1. The space due to the removal of the clay and mud was filled with earth filling from the site of the dock, and this filling was, I believe, rammed in horizontal layers up to the level of the top of the mud. Above that level the same description of filling was deposited from ordinary earth waggons or barrows and was not rammed in layers.

The whole of the backing had been brought

up to coping level or thereabouts and the wall gave way about a week afterwards. The above description of the wall and backing which is I believe at least approximately correct, will be better understood from the accompanying cross-section.

The stress to which a retaining wall is exposed is dependant on the nature of the ground and filling behind it, or in other words on the slope at which the ground will stand without slipping if unsupported. Having considered these possible stresses and on the assumption of the very unfavourable ground which existed behind the wall, I am of opinion

that the strength of all parts of the wall itself against any stress which could come upon it, is ample. The cause of the failure of the wall, in my opinion, is not therefore due to any want of strength ~~of~~ the structure itself.

The next point for consideration is the nature of the earth beneath the foundations. Two pits had been dug in the ground near the present position of the front of the wall to a depth of about 2 feet below the bottom of the wall, and I was thus enabled to examine the nature of the ground which supported the wall.

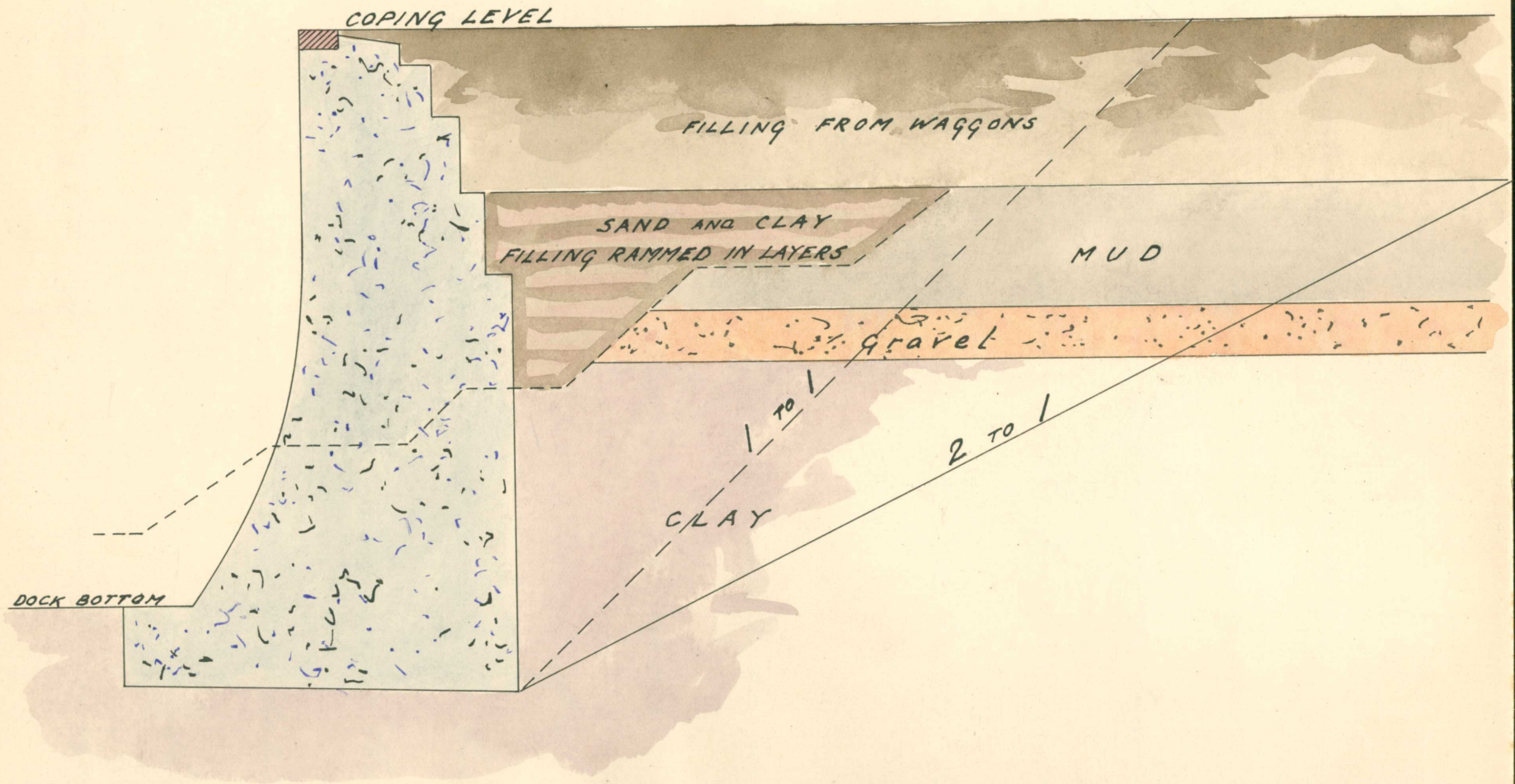
The soil consists of a hard and stiff clay at the level of the bottom of the wall. The clay

SOUTHAMPTON DOCKS.

DEEP WATER DOCK.

SECTION OF NORTH WALL.

Scale 1 in = 12 ft.



resembles portions of the London Clay, and it does not vary greatly in character or density up to Dock Bottom, though the upper layers are somewhat less stiff. The foundation of the wall was placed at a depth of 6 feet below dock bottom.

I requested Mr Giles to make an experiment as to the sustaining power of the clay adjoining the present position of the North wall of the Dock. Accordingly a hole was dug 6 feet square and 7 feet deep (that is one foot below the bottom of the foundation of the Dock Wall at that point) and in this hole an iron plate 3/8" thick and 2'. 2" square

was laid on which was built a brick pier 2 feet square, corbelled out at the top to about 3 feet square. On this were laid Railway metals 49 in number, weighing 12¼ tons. The Brickwork added 2¼ tons and the total weight was 14½ tons, or 3·6 tons to the square foot. There was no perceptible squeeze until the 4 last rails were laid on when the pier sank a little at one edge. This, it was thought by Mr. Giles, was more owing to the weight being a little on one side & not so much to the direct load. Without the last 4 rails, up to which time there was no apparent shrinkage, the weight was 3¼ tons to the square foot.

The sustaining power of the clay as indicated by this experiment is less than I should have been prepared to expect from inspection of the clay itself, but I have little doubt that it (would have borne) a greater weight than 3¼ tons to the square foot if the whole area of the 6 feet hole could have been experimented on instead of mearly an area of 2 feet, and I think it would not be unreasonable to suppose that the clay would be equal to supporting a load of about 4 tons on the square foot over a large area.

As the result of my inspection of the clay and from the information afforded by the experimental load, I am of opinion that the cause of

the accident is not to be found in any vertical subsidence of the clay, though there is no doubt that the stress on the extreme toe of the wall must, from the nature of the ground behind the wall, have been severe and approaching to 4 tons on the square foot. The view that the wall did not fail from the vertical subsidence of the clay is proved also by the fact that the wall after its movement is still in a vertical position, whereas if the clay had subsided it would have done so more at the toe of the wall than at the back and the wall would have tilted forward.

The earth supported by the wall however would exert two forces, one tending to compress the earth

beneath the wall and the other tending to make the wall slide forward horizontally, and it is now necessary to consider more particularly the nature of the earth upheld by the wall and the horizontal strains which would be devel-
-oped by it.

The clay, especially its upper beds, is not entirely homogenious but has laminations in which minute layers of some kind of loam or sand exist, the thickness of these is however sufficient to contain and pass water which is highly stained with iron, and no doubt comes out of the gravel bed.

It will be seen from the section on p. 9 A

that allowing for the sloping back of the clay and the removal of the mud, the slope of the ground behind the wall from the base of the wall to the top of the rammed filling was approximately 1 to 1 and that above the mud there was a height of about 13 feet of backing resting on a bed of mud.

I consider that ground such as I have described would not stand at such a slope as 1 to 1 but would more probably require a slope of 2 to 1 for stability. The ground behind the wall would thus give rise to very considerable horizontal pressure which would be much in excess of that produced by ground and backing such as is ordinarily

found behind heavy retaining walls.

The forces tending to keep the wall from sliding were :—(1) The friction due to the weight of the wall resting on the clay

(2) The resistance of the earth in front of the wall, which as I have said was 6 feet in depth.

The friction due to the weight of the wall depends on the nature of the ground on which it rests, and to its being wet or dry. It will vary from 2/3 to 3/4 of the Walls' weight on good soil, such as gravel, to 1/2 on dry earth, and is as low sometimes as 1/4th or 1/5th, on wet clay.

The resistance of the earth in front of the wall depends on the density and nature of the earth and on its power of resistance to being

displaced by being lifted upwards from in front of the wall. This last would be much diminished by any dip of the stratification away from the wall, of which there are signs now visible in the ground in front of the wall.

It is clear that in the present instance the sum of these resistances was insufficient to counteract the thrust of the earth behind the wall.

I believe that under the pressure of the upper 13 feet of earth filling, the mud began to be squeezed outwards and caused compression of the backing behind the wall and that this force was sufficient to cause a slight movement or bending of the wall horizontally. The beds of

backing being disturbed, water began to pass from the gravel into the clay, through the sandy layers and in disintegrating it, largely increased the horizontal pressure. Moreover, as through the Clay and over it, water found its way to the back of the wall and to some extent, beneath it, the friction on the base was rapidly diminished by the clay being wet, and such a pressure was thus brought on the depth of 6 feet of clay in front of the wall that it was displaced and pushed upwards. As soon as movement was established the wall moved forward with very slight resisting power until the earth and backing adjusted themselves to their angle of repose, when all

horizontal pressure ceased.

To sum up therefore, my reply to your first question is, that the cause of the misfortune was, in my opinion, the existance close behind the wall of the mud and clay, and of the presence of water in the gravelly bed, coupled with the fact that the backing, rammed in layers, had so much clay mixed with it, that water could not readily find access to the pipes which had been provided through the wall for the purpose of relief.

I. The second question is, "an opinion as "to the precautionary measures to be taken to "avoid a recurrence of slip when the wall is rebuilt."

The precautionary measures to be adopted

in rebuilding the wall are, in my opinion to carry its foundations considerably deeper into ground undisturbed by the movement which has taken place and to remove the clay and mud to a much greater distance behind the wall, replacing them with more and better backing, which should rest on horizontal beds. In addition to this, all soaks and drains of water from the gravel should be led through the backing to the drain pipes through the wall so as to avoid as far as possible any action of the water on the Clay beds.

I think also that the nature of the earth backing itself, might be improved with advantage, though I do not consider that this was the main

cause of the failure of the wall, which is to be found more in deficiency of quantity than of quality of the rammed backing. It was selected, no doubt, with care from the most suitable parts of the Dock excavation, but it consisted of a considerable quantity of clay mixed with sand and loam and I should have preferred lighter and less retentive material. There would be no difficulty I think in burning some of the stiff clay from behind the wall and mixing it with the more sandy portions of the present selected material or, if it were preferred, chalk or gravel might be used for this purpose instead of the burnt clay.

3. The last question which you ask is "as to "any steps to be taken to avoid any further "slip at any other portion of the dock walls."

I think that the steps which should be taken at the present time in respect of the other walls are in the direction of diminishing the pressure behind the walls by using a greater width of backing, resting on horizontal beds, and in improving its quality, keeping at all times a free exit through the wall for any water which may accumulate in the gravel beds.

I would also suggest that the upper parts of the backing above high water mark, should, if practicable be left unfilled until the water

be admitted to the dock, when of course the pressure of the water will counterbalance all the horizontal strains of the earth behind the walls.

I hope and believe that these precautions will be sufficient to prevent any further movement of the walls of the dock, but if any sign of any further giving way of any of the walls is observed, I should agree with Mr. Giles in recommending that either a continuous wall or buttresses should be carried down in front of the foot of the present walls to a depth of 12 or 14 feet below Dock bottom, so as to oppose additional resistance to any sliding movement.

Such a work, which is akin to underpinning,

would have to be conducted with very great caution and in shorth lengths, so as to avoid any risk of weakening the present hold of the wall in the ground.

In making the above remarks I may perhaps be permitted to add that the wall is so massive and well proportioned that it may well have seemed difficult to believe that even such treacherous soil as that which it supported for a short time, could produce a thrust sufficient to make it slide on its base.

Thus the size and weight of the wall perhaps induced a reduction in the width of the rammed backing which in more favourable ground would not have been injurious.

The failures of retaining walls, of which there are many examples, are usually not due to any fracture of the wall or to their being over-turned, but are, as in this case, caused by a sliding movement. The great pressure which can be brought on the back of a retaining wall by soft soil becoming displaced or being mixed with water and disintegrated, is extremely difficult to appreciate beforehand, being a matter of estimate of what will be the angle of repose of the earth when affected by water or any other circumstances which will alter its behavior after it has been placed in position.

The amount of this pressure, depending

as it does, wholly on the behavior of the soil under varying conditions (which cannot be foreseen with any certainty) defies any exact previous calculation.

I am, dear Sir,

Yours faithfully

(p') J. Wolfe Barry.