Discussion.

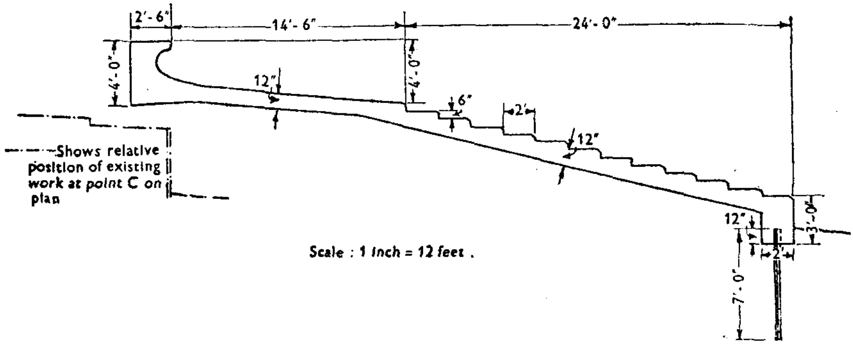
The Chairman said that the meeting was the first meeting of the Division which had been held since " VE day," and he could not let the occasion pass without some reference to the victory which had been achieved on the continent of Europe, in which engineers had played a vital part. He was sure they would continue to play that part until the enemy in the Far East was also defeated.

The Author introduced the Note with the aid of a series of lantern slides.

Mr. F. M. G. Du-Plat-Taylor observed that in 1904 he had had occasion to repair the Brunswick wharf at Blackwall, which was built in about 1800, and he had been surprised to find how good the cast iron was. It was not crystalline and appeared to be in a perfectly sound condition. Some of the piles had gone, but it was interesting to know that a wall like that could last so long, as cast iron usually had a shorter life.

With regard to the wharf at Rouen, on wooden piles, he wondered what happened to the air which was trapped at the back of the wall, because the wall projected a good deal lower than the ground at the back. Considerable air pressure would be developed as the tide rose behind the wall, the air being caught in that recess

Fig. 10.



About seventeen years ago he had built a sea defence wall of the type illustrated in *Fig. 9*, more than a mile in length, with a varying number of steps (*Figs. 10* and *11*). Beneath the toe, or lowest step, a line of steel sheet-piling was driven down into the clay. The wall was of reinforced concrete. The number of steps varied according to the inclination of the beach.

The sheet-piling was driven in a continuous line, in several sections.

The contractors had a good deal of difficulty in keeping the piles upright. The difficulty of creep was overcome by pitching sets of seven or eight piles together, and then driving each pile for a short distance successively. If that had not been done, the creep would have necessitated the insertion of a tapered pile every 200 or 300 feet. It was very important that the piling should be watertight, as the stability of the

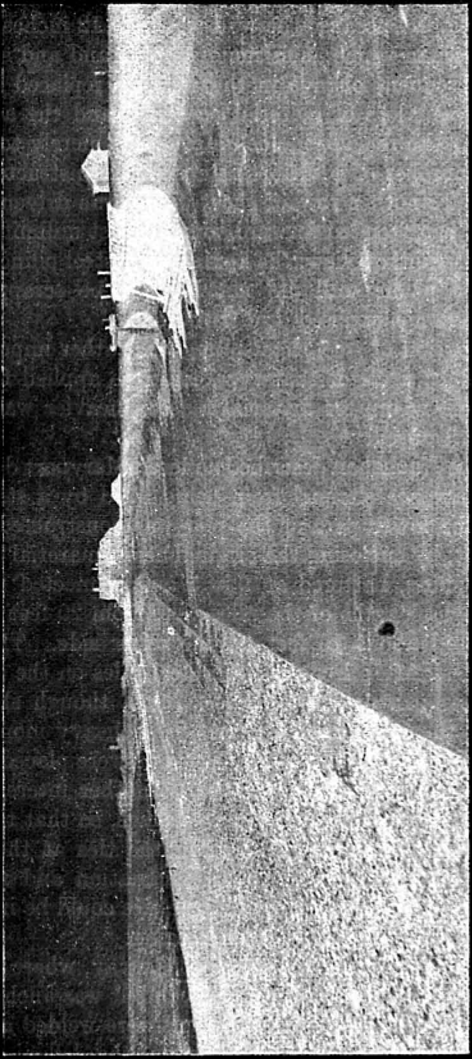


Fig. 11.

whole wall really depended upon that. It sometimes occurred, in a heavy on-shore gale, that the beach was washed out to depth of 4 feet or 5 feet; that would temporarily uncover part of the piling, and if the latter was not watertight a current would be set up through the piling which might gradually wash out sand from beneath the wall, and so cause cracking or collapse, because the wall was only 12 inches thick.

In most cases in which gales removed the sand and shingle in front of the wall a subsequent change in the weather replaced it. But in some cases a permanent loss of material occurred, and the advantage of that design was that the remedy in such a case was merely to extend the wall. The requisite number of additional steps were constructed in front of the original toe and another row of sheet-piling was driven farther out, and the wall could be extended forward to an almost unlimited degree.

From that point of view, the boxing with steel piling was an essential feature, as the whole wall did not have to be scrapped, because the foundations were not exposed or distributed.

That application of steel sheet-piling was rather important, because in many places light walls of that type could be applied for the protection of the foreshore, where for financial reasons heavier walls of the gravity type could not be used.

Mr. Maurice Nachshen described a pier at Maryport designed to protect the harbour entrance channel from being filled by a strong littoral drift of shingle. The lower part of the pier was constructed before dredging was carried out, by enclosing the original beach material between two rows of steel sheet-piling, battered at 1 in 3 and connected by tie-rods above beach-level. The lengths of the piles were from 20 feet to 30 feet on the channel side and about 16 feet on the other side. The superstructure was of concrete. After dredging, the sheet-piles on the channel side were exposed over a span of about 8 feet which, though short, was heavily surcharged by the superstructure, producing heavy moments and shears. There were no walings to the wall. Tie-rods were placed at every trough, 2 feet 9 inches apart centre to centre. Another interesting feature was that the tie-rods were placed in 6-inch casings, so that the superstructure could settle without danger of shearing the ties at the sheet-piles. In many places the tie-rods were at an inclination and the washers were made with a spherical seating, so that the ties could be inclined at various angles and the nuts still have a good bearing.

Another rather unusual case arose at Galway, where a small sheet-pile wall was constructed which was not driven but was anchored to rock.

The piles were of the *Ougrée* type and were welded at alternate interlocks. When filling with stone was begun, the deflexions were found to be much greater than had been expected. Careful measurements were made, and it was found that the deflexions corresponded very closely with calculation based on the minimum moment of inertia of the piles about an inclined neutral axis.

One lesson to be learned from that was that in the ordinary form of sheet-pile construction considerable shear resistance was developed from the friction of the piles in the ground at the bottom. It was also necessary to look very carefully at the shear resistance at the top and to provide for it by waling arrangements or by welding. Research was desirable into that aspect of the matter.

Developments might well be made in sheet-piling. The main requirement was to obtain stronger sections than were now available, to enable the ordinary straightforward wall, such as that illustrated in *Fig. 2*, to be built with heights of up to 70 feet, so that it could be used in deep tidal waters. Relieving platforms and the like were really devices to reduce the bending moment of the piling. Perhaps something might be devised to enable tie-rods to be attached at lower levels, possibly below water.

Another development might be the construction of dolphins made of boxes of sheet-piling, perhaps of cylindrical form, filled with stones or earth. He would also like to see non-corrosive steel of a rather better quality, with higher resistance than the steel used at present, and produced at a reasonable cost.

Mr. J. E. G. Palmer observed that the Author had made the problem appear very easy, but it was not really so. Considerable trouble could be experienced in driving sheet-piling, and a contractor using sheet-piling for the first time could get into very serious difficulties. Fortunately the Author had realized that. Mr. Palmer suggested that anyone who was going to use sheet-piling should first obtain a copy of " The B.S.P. Pocket Book." One difficulty mentioned in that book was that the piling had a tendency to get out of plumb as it was driven, and several pages were devoted to describing various means of overcoming that difficulty, one of which was to pitch the piles in panels of several at a time. Mr. Palmer had had to drive a considerable length of sheet-piling in the construction of a slipway for trawlers at a port on the east coast involving a cofferdam of a rather unusual shape, 300 feet long. B.P.3 section was used, and three specially made tapered piles had to be driven in the length of each side to keep the piling plumb.

Steel box piles were excellent things, being very easy to handle, but the question often arose whether or not to provide them with a toe. The excellent handbook to which he had referred above did not contain any details of a toe to a box pile.

With regard to the very vexed question of the length of life of sheet-piling, the Author had stated, very fairly, that: " There is some uncertainty about its durability, especially of light sections, when an effective life of more than a few decades is required." Could the Author give some actual examples of sheet-pile walls that had lasted a longer or a shorter time than that ?

Mr. A. W. Skempton observed that he wished to support the Author's plea for more field measurements. As the Author had suggested, there were several very interesting possibilities in connexion with sheet-piling, and from a technical point of view there did not appear to be much difficulty in measuring the anchor tie pull and the earth-pressures on the piling.

The results of such field observations should, however, be correlated with the results of borings and tests to determine the mechanical properties of the strata, for only with such data could the full value of the observational work come to light. The object of the field measurements was not only to determine the actual stresses in any design, but also to check existing methods of earth-pressure calculation; and from a broad point of view the latter object was the more important.

The need for field measurements was particularly urgent with clay strata. Clays, on the whole, presented a more difficult problem than sands and although several theories existed concerning the earth-pressures exerted by clays, no real confidence could be felt in those views until they had been tested against field observations on full-scale engineering structures.

One of the very few examples of such observation was presented by the work recently carried out in the Chicago subway,[1] where, as shown in *Fig. 12* (a), cuts about 35–45 feet deep were made through a layer of sand, followed by stiff clay and then by a thicker bed of soft clay which, near the bottom of the cut, became rather stronger. Careful sampling and testing were carried out to determine the stratigraphy and the shear strength of the clays; and a very large number of borings were made, usually about 300 feet apart centre to centre, along the whole length of the excavation works.

Fig. 12 (a) also showed a typical calculation of the active and passive pressures, based upon Bell's equation [2] with the assumption that the angle of shearing resistance was zero in the clays. Theoretical reasoning existed for supposing that that assumption was substantially correct for clays, in those cases where the opportunity for water-content changes in the clay was small. In Chicago that was clearly true, for the cuts were excavated quite rapidly and the observations could be made only over a short period of time.

From the calculations, the difference could be found between the total active pressure and the total passive resistance, and that difference could be compared with the sum of the measured loads in the struts. The two results should be equal if the theories were correct.

In *Fig. 12* (b), that comparison was made for seven typical sites along the length of the excavation, and the agreement between calculations and observations appeared to be reasonably close. Naturally, other values of ϕ were chosen; but only with very small values, certainly less than 5 degrees, could any measure of agreement be obtained.

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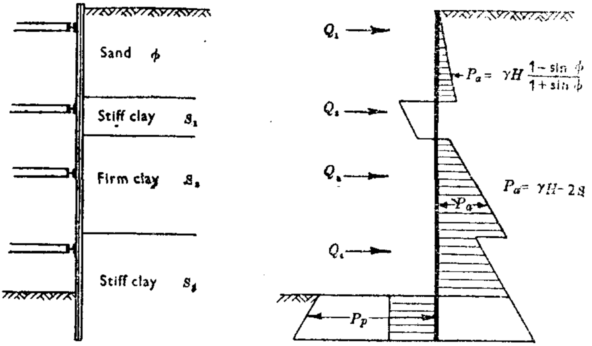
[1] R. B. Peck. Proc. Amer. Soc. Civ. Engrs, vol. 68 (1942), No. 6, p. 900.

[2] A. L. Bell. Min. Proc. Instn Civ. Engrs, vol. cxcix (1914–15, part I), p. 233.

Observations of that nature were therefore obviously of the greatest importance, for they could lead to the most valuable checks on the theories, as in that particular instance where the rather revolutionary idea that ϕ could equal zero in clays was confirmed. But many more field observations were required before the whole problem would become clear, and the example of the Chicago work should be repeated.

Figs. 12

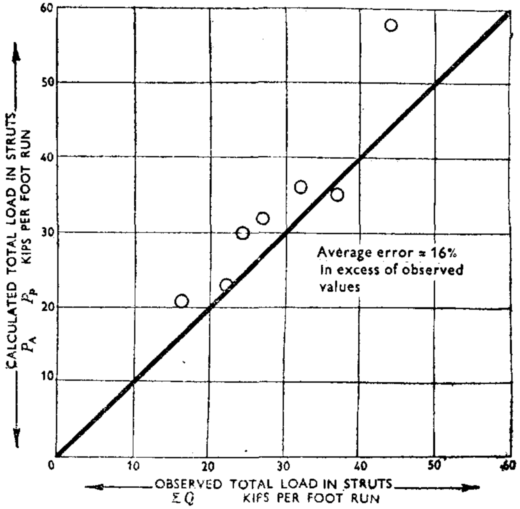
(*a*)



$P_p = \gamma H + 2{\cdot}5s$

PRINCIPLE OF CALCULATIONS.

(*b*)



RESULTS.

EARTH-PRESSURE CALCULATIONS AND OBSERVATIONS, CHICAGO SUBWAY.

The probability that clays behaved, from the point of view of stress conditions, as if they were frictionless (provided no water-content changes could take place) was of very considerable practical significance. *Fig. 13* illustrated a typical example of a sheet-pile wall. On the assumption that $\phi = 0$, the active and passive pressures at the dredged level were,

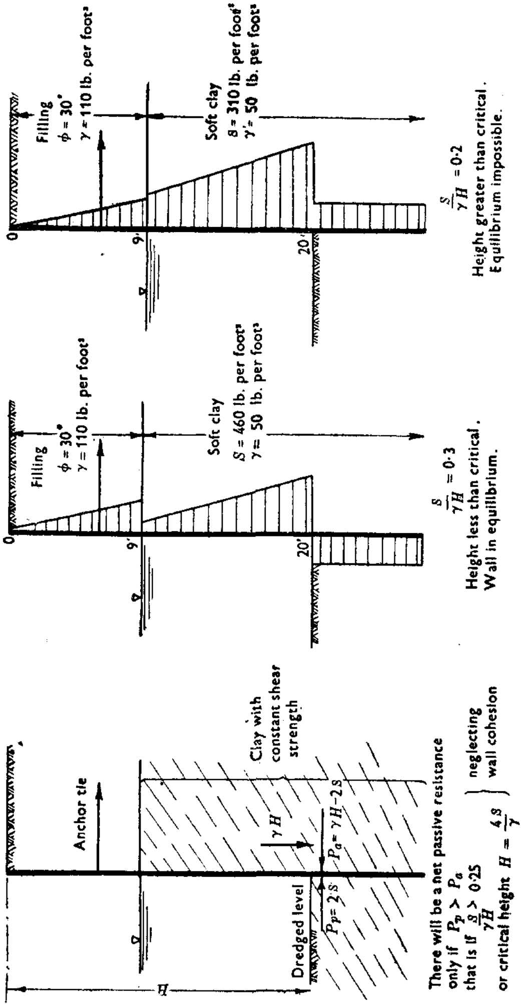


Fig. 13.

CRITICAL HEIGHT FOR SHEET-PILE WALLS IN CLAY

$$p_a = \gamma H - 2s$$

and

$$p_p = 2s$$

where γH denoted the weight of strata above that level, making due allowance for hydrostatic uplift below low water, and s denoted the shear strength of the clay at dredged level.

Clearly if there were to be a net passive resistance in front of the wall

$$p_p > p_a$$

or

$$4s > \gamma H$$

or

$$\frac{s}{\gamma H} > 0{\cdot}25$$

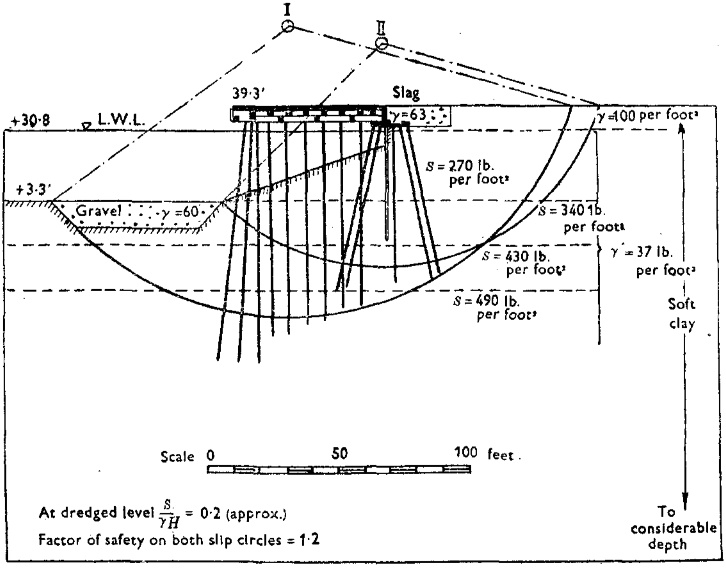
In other words, if $\frac{s}{\gamma H}$ exceeded 0·25, a net passive resistance could be built up in front of the sheeting and equilibrium could be obtained by a sufficient penetration. But if $\frac{s}{\gamma H}$ were less than 0·25, no net passive resistance was possible unless the penetration were increased to include a deeper and stronger stratum of clay or sand. If, therefore, there was a thick layer of clay, the strength of which was less than 0·25 γH and remained appreciably constant with depth, it would be a very uneconomic procedure to use any ordinary anchored sheet-pile wall, and recourse should be made to another type such as the open-slope or the platform design.

The Lindholmen quay, in Gothenburg harbour, Sweden, formed an example of the open-slope type, *Fig. 14.* There the value of $\frac{s}{\gamma H}$ at dredged level equalled about 0·2 and the strength of the clay increased only slightly with depth. The open slope obviously increased the stability by removing a large triangular wedge of clay beneath the decking. In the platform type the overburden pressure γH at dredged level was reduced very appreciably by the weight of all soil above the platform, and stability might then be possible in a case where otherwise no net passive resistance could be developed. An example was shown in *Fig. 15.*

That conception was, perhaps, rather novel, but it was only one aspect of the new knowledge of earth pressures and soil mechanics. The design of quay walls, even in clays, was rapidly becoming a rational procedure, but reasonable certainty in methods could be brought about most surely by field observations, borings and sampling. Should any opportunities for that work arise, the Building Research Station would be very grateful for the opportunity of carrying out the measurements.

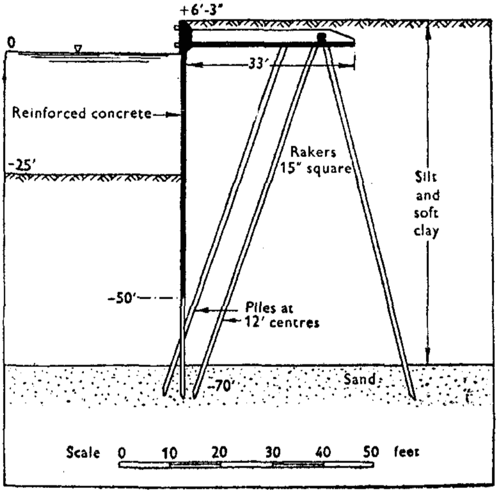
Mr. C. Peel observed that during recent years it had been necessary to modernize a number of quays in the Port of London, where the conditions for improvement works of that sort were rather peculiar and different from those of entirely new constructions on open sites. The work had often had to be carried out quickly, in order to minimize interruption to traffic, and often over water or in water or from existing quays. The type of construction that had been developed involved the use of reinforced

Fig. 14.



Lindholmen Quay, Gothenburg.

Fig. 15.



Platform Type of Quay Wall at Nörresundby, Denmark.

concrete cylinders in an open type of quay with pre-cast concrete piles driven therein, filled with mass concrete, and reinforced-concrete sheet piling at the back to retain the forward thrust of the backing, and heavy reinforced-concrete coping beams and deck, with the minimum of separate beams.

Two quays of that type in the Victoria dock were described by Mr. R. R. Liddell, M. Inst. C.E., in a Paper presented before The Institution in November, 1938 [1].

In one the old timber sheet-piling had become very decayed, and it had been necessary to renew the quay. A good many years before the reconstruction of the quay some reinforced-concrete sheds had been built at the back, and at that time ties were left projecting from the pile caps, so that ultimately, when some form of quay was built to replace the old quay, the work could be tied on to the newer foundations.

The new quay consisted of a single row of reinforced-concrete cylinders, 24 feet apart, with concrete piles driven therein into a gravel bottom. The depth of the water was about 31 feet. The reinforced-concrete sheet-piles were 35 feet in length, and 24 inches by 12 inches in section. As it became necessary to cut the old tie-rods in order to prevent any subsidence, the sheet-piles were tied back to the shed pile caps. There was a heavy coping beam, transverse beams with a very thick deck, and no other beam work at all.

A lantern-slide showed a typical section of the second quay, on the north side of the dock. The structure, about 3,000 feet in length, was entirely self-supporting. It consisted of three rows of reinforced-concrete cylinders, with reinforced-concrete piles therein. Heavy portal beams connected the three rows. The reinforced-concrete sheet-piles at the back of the quay were 14 inches by 14 inches in section and 45 feet long. The construction included a capping beam, a heavy coping beam, and a thick deck, with a central longitudinal beam and intermediate transverse beams. As much pre-cast work as possible was used for the soffits. For the most part the work was carried out in the water; that was to say, there was no dry land from which to work and the work was done from staging. The dock bottom was deepened and dredged gravel was deposited on the site before the quay was built. Subsequently the front slope was finished off. Reinforced-concrete sheds had subsequently been built at the back, involving large numbers of piles, but, in spite of all the displacement and vibration, there had been no movement whatever of the quay. Ties were left projecting from the portal beams and they were tied into the shed foundations. The whole of the ground was very good gravel, so that the work did not give any opportunity of proving or disproving clay theories. At first it was thought that difficulty might be experienced in driving the

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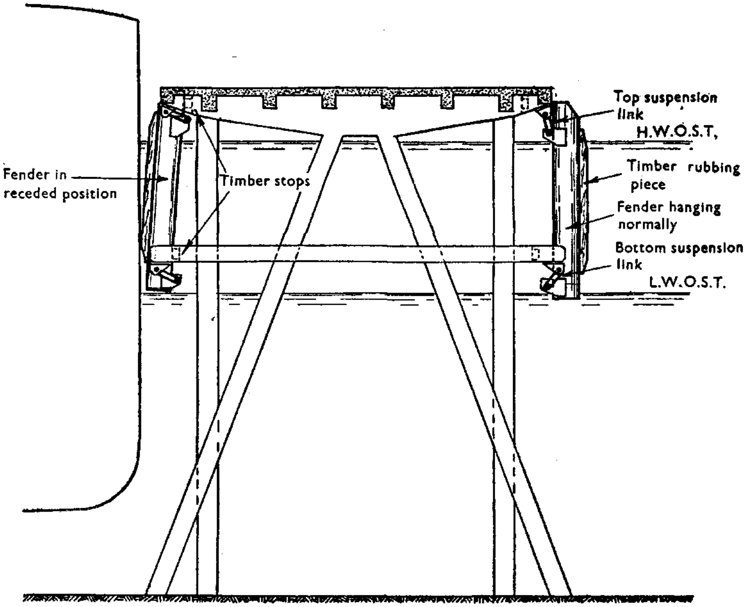
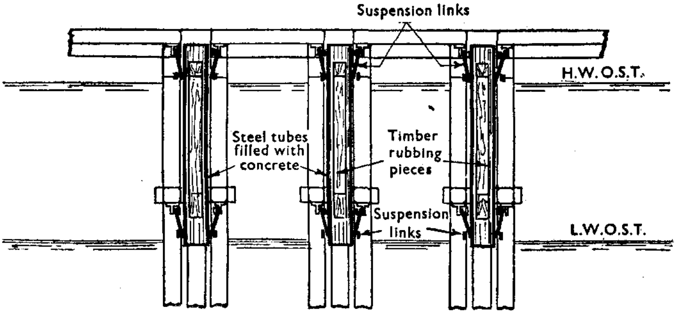
[1] "Improvements at the Royal Docks, Port of London Authority." J. Instn Civ. Engrs, vol. 10 (1938–39), p. 283 (Jan. 1939): see *Fig. 9*, p. 299, and *Fig. 19*, p. 307.

sheet-piles through the gravel, but actually the contractors scooped out a hollow in the deposited bank and no difficulty was experienced.

Figs. 16.



CROSS SECTION.



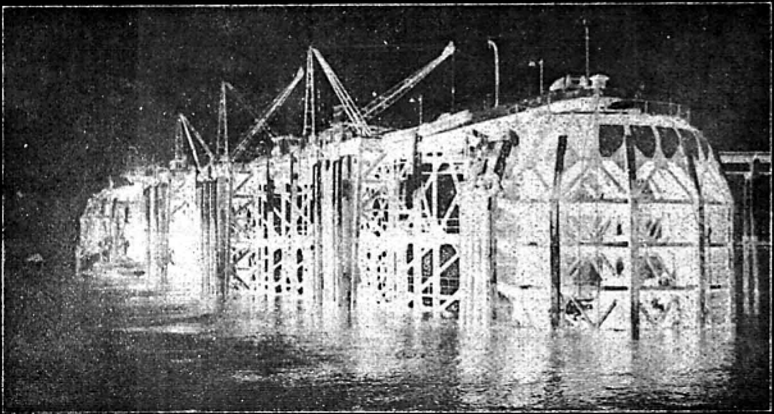
FRONT ELEVATION.

REINFORCED-CONCRETE JETTY EQUIPPED WITH SUSPENDED FENDERS.

The piles were driven with a 4-ton semi-automatic hammer, and no difficulty was experienced in driving. The piles tended to lean, but in the gravel, instead of leaning forward in the same way as steel sheet-piling, they tended to kick forward at the bottom. A special tapered pile was made for each bay between cylinders and had simply to be dropped into position.

Mr. A. L. Baker, referring to the Author's statement regarding the weakness of open-piled jetties, observed that various types of spring had been largely used in the last few years to reduce the impact forces produced by ships.

Fig. 17.

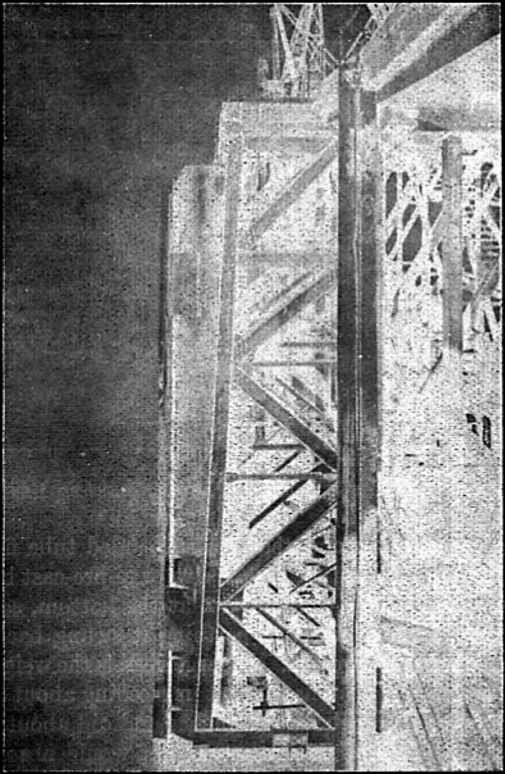


Pier-head with Bell Dolphins and Suspended Fenders

A newer type of fender consisted of a suspended tube filled with concrete (*Figs. 16*, *17*, and *18*), either cast in situ or in pre-cast blocks and suspended by two chains at the top and two at the bottom, so that when it received pressure from the vessel in berthing it swung back and up and work was done in lifting the weight. In large vessels the weight would need to be between 20 tons and 30 tons, so that in receding about 3 feet 6 inches the fender lifted about 30 inches to 36 inches and did about 900 inch-tons of work. Two or three fenders of that weight would absorb the kinetic energy of large vessels of about 15,000 tons, berthing at a speed of 1 foot per second, which was a very high berthing speed for a vessel of that size. If an open jetty of the type shown on the slide were equipped with fenders of that type, the forces of impact were reduced, and the raking piles could safely withstand the stresses. If the supporting power of the ground were weak, they enabled a light type of structure to be used without failure taking place in the foundations.

That type of fender prevented damage to ships due to currents or wind causing them to strike dock walls in berthing under awkward conditions. The fender could be added and suspended from brackets and the berth made quite safe for ships berthing under all conditions. That form of construction had been used during the war at berths in Scotland where ammunition ships rounded the end of a quay wall and were continually colliding with the end of the wall and suffering severe damage. The fenders acted quite quickly, and afterwards ships passed round the end of the quay wall under very severe conditions without suffering any damage at all.

Fig. 18.



SUSPENDED FENDER

The setting out of the suspension of the fenders was important. The suspensions had to be set out so that a line through the top links and the bottom links intersected the vertical line through the centre of gravity of the fender at a fairly low point. Then the fender, when pressed at any point between high tide and low tide, receded without turning about either of the suspension points. It was a practically parallel motion.

On the north-west coast a berth was constructed in the open sea, about ¾ mile from the shore, and on a site subject to on-shore gales of 80 mile per hour, so that the conditions were very severe. The berth was constructed originally for oil tankers about 500 feet in length. As the war proceeded, shorter boats had to be brought in, and intermediate shock-absorbing fenders had to be added, so that the light construction of the berth could withstand the blows. When a fender was pressed it receded about 3 feet 6 inches. At the same time it built up a resistance of up to about 70 tons or 80 tons, so that the shock-absorption was very high, and it had been proved, through vessels colliding with the jetty, that, even though severe collisions took place at a speed of, say, 1 foot per second, the fenders were capable of absorbing that shock so that no damage was done either to the jetty or to the tanker.

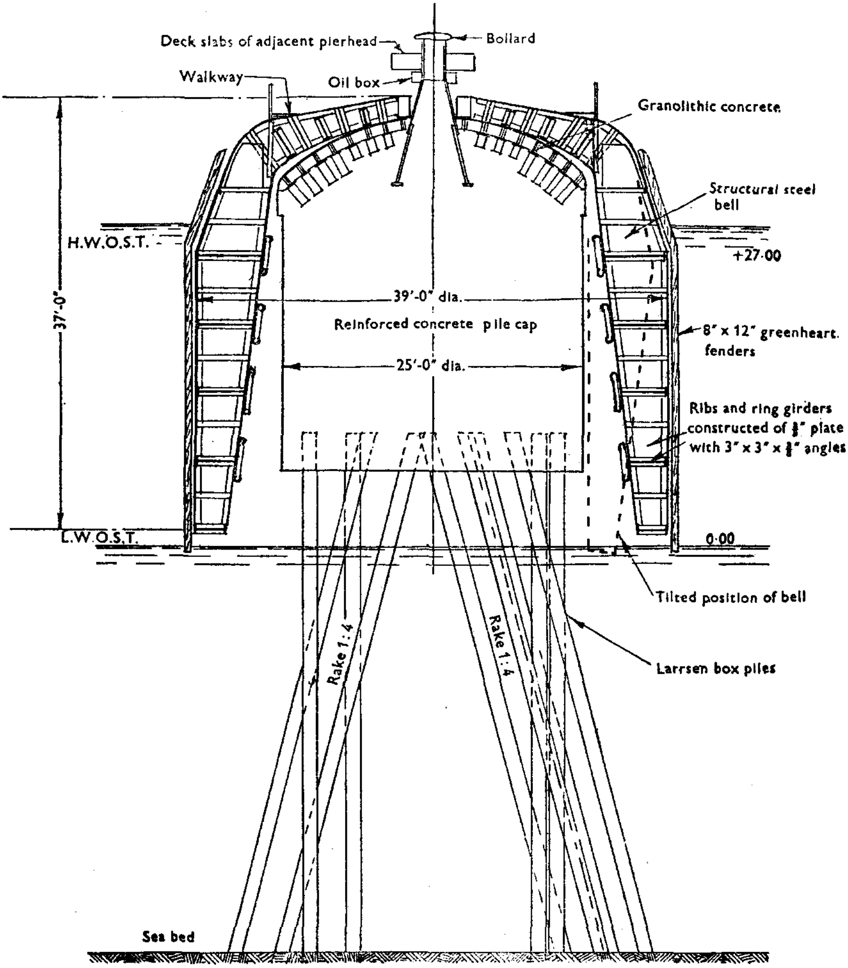
In the complete berth there were three groups of suspended fenders: a group of three at the centre and groups of two each at two other points. At the ends of the berth were two dolphins, which assisted the ships in coming into the berth. The channel was very narrow, and, with high on-shore wind, instead of coming to the moorings off the berth and warping in slowly, ships were liable to collide with the north dolphin or the south dolphin. In order to reduce the cost of the dolphin, and to allow the ships to collide with the structure without severe damage to it or to themselves, a new type of dolphin was designed, which consisted of a raking pile sub-structure, having a reinforced-concrete cylindrical head, with a spherical bearing, over which was constructed a steel cage with a bearing of slightly larger radius than that of the reinforced-concrete bearing underneath (*Fig. 19*). The fenders were fixed on to that cage, so that when ships collided with the fender the cage receded and built up an increasing resistance, up to about 150 tons, through a movement of about 4 feet, which gave a very high shock-absorbing value. The cage was also free to rotate, so that it did not matter in which direction the ship collided with the dolphin; the fender always receded from the ship and absorbed even the most severe blows.

Normally the steel cage weighed about 150 tons and bore at its centre, but when it was pressed by a ship at the side the point of pivot travelled from the centre to the side, so that the resistance built up from nothing to an amount about equal to the weight of the cage when the point of pivot had travelled to the outside. The pointer was now on the reinforced-concrete inner spherical bearing, and the cage was free to rotate on that bearing or to roll over, so that whichever way the ship collided with the dolphin it always met with a receding fender which was very highly resilient.

Fig. 20 showed a resistance movement diagram. The movement was shown on the vertical scale, and the area within the diagram was equal to the work done in pressing the cage over and to the kinetic energy destroyed in the ship during collision.

Two schools of thought existed with regard to jetties of that type. The present tendency was to provide resilient fenders so that when ships berthed too rapidly they did not suffer any damage and did not cause too big a reaction to come back on to the substructure of the jetty. That seemed to be the right direction of development, because it could not be always guaranteed that a ship would berth slowly in all circumstances. The second school of thought considered that a dock should be made formidable in appearance, so that captains of ships would always berth very slowly for the sake of their vessels. That probably applied in nine

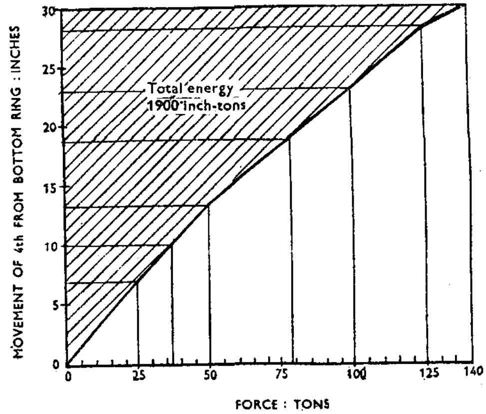
Fig. 19.



CROSS SECTION

cases out of ten, but on the tenth occasion a combination of wind and current and perhaps the captain's state of health, or something like that, might cause the ship to be berthed at a speed of 1 foot per second, instead of 1/10 foot per second, with the result that very severe damage would be done. Therefore it seemed right that the engineer should provide a buffer for the ship to collide with, in the same way as buffers were provided at terminal stations on railways.

Fig. 20.



Bell Dolphin.
Graph Showing Energy-absorption of Dolphin.

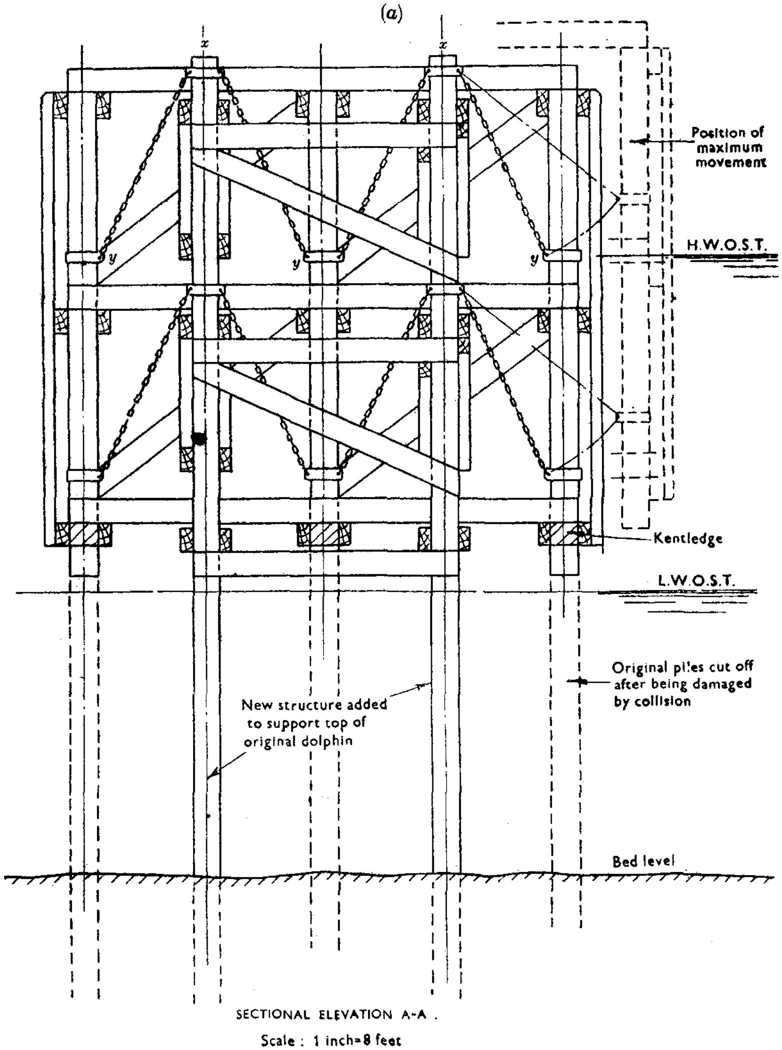
Mr. G. C. Blofield observed that he had recently had to deal with a case of a dolphin which had been destroyed and the same idea had occurred to him as to Mr. Baker, namely, to try to make use of an existing structure, suspending it on chains.

Figs. 21 (*a*) *and* (*b*) showed a nine-pile dolphin suspended on all four sides. The dolphin was destroyed at ground-level and all the piles were broken off. It did not collapse completely, but it was out of use. He considered that it might be possible to drive in four new piles at (x) and brace them strongly, so that they would come up to (x) but would be completely independent of the old structure, and would support the latter by chains from (x) to (y), with perhaps other chains lower down. Unfortunately he had not had the opportunity of putting that idea into practice, so that he could not say whether it would have worked or not. The idea was that impact in any direction would rotate the free point about the points at (x), so that the whole weight of the structure, and not the weight of one single fender, would be operating against the ship. Having single fenders suspended was open to the objection that one or two fenders had to be heavy enough to resist the whole weight of the ship, instead of a number of fenders being brought into play simultaneously.

The Chairman reminded the meeting that the subject of the discussion was sheet-piling in maritime works; the question of fenders was interesting and at least germane to the subject under discussion. A résumé had been given in the note of sheet-piling, timber sheeting, reinforced-concrete sheeting, and steel sheeting, and in the course of his career the Chairman had dealt with all of them. He had had some unfortunate experiences from time to time, and one of the worst trials had occurred in building a quay

Figs. 21.

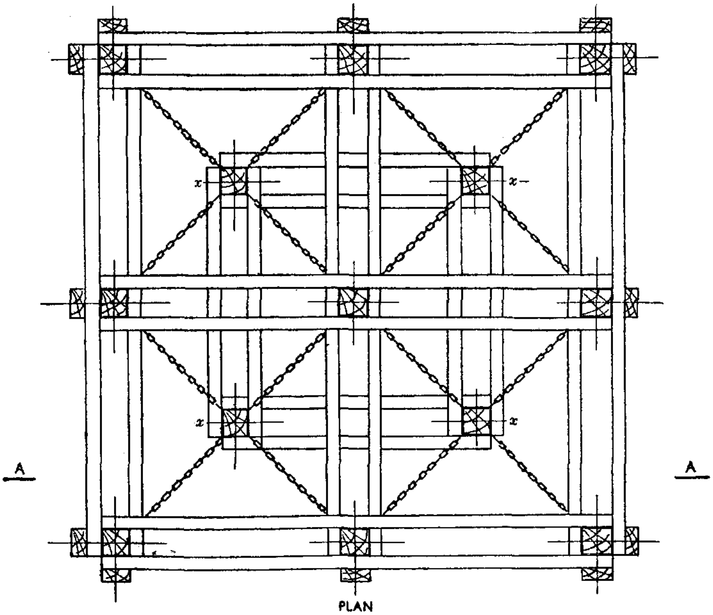
(*a*)



HANGING DOLPHIN.

Fig. 21.

(*b*)



PLAN

Scale : 1 inch=8 feet

HANGING DOLPHIN.

SCHEME FOR ADAPTING DAMAGED FIXED DOLPHIN TO FORM RESILIENT STRUCTURE.

wall, some thousands of feet in length, of steel sheet-piling, with concrete topping, and with a reclaimed area behind it to accommodate timber sheds —that area having been a timber pond. It was all beautifully designed. Very fine timber sheds were to be erected on the reclaimed area, carried on bearing piles, and the quay wall was to be tied back to the rows of piles for the timber sheds. Dredging was being carried out in front and ballast was being pumped from the front into the filled area, when the wall moved forward—3 inches, 6 inches, 9 inches, 12 inches—and continued to do so for many weeks. Finally he adopted a most unlikely scheme. Timber piles were driven in the hard ground beyond the boundary of the old timber pond, 300 feet away. All the old wire rope crane bonds that could be found throughout the docks were seized and stretching screws were put in them, and the wall was tied as tightly as possible to the timber piles in the solid bank 300 feet away, with such tension as could be exerted. That might be considered a very unusual expedient to adopt, but it held the wall until the shed piles could be driven in and the wall tied up properly; and the wall was intact to the present day.

The Author had presented an excellent Note and had aroused an excellent discussion. Support had been expressed for the Author's constructive suggestion that an effort should be made to obtain some measurement of the forces which were not understood. The beginning of all research was accurate measurement. Mr. Skempton had indicated that the Building Research Station possessed instruments for measuring tension and compression, and, with the co-operation of those who had the privilege of building walls, it should be possible gradually to accumulate data that would be of some use.

The Author, in reply, said he was sure that, after hearing the Chairman's harrowing experience in dealing with the forces of Nature, everyone present would treat them with even more respect in the future.

In reply to Mr. Du-Plat Taylor's remark about the quays at Rouen, vents covered with grids were provided to release the air trapped under the platform during rising tides.

The best method known to him for dealing with creep of sheet-piling was to pitch and interlock first of all a panel of about a dozen piles and drive the first and last down either to the full depth or perhaps half-way, so that both were vertical and provided a guide to the piles in between, which then had to go down vertically in the same manner. If there were no obstruction in the ground, and the work were properly carried out, there was no reason why taper piles should ever be used.

He believed the stepped sea wall had been originated by Mr. Du-Plat-Taylor, and to his knowledge it had been built in a number of places all round the coast. A point which was perhaps not appreciated by everyone was the necessity of having a fairly long stepped apron which broke up the waves before they got to the top. Another point to be remembered was the necessity of combining a wall of the type in question with groynes, so as to maintain the beach as well as possible.

The provision for settlement described by Mr. Nachshen, so that no direct pressure could come on the tie-rods, was a point which was frequently neglected, especially in ordinary anchored sheet-piled walls where the unsupported length of the tie might be quite considerable while the filling was being placed. It was a very good plan to make provision to support the tie and to arrange it in such a manner that if the filling settled no direct pressure would be imposed on the tie. That could be done by supporting the ties on light bearing piles driven down to a firm stratum. Another, though less effective, method would be to place the ties along the inverts of earthenware pipes about 3 inches to 6 inches larger in diameter than the ties. The pipes would then prevent the filling from pressing directly on the rods. It might be noted that ties were very flexible and could withstand a large deflexion at mid-span without being overstressed.

A plain wall of that kind, if of a considerable height, was not necessarily economical, because the size and length of the tie-rods increased in proportion to the height. The same applied to the anchorages, which not only increased in size but also had to be placed very deep to ensure that the ground in front of them was able to develop the necessary earth resistance. His own experience had been that, above a certain height, a very large proportion of the cost seemed to go into the ties, anchorages, and so on, and it was actually more economical and positive if the construction were combined with a relieving platform carried on raking piles. Tie-rods could admittedly be attached below water-level and means now existed of welding under water, but expensive diver's work was involved. Moreover, if the ties were fixed a long way down the wall, so as to minimize the bending moment in the sheeting, they came near the centre of gravity of the earth-pressure and carried a large proportion of the total load, thus becoming still more cumbersome. For that reason he had suggested that, with the materials available at present, the maximum economical height for a plain anchored wall would be roughly from 35 feet to 50 feet.

He was glad that Mr. Nachshen had mentioned the excessive deflexion of the sheeting at Galway, which was not driven into the ground but was merely supported on the rock. Some engineers were doubtful whether sections of steel piling with interlocks along the neutral axis developed the full section modulus—whether there was enough friction in the interlocks to develop the necessary shear and to prevent the outer piles sliding relative to the inner. The majority of piling sections had very close-fitting interlocks and his own practice was to regard the inner and outer piles as forming one solid unit, except when the piles were not driven into the ground to any reasonable depth. That might be the case in a cofferdam driven through a few feet of very soft clay or mud down to impenetrable rock. It was then advisable to connect the piles together by pressing, welding, or other means. He felt that his views on the subject were confirmed by the behaviour of many sheet-pile structures designed on that basis, particularly cofferdams subjected to water-pressures which could be calculated with considerable accuracy. In normal circumstances the necessary shear resistance would, he thought, always be developed by the friction in the interlocks due to the piles being driven into the ground. Some extensive research on the lines suggested by Mr. Nachshen had, in fact, been carried out, and that showed that relatively small frictional forces were sufficient to bring the section modulus up to, or almost up to, that of the solid section. In those investigations the sheet-piles were tested as simply supported beams subjected to concentrated loads; the actual section modulus was then determined from measurements of the deflexion and from the stress in the piling, obtained from extensometer readings. Various interlock conditions were tried. In the first series of tests the interlocks were oiled to reduce friction; in the next they were dry, then filled with loose sand, later secured by wedges, and finally welded at the ends. It was found that, whilst the oiled piles behaved almost as separate units, a small quantity of loose sand in the locks increased the modulus to about 75 per cent. of the full value. Wedges or other light means of restraint increased the modulus near enough to its maximum.

Some dolphins of sheet-piling with filling of soil or concrete had been built, including a circular one in the north a short time ago and two of rectangular shape on the Thames.

He agreed with Mr. Nachshen's desire for the production of steel which would not rust and would have considerable strength, and, although that was a counsel of perfection, there would doubtless be continued improvements in that direction.

Mr. Palmer had mentioned matters which most of those present had probably been compelled to consider at one time or another. The Author agreed emphatically that the contractor who undertook sheet-piling work should have experience in that class of work, and should also take pride in it. Many of the older foremen had grown up with the idea that sheet-piling was a temporary job and therefore it did not matter what it looked like. He did not think they would be allowed to lay bricks in the same manner. It was all a matter of craftmanship.

The provision of box piles, or any other kind of tubular pile, with a shoe depended entirely on the type of ground. It was very convenient to drive a tubular pile open-ended, provided that the ground at the bottom was good enough to take whatever load would be imposed on the pile later. In the majority of cases that method could be adopted, but sometimes it was necessary to develop some extra bearing capacity by closing the bottom of the pile by a shoe.

He would not commit himself on the subject of the durability of steel piling, but he thought that a very good idea of the length of time that a steel pile structure would last could be obtained from the Report of the Sea Action Committee of The Institution. The results were also confirmed by observations on various existing structures.

He was glad to have Mr. Skempton's support for the necessity of taking measurements and comparing them with calculations based on theoretical considerations and on the properties determined from sampling and boring. He did not know many cases in which that had been done. One had been mentioned by Mr. A. L. Harvey, M. Inst. C.E., in his Paper presented recently before the Division.[1] In that case measurements had been taken of the extension and therefore of the load in the tie rods. He wished that provision for measurements was made more often and considered that it should form a recognized part of design and construction. He was sure that the results would be very valuable.

Mr. Skempton had given a very clear exposition of the conditions that governed the equilibrium of plain sheet-pile retaining walls, as distinct from walls with piled platforms in front or of behind the sheeting. It might

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[1] "Two New Quays at Tyne Dock, South Shields." Maritime Paper No. 1. (1945).

be worth mentioning that the minimum shear strength necessary to permit the construction of a plain wall of given height was affected by the adhesion of the soil to the wall and by any re-distribution of earth pressure behind an anchored flexible wall. For instance, if the adhesion or wall cohesion were assumed to equal the shear strength of the soil, which was quite likely in soft or medium clays, a shear strength of less than $0{\cdot}2\gamma H$ would be sufficient to ensure equilibrium. That did not alter the fact that, if the soil were perfectly uniform and had a shear strength below the critical value, it would be impossible to make the wall stable, whatever the penetration. Notwithstanding the apparent paradox, nothing would be gained by driving the piling any deeper into the soil.

Mr. Peel had described some interesting work carried out at the Port of London. Mr. Peel was very fortunate to have such a good anchorage ready made for him in the form of the foundations of the sheds. The Author had noticed that the tie-rods holding the old timber sheeting were cut through as the work proceeded: that was another example of the time-factor that came into earth pressures to a greater extent than was often realized. The timber sheeting had to stand up for some time until the pressure was taken off it by the new concrete sheeting, and there was nothing to hold it when the ties had been cut through. If he understood Mr. Peel correctly, the concrete piles for the foundations of the warehouses were driven through the considerable thickness of gravel deposited there during the work. Usually it was better to drive bearing piles before sheet-piling, but in that particular case the gravel, being very loosely deposited, was compacted sufficiently by the vibration of pile-driving to allow for the displacement of the concrete piles.

Mr. Baker and Mr. Blofield had dealt with the question of dolphins, and he was gratified to know that the problem was now being approached in a scientific manner. He would like to know more about the speed at which ships came alongside. Whenever he had to consider that problem he had to make a guess, and some precise information on the subject was extremely desirable.

The Chairman announced that the constitution of the Divisional Board for Session 1945–46 would be as follows :—

Appointed by the Council in accordance with Rule 1 of the " Objects, Construction, and Rules " :—

Mr. Asa Binns, *Chairman.*
Mr. S. C. Carter.
Mr. R. D. Gwyther.
Mr. W. P. Shepherd-Barron.
Sir Arthur Whitaker.
Mr. C. A. Wilson.

Elected by the members present at the Meeting in accordance with Rules 10 to 14 :—

Mr. G. Kenyon Bell.
Mr. J. Guthrie Brown
Mr. Jack Duvivier.
Sir William Halcrow.
Mr. Savile Packshaw.

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