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" Some Designs for Flexible Fenders " †

by

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Mr J. A. Williams stated that the Author seemed to have had rather mixed results with the type of structure depicted by *Figs 11* and *12*, although in his oral introduction he had briefly referred to some further developments which had been made.

Mr Williams was of the opinion that the novel design of kinetic-energy-absorbing fender, described by Mr Ridehalgh and illustrated in *Figs 25*, offered a number of advantages over swinging fenders, and he suggested that, even with the latter, some of the disadvantages experienced by the Author could, to some extent, be mitigated.

For instance, the vexed question of longitudinal blows which, as the Author had remarked, were often ignored altogether, might be tackled by connecting all the swinging blocks together laterally, so that when one received a glancing blow the resistance of a number of blocks was mobilized. That, of course, pre-supposed adequate lateral clearance between fenders and supporting structure—a feature which, in the later designs described in the Paper, had been deliberately avoided. Mr Williams submitted that the ideal aim was the provision of ample lateral " swinging room," rather than the confining of movement to slots normal to the face of the berth. The inter-connexion of the blocks might also help to damp out the effect of waves. Those advantages could only be gained, however, at the cost of making provision for somewhat obtuse secondary stresses in the blocks themselves, the suspenders, and the supporting structure. The maximum

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† Proc. Instn Civ. Engrs, Part II, vol. 2, p. 42 (Feb. 1953).

direct force which could be developed in the suspenders was similarly troublesome to evaluate, and model-analysis was no doubt desirable.

He suggested that the following improvements could be effected in the actual shape of the blocks :—

(*a*) The working faces of the blocks could be widened out in plan and the facing timberwork dressed, roughly, to curves, both horizontally and vertically. That would (1) afford more cover, per block, to the face of the berth; (2) tend to make the fenders " ride " glancing blows; and (3) tend to concentrate the blow at the neutral axis of the block.

(*b*) More " balance " with, probably, a reduction in secondary stresses, would be achieved with a comparatively wide and shallow block, rather than one which was narrow and deep (see *Figs 11* and *12*).

Mr Williams noted that difficulty had been experienced in tightening the turnbuckles in the suspension gear (see p. 58). He had recently contemplated a similar arrangement for a tentative design—the suspenders being chains; had the design been adopted, no doubt the same trouble would have been experienced. Incidentally, it had been proposed to incorporate a locking device to prevent the couplings slackening back under operational conditions.

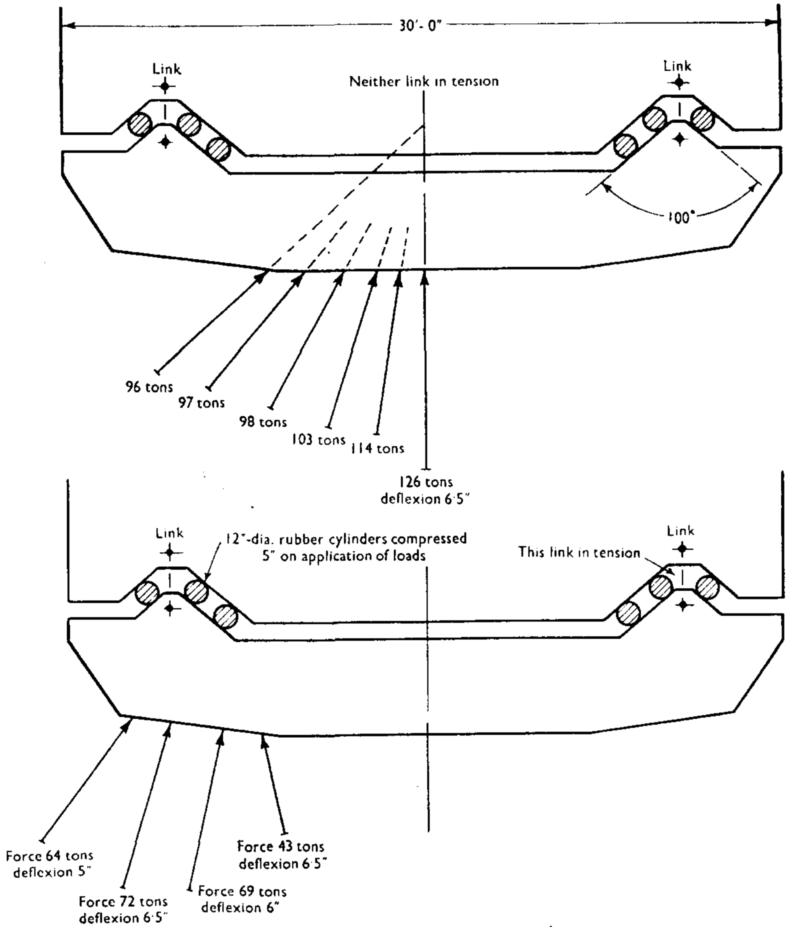
In that same tentative design, which catered for vessels of about 50,000 tons displacement, the intention had been to provide a swinging fender, with enlarged head, in each bent of the berth so that a very nearly continuous flexible-fendered face would be presented to the vessel. Each individual block was to be capable of absorbing 50 per cent of the assumed blow with (when struck at 90 degrees to the berth) an 18-inch rise and a 4-foot-6-inch travel.

Mr D. C. McCormick stated that the scheme referred to by Mr R. B. Kirwan in the oral discussion had been further developed.

The arrangement was shown diagrammatically in *Figs 38*; the two wedges protruded from the back of an " apron " of concrete which either hung in front of the jetty or stood on a group of fender piles. Two strong tension links prevented the apron moving away from the jetty under an eccentric load and brought more of the rubber cylinders into use. The Figures showed the deflexions under a selection of different forces sufficient to compress some of the rubber cylinders by 5 inches, but the ultimate capacity of the group was considered to be well beyond those figures.

Mr A. M. Robertson was particularly interested in the Author's observations on gravity fenders since he personally had refrained from using them at exposed sites; he had seen some at a Scottish loch pulsate considerably when there was extremely little wave action, indicating that they would tend to create trouble by excessive wear, and throw up water if used at exposed sites.

Figs 38



The design of simple fendering and dolphins appeared to have been retarded by the refusal of some engineers to accept the following easily proved and long-known facts :—

(*a*) The work absorbed by a member in bending was directly proportional to the length of the member, irrespective of whether it was simply supported or one of the unbraced legs of a dolphin.

(*b*) Provided the shear stress was not exceeded the work absorbed by a fender member in bending was independent of the location of the impact.

(*c*) The greater the deflexion of a fender, the more it would be relieved by its neighbours.

The Admiralty had demonstrated by numerous examples that it was practical and economical to base their designs on the above facts. Nevertheless, it was still common to see timber lead-in jetties and dolphins braced down much too far and fender piles supported at close intervals.

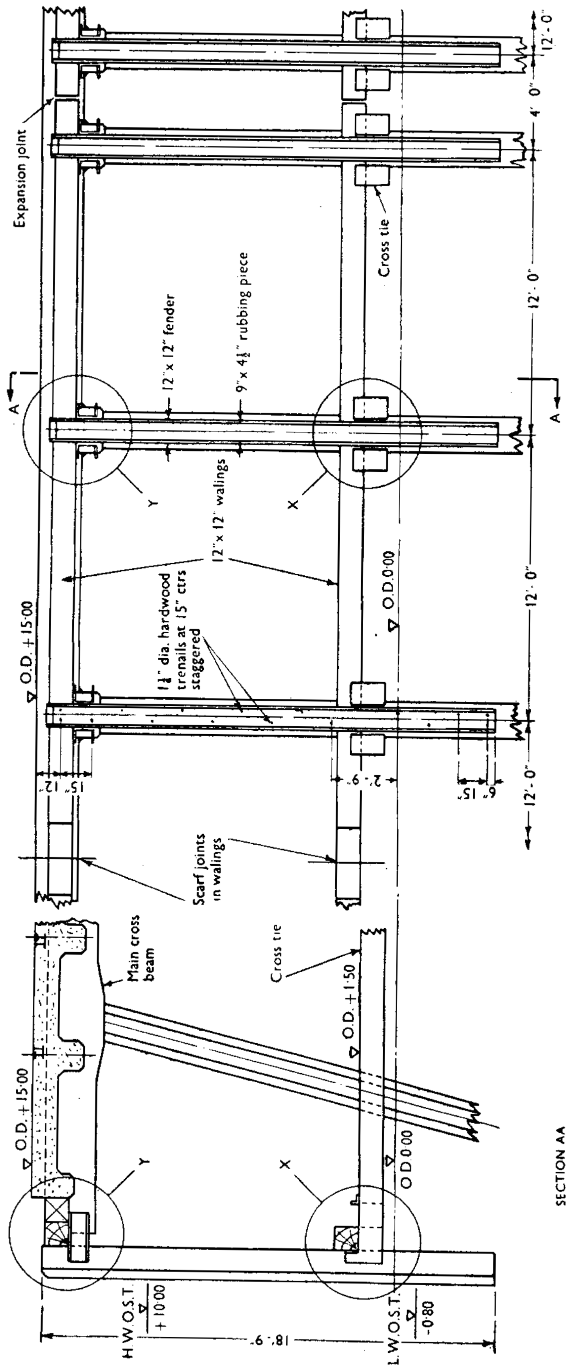
Fender design had, in Mr Robertson's view, also suffered from a lack of facts about the timber known as greenheart. That natural material was not just a little stronger than " softwood," but had more than twice the strength of Douglas fir in bending, and could absorb more than three times as much work for practically the same cost as pressure-creosoted Douglas fir. Furthermore, greenheart was not weakened by knots and faults as were many other timbers, and from observations carried out over the past 20 years, on both new and old greenheart, the latter obtained from structures more than 80 years old, it seemed to be the most consistent and fault-free of the timbers in use today. In recent bending tests on greenheart to check published figures, it had been found that three specimens having cross-sections of 2 inches by 2 inches broke at about 23,000 lb. per square inch. That was two-thirds of the yield-point stress and one-third of the breaking stress of mild steel, and twice the crushing resistance of the best factory-made concrete.

When stressed to only 11,700 lb. per square inch, single 60-foot greenheart logs, of 14-inch-by-14-inch and 16-inch-by-16-inch section, would absorb 146 and 192 inch-tons respectively, but owing to the favourable shape of the " work diagram," they would absorb approximately 730 and 960 inch-tons respectively before breaking. It was therefore very difficult to decide just how much work greenheart fendering could be relied upon to absorb, but its capacity was obviously very high and superior to any other fender available at the same cost ; consequently very great advantages and economies would result from tests on sections of greenheart fendering, backed by systematic tests on full logs as imported, to determine the effect of repeated loading in the region of the breaking load. Mr Robertson was thinking in terms of fendering for general-purpose wharfs and jetties, and believed that vertical greenheart fenders, suitably grouped by horizontal walings, and supported at deck level by long longitudinal greenheart logs arranged to spring under or over the deck, and supported at their ends with bonded-rubber units, would provide the most economical and satisfactory form of fendering. A greenheart deck " spring " was much cheaper than rubber units at each vertical.

It would be interesting to have the Author's views on the merits of vertical and battered fender piles. Battered piles would appear to be capable of rocking wall-sided vessels and making them absorb work ; they would also reduce the deck reaction, and in consequence lead to cheaper main structures.

Mr A. H. Robinson, referring to design No. 1, observed that a jetty with similar fenders had been constructed at Singapore about 1938. That jetty had fenders, illustrated in *Figs 39* (*a*), (*b*), and (*c*), which

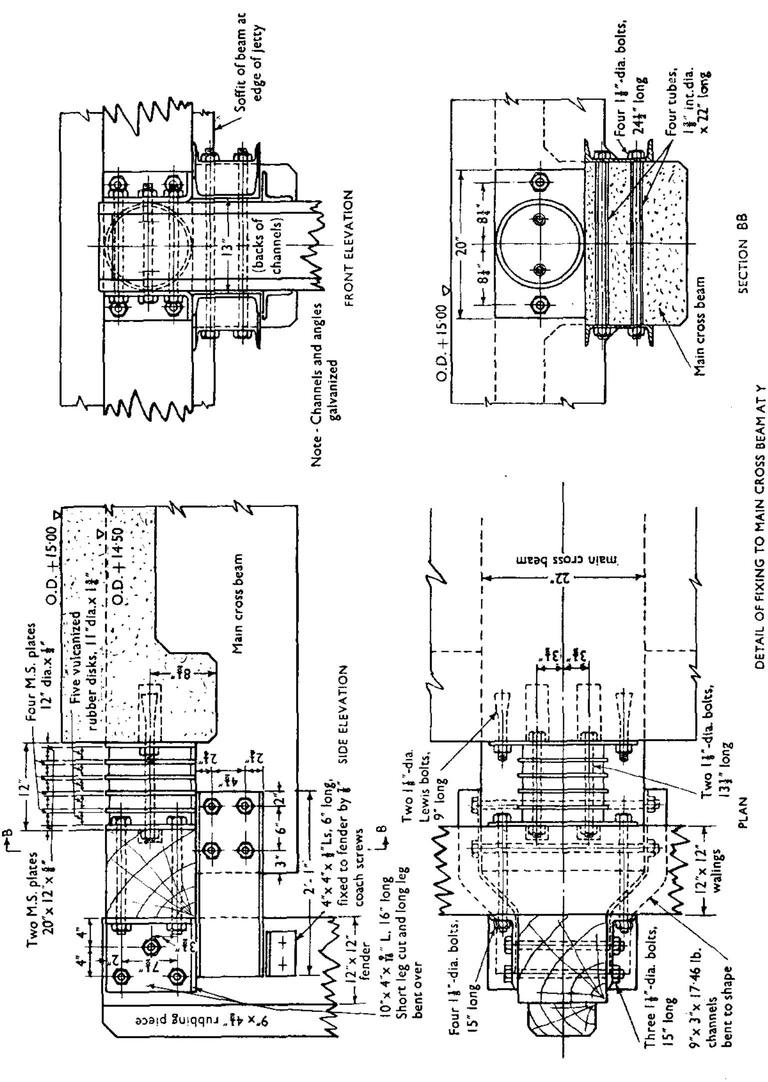
Figs 39 (*a*)



General Details of Jetty Head

cantilevered down below the low-water line and were fixed by rubber buffers at high and low level, as distinct from driven fender piles with buffers at high level only as in design No. 1. It also had 12-inch-by-12-inch horizontal walings at high and low level, which would transmit a glancing blow along the line of fenders.

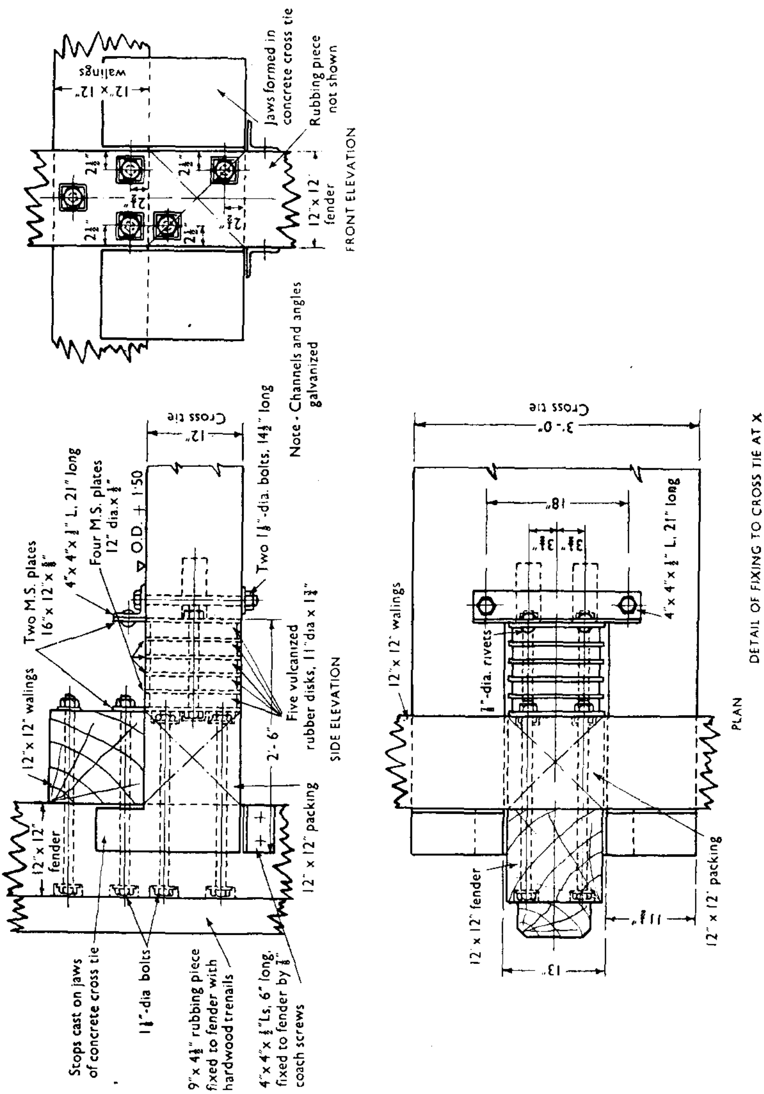
So far as could be ascertained, the buffers at present fitted were the original ones. The high-level ones were as good today as the day they



Figs 39 (b)

were fitted, even though they had been exposed to the tropical sun and rain for about 14 years, but the rubber at the low level, which was between high- and low-water marks, had hardened.

The fendering had proved itself more robust than design No. 1, mainly because of its capacity to transmit glancing blows through the heavy horizontal walings.



Figs. 39 (c)

Additional protection for the jetty was now provided by the use of catamarans which might well be provided with advantage for all jetties. It would probably help greatly if catamarans came to be regarded as an integral part of the structure and not merely as a desirable appendage as they were usually looked upon at present.

Mr H. S. Waddington remarked that many examples were given in the Paper of fendering consisting of a row of isolated piles driven into the sea or river bottom in front of a wharf or jetty and held only at cope level. Would the Author say how those isolated piles were standing up in use, particularly with regard to glancing longitudinal blows?

Design No. 19, with its timber piles unsupported for 50 feet, was delightfully simple—almost too simple to be true, especially in view of the sizeable vessels (4,000 tons) expected to use the berth. The arrangement adopted with piles at 10-foot centres was fundamentally the same as in the superseded design No. 17 at that jetty, except that the old piles were presumably at 20-foot centres. It was found that timber rubbing pieces had been torn off the earlier fendering system; was the greater longitudinal "give" in the new design preventing a recurrence of that trouble? On p. 76 of the Paper it was suggested that the effect of the impact load was often near the deck, and that was corroborated in an earlier Paper.[1] To guard against the possibility of a flared bow making direct contact with the deck of the jetty and maybe, if under way, catching the side of a fender, a horizontal fender would appear desirable at about cope level. In order to deal with glancing blows at lower levels, further horizontals could be provided.

Had the Author considered any scheme, somewhat on the lines of *Figs 40*, as a variation to design No. 19? The diameter of the rubber buffers would be less than in the Author's design because the stiffness of the timberwork would bring more buffers into play. Fendering with that type of face (verticals at about 10 feet and horizontals at 5-, 6-, or 7-foot centres) had been common practice for many years on timber quays. Although it might be thought that small craft would run the risk of being caught under the horizontals on a rising tide, experience indicated that no such difficulty was found with vessels down to the size of tugs and barges. Whether such an arrangement would be suitable for the site for which design No. 19 was prepared would depend on the type of craft and other local conditions. The scheme outlined in the sketch would be more expensive in first cost than the Author's design, but would give full protection to the jetty against ships' blows from all directions and at all points, would spread the impact load over a longer length of the jetty, and would probably not require so much or such constant maintenance attention.

Mr H. W. Stephenson, referring to the berthing velocity of $\frac{1}{2}$ foot per second recommended on p. 75 of the Paper, observed that at one wharf

[1] A. W. Rooke, "Improvements in Jetty Design, with Special Reference to Systems of Fendering." Maritime Paper No. 14, Instn Civ. Engrs, 1949.

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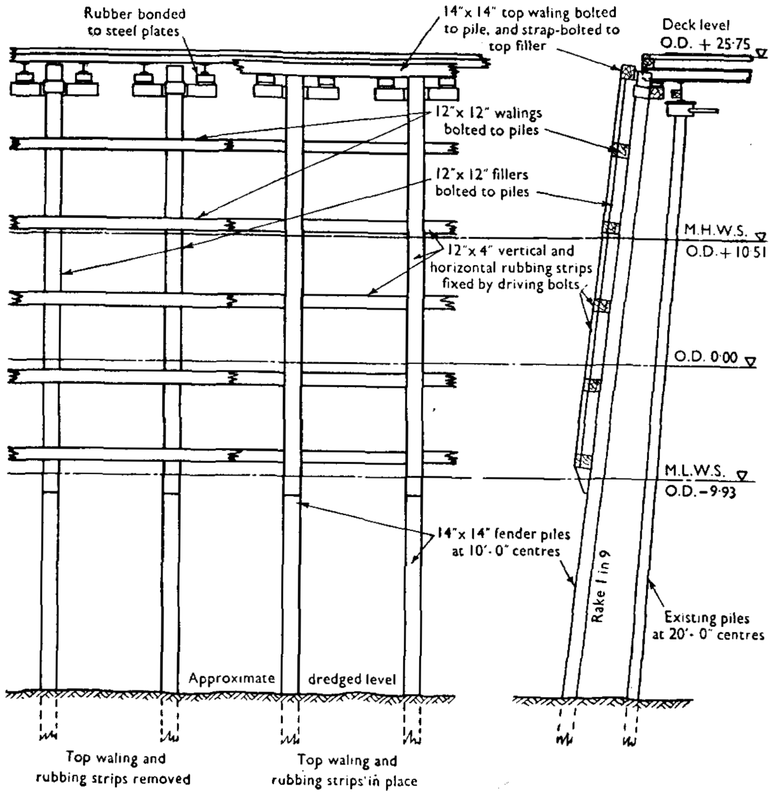
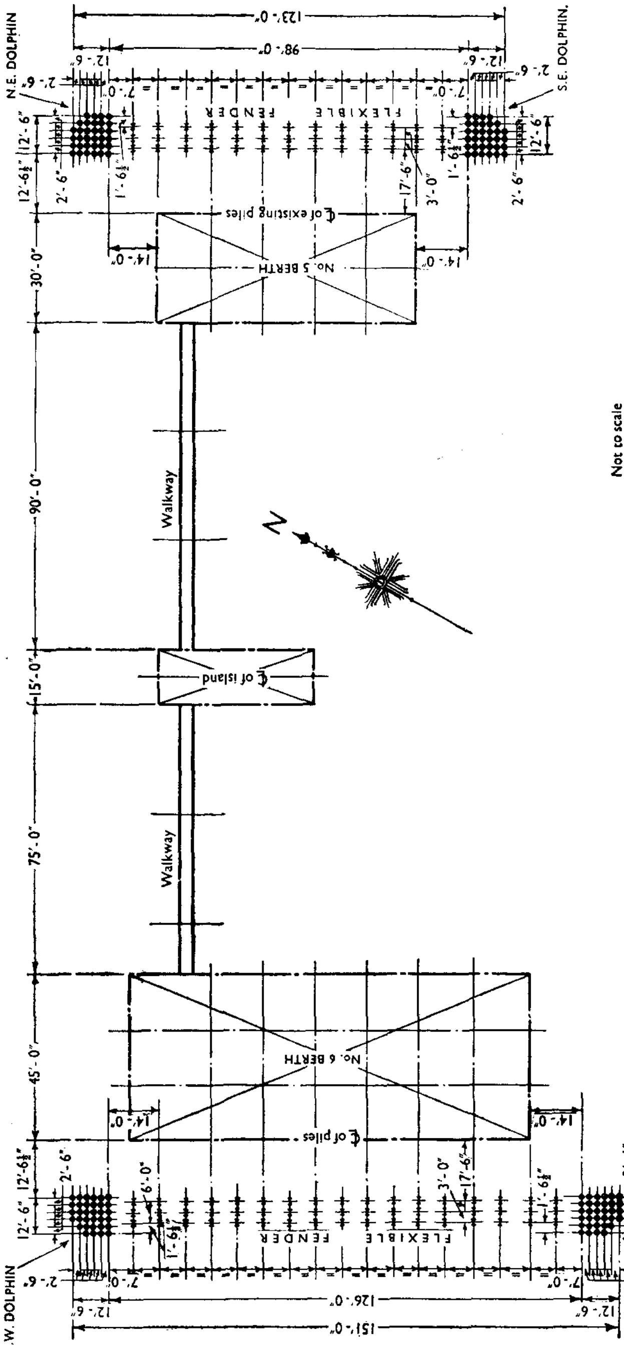
Figs 40



where flexible fenders had been installed, observed deflexions inferred berthing velocities on not infrequent occasions as high as 1¼ feet per second for ships of 10,000 tons. It seemed clear that, had the design berthing velocity been ½ foot per second, the fenders' life would have been uneconomically short. The maximum absorption of elastic energy per fender was 3,100 inch-tons, the corresponding deflexion at deck level being 4 feet 6 inches.

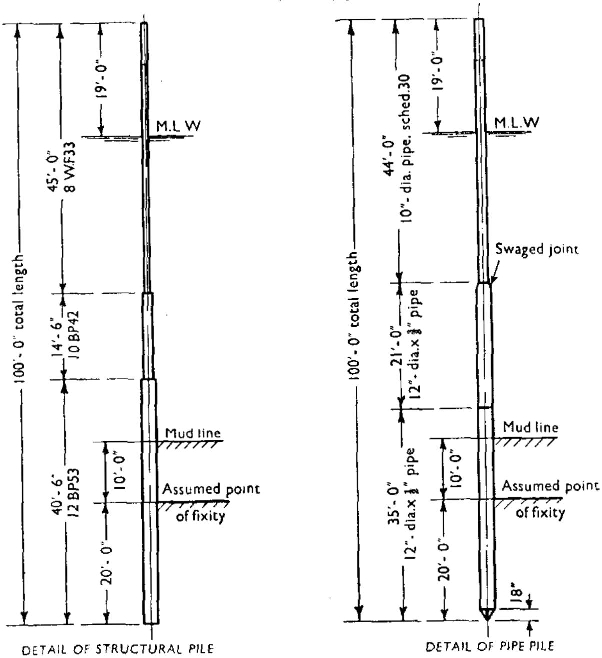
The fenders consisted of three rows of H-piles framed together to spread a point impact but unbraced in any direction, with a pipe pile cluster at each end (see *Fig. 41* (*a*)). The piles were of multi-section (*Figs 41* (*b*)) for the most efficient use of elastic energy. Yield point was reached throughout the piles at full deflexion, when the fenders touched the cantilever section of the wharf (see *Fig. 41* (*c*)). For a catastrophic impact, the cantilever section was designed to crumple as the fender was deflected past yield point,

Fig. 41 (a)



General Arrangement of Wharf and Fenders

Figs 41 (*b*)

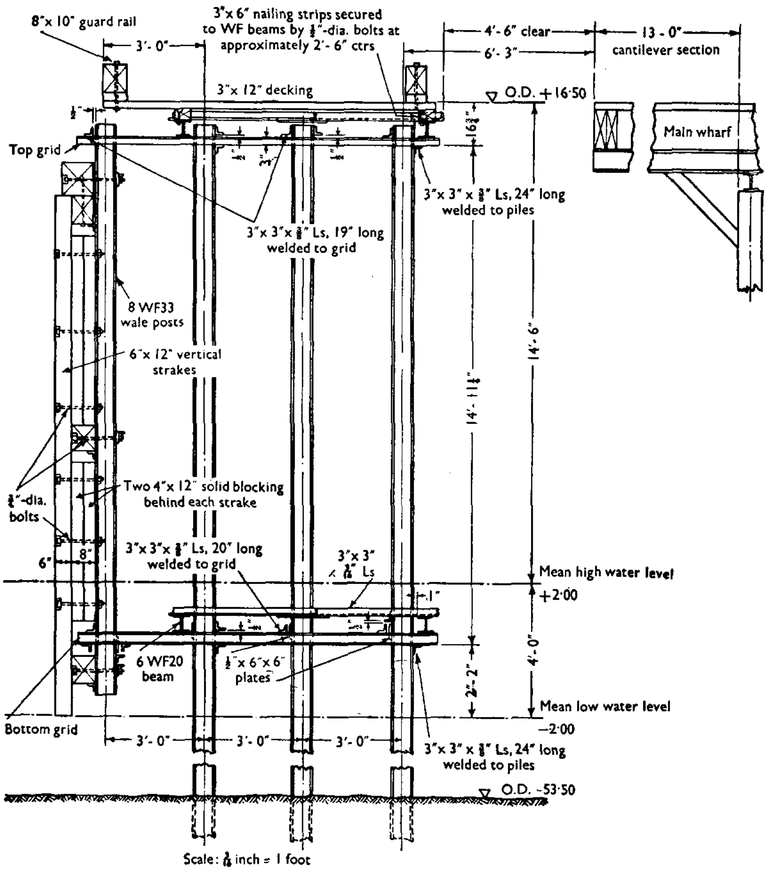


and energy continued to be absorbed non-elastically until the fender contacted the main wharf structure. The non-elastic energy would be considerably in excess of the elastic.

The cost of the two fenders was £10 per inch-ton of elastic energy, for 20 inch-tons per linear foot of wharf, or £200 per linear foot of wharf. It was not possible, owing to the weakened condition of the main wharf structure, to allow any lateral load to be transmitted to it by the fenders, however cushioned, and that factor contributed to the high cost. The fenders, however, in effect provided extra wharf space, and suggested the possibility, in suitable circumstances, of a flexible wharf.

Shortly after the completion of the wharf, a ship unberthing had struck a corner dolphin a diagonal blow. There had been no apparent set in the longitudinal direction but the connexions between dolphin and wharf had sheared, and the dolphin had sustained a permanent set, in the transverse direction, of approximately 6 feet. When the timber framing (bolted 18-inch-by-12-inch sections) of the dolphin had been removed during repairs, the piles had sprung back to within 2 feet of their original position, revealing a valuable source of energy absorption in the deformation of the timber framing. It was estimated that the energy of the impact had been 3,000 inch-tons, including non-elastic deformation.

Fig. 41 (*c*)



Typical Section of Fender

The Author, in reply, stated that heavy isolated free-swinging fenders, wider in plan, as suggested by Mr Williams, were incorporated in a jetty now under construction, and a series of smaller continuous gravity fenders were included in another jetty which it was hoped would be built soon. Designs on both those lines, however, were difficult to evaluate completely and it would be premature to discuss them until some experience of their actual behaviour in use was available.

The arrangement shown by Mr McCormick in *Figs 38* was an ingenious method of taking blows at various angles by rubber, mainly in compression all the time. But the movement of the fender unit proper at 6·5 inches was not very great and, as a consequence, although the thrust of 126 tons was quite high, the kinetic energy absorbed was hardly 400 inch-tons.

Mr Robertson's reference to greenheart was particularly important. Even greenheart could be severely attacked by Teredo in some waters, but where that was known to be impossible the Author agreed that greenheart fender piles with some flexibility provided at deck level should produce a simple, effective, and relatively cheap solution. He had not had much experience with battered fender piles except that those in design No. 17 had given no indication that they would have failed sooner had they been vertical. It was doubtful if the reduction in deck reaction with battered fender piles would be really significant, and on the whole the Author saw no positive advantage in them.

Mr Robinson's confirmation as to the life of rubber itself was valuable but, although that fendering system had lasted well, it was a design which necessitated tidal bracing—almost at low-water level—and that in itself would add considerably to initial costs.

Mr Waddington's proposal in *Figs 40* was thought to be an improvement, but general Admiralty practice was to avoid longitudinal fendering wherever possible, and in the case of design No. 19 it was also necessary to keep first costs as low as possible. That design had not yet been built and if, when it was, it showed signs of weakness some strengthening with longitudinal fendering might have to be accepted.

Mr Stephenson's example was very interesting. The Author agreed that when actual berthing velocities were known, they should be adopted in place of the arbitary figures of ½ foot per second. But in the case quoted by Mr Stephenson it seemed that head-on collisions embodying the full weight of the ship, rather than half of it, were involved. Those were very severe conditions indeed, and if it was not possible, or not economical from a shipping viewpoint, to insist upon more careful berthing of the ships, then the costly remedy of fendering at £200 per linear foot had to be accepted. It would be interesting to know if the use of greenheart instead of steel would have been practicable and cheaper. Deliberately to design for deflexions of 4 feet 6 inches was a bold attitude but, in the Author's view, a very proper one, and was well confirmed by the subsequently recorded deflexion of 6 feet in one of the dolphins. It was difficult to imagine, however, that movements of that order could ever be tolerated in a wharf structure as a whole.
