United States Patent [19]

Holley, Jr.

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[54] **TORSION-MODE BREASTING DOLPHIN**

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[52] **U.S. Cl.** **61/46,** 61/48

[51] **Int. Cl.** **E02b 3/22**

[58] **Field of Search** 61/46, 48; 114/230, 219

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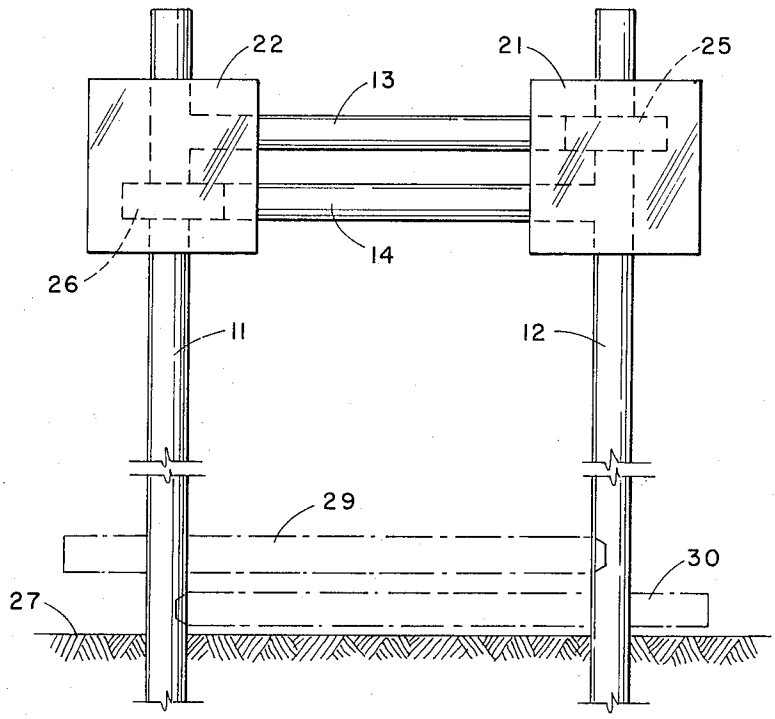
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[57] **ABSTRACT**

A breasting dolphin is provided wherein a significant portion of ship docking forces are absorbed by torsion in individual piles of the dolphin. Torque arms secured to each of the piles and extending horizontally therefrom receive the initial force of an impacting ship and apply this force to torsion loading of the piles. The outer ends of the torque arms are spaced from and extend beyond companion piles so that unusually heavy horizontal loads cause the outer ends to contact respective companion piles, exerting thereafter a bending moment on both the contacted pile and the pile to which the torque arm is attached.

16 Claims, 8 Drawing Figures



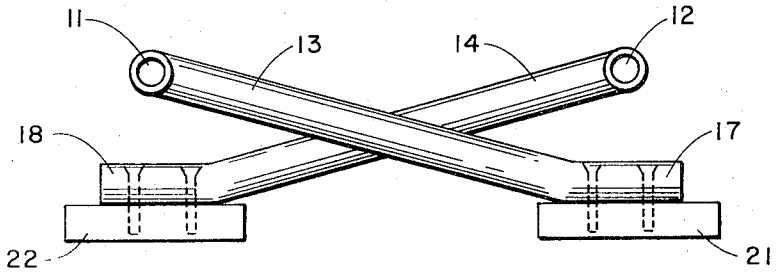


Fig. 1

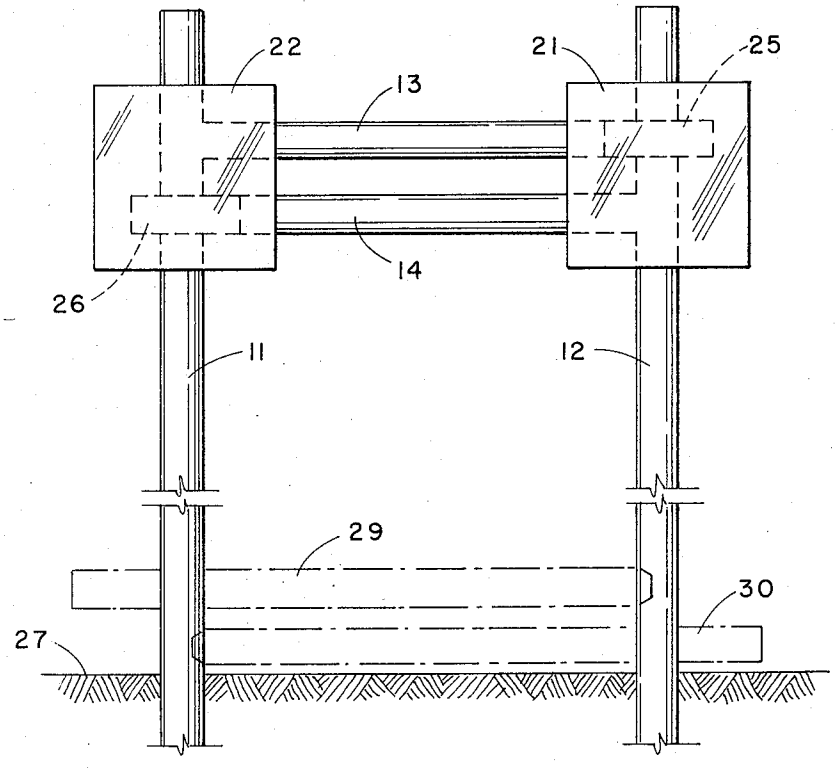


Fig. 2

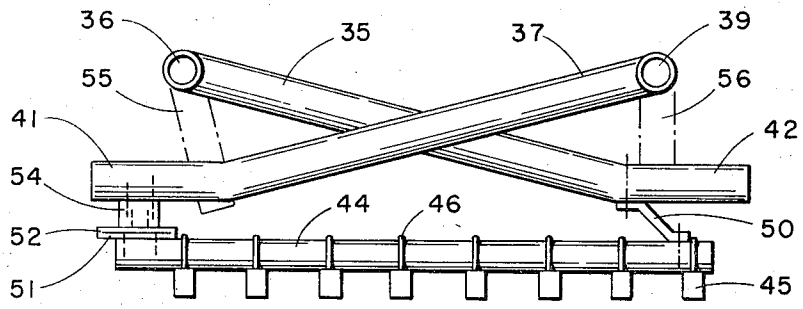


Fig. 3

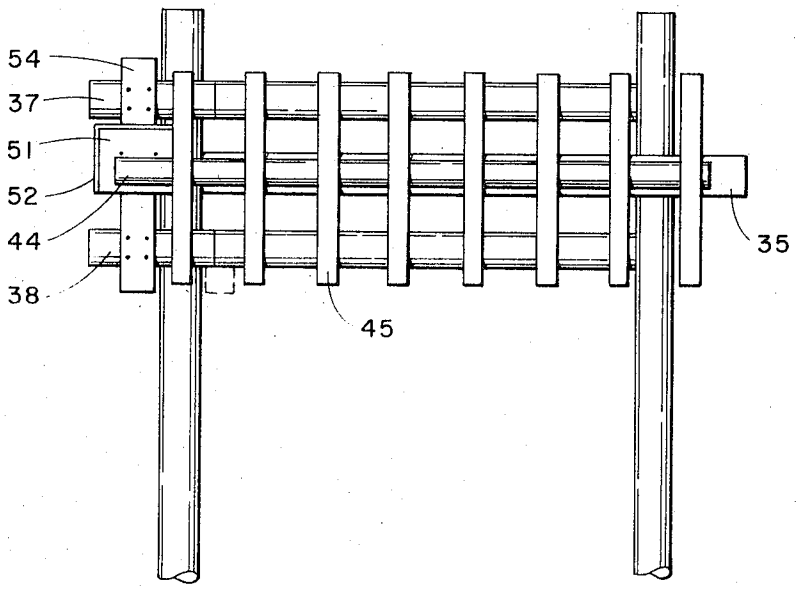


Fig. 4

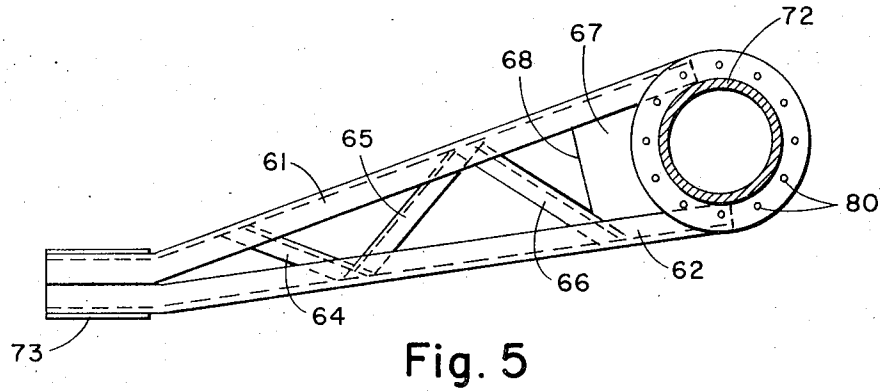


Fig. 5

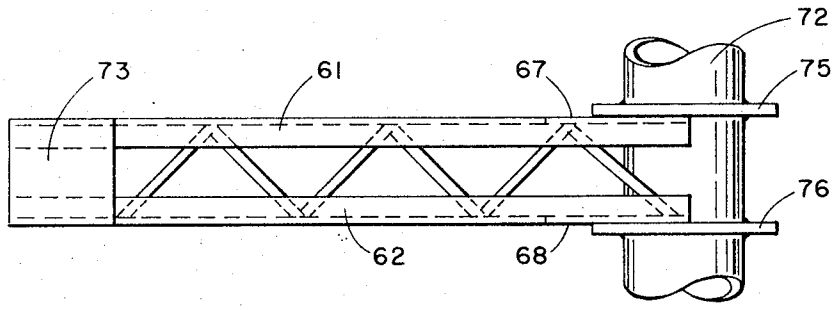


Fig. 6

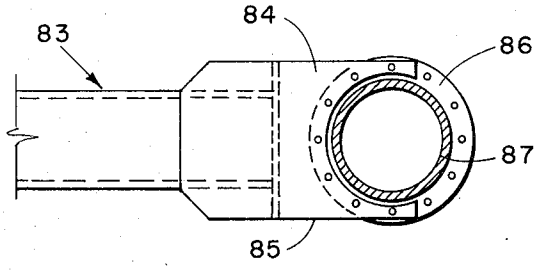


Fig. 7

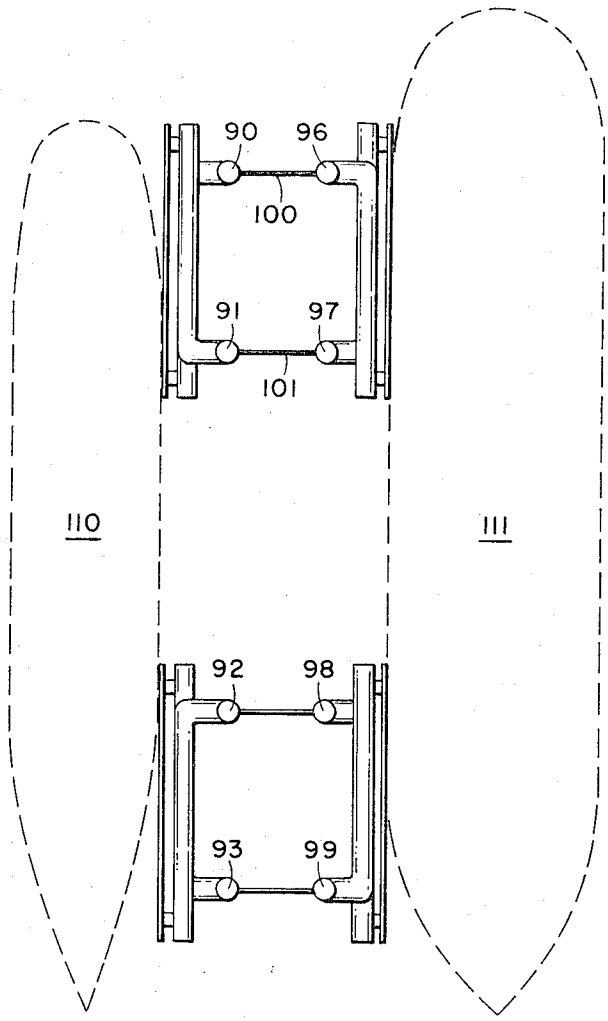


Fig. 8

TORSION-MODE BREASTING DOLPHIN

The invention described herein may be manufactured and used by or for the Government of the united States of America for governmental purposes without the payment of any royalties thereon or therefor.

The present invention relates generally to dolphin constructions and, more particularly, to a dolphin arrangement wherein a significant portion of the loading forces are absorbed by torsion in the individual piles.

It has been recognized that the torsional stiffness of the individual piles may be utilized to suppress the effect of dolphin torque loading on a cluster of piles. In such constructins, the torsional stresses in individual piles typically are relatively small, and almost all of the elastic energy which the dolphin absorbs is energy associated with pile bending stresses. Essentially, this results from the fact that the total dolphin torsion moment is proportionate to the horizontal eccentricity of the force applied by an impacting ship, whereas bending moment is proportionate to vertical distances from the force to any point in the pile beneath the water and into the sea bed. Typically, the latter reaches values very much larger than the former.

It is recognized that the elastic energy which a tubular pile, loaded at one end and supported at the other end, theoretically can absorb by torsion stress, is approximately five times greater in the pure torsion stress mode than in the bending stress mode. This reflects, in part, the fact that a pure torque, about the tube axis, applied to one end of the tube, is transmitted undiminished to the other end, that is, the resulting stresses, at their maximum permissible values, exist throughout the entire length. In constrast, when a load transverse to the tube axis is applied at one end, producing only bending stresses, the bending moment increases from zero at the loaded end of the tube to its maximum value at the opposite end, that is, the permissible bending stresses cannot be realized at all points along the tube length.

The superior energy absorption in torsion results also from the fact that, depending on the tube cross section, the torsion stresses can be nearly constant throughout a section. In a tube which has a thin-walled circular section, that is, a pipe such as is typical of steel pipe piles, the torsion stresses can be taken as essentially constant throughout the section although there is a trivially small variation in these stresses across the thickness of the pipe wall. In contrast, bending stresses across such a section vary, linearly, from maximum tension stress at one extreme point to an equal maximum compression stress at a point 180°round the perimeter therefrom.

Since elastic energy absorbed, per unit volume of the tube material, at any point in the tube is proportionate to the square of this stress intensity at that point, it will be apparent that maximization of total energy absorbed requires that all points be stressed, as nearly as possible, to permissible stress limits. Ideally, this would require that the tube be subjected to pure torsion only. Practically, in a tubular pile, the stresses are developed not by a pure torsion loading but rather by a horizontal force located at an elevation near the pile top and with some horizontal eccentricity. Thus, while the pile experiences no bending moment at the elevation of the applied force, it must experience bending moments at lower elevations. However, by requiring that the force

exerted by an impacting ship be applied to the pile through a relatively long horizontal torque arm, the magnitude of torsion stresses relative to bending stresses can be increased. When a force of given magnitude is thus applied through a horizontal torque arm, the magnitude of bending moment in the pile remains unchanged because the elevation of the applied force is unaffected by the addition of the torque arm. However, bending stresses and torsion stresses combine in such a manner that a small reduction in the magnitude of maximum bending stress results in a substantial torsion stress which can be permitted at those locations where both types of stress reach their maxima.

For an isolated dolphin which is required to accept loads at all points around its perimeter, and from a wide range of directions, there does not appear to be any practical way to mobilize the torsional energy capability of the piles. However, there are certain dolphin applications in which energy need be absorbed for only a very narrow range of directions of applied force.

It is, accordingly, a primary object of the present invention to provide a breasting dolphin wherein a substantial amount of energy is absorbed by torsion in the individual pilings.

Another object of the present invention is to provide a single-side breasting dolphin which utilizes the torsional stiffness of the individual piles to absorb elastic energy.

Another object of the present invention is to provide a tow pile dolphin arrangement wherein normal loads are absorbed by both piles primarily in a torsional mode, and wherein the stiffer bending mode dominates under overload.

Another object of the present invention is to provide a two-sided breasting dolphin which can be utilized in pairs to form a long mooring facility.

Another object of the present invention is to provide a two-pile dolphin arrangement utilizing pipe pilles where ship impact forces are transmitted by torque arms to either one or both of said piles as torque and bending moments depending upon the point of application of said forces with respect to the position of said piles.

Another object of the present invention is to provide a two-pile dolphin arrangement where normal loads are absorbed by one or both of the piles in a torsional and bending mode, and wherein, the bending mode of the pile nearer the point of application of said load is mobilized for overloads. Other objects, advantages and novel features of the invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings in which like numerals represent like parts throughout and wherein:

FIG. 1 is a plan view of a single-sided dolphin embodying the present invention;

FIG. 2 is a side elevation of the dolphin embodiment of FIG. 1;

FIG. 3 is a plan view of an alternate embodiment of a single-sided breasting dolphin structure; FIG. 4 is a side elevation of the embodiment of FIG. 3;

FIG. 5 is a plan view of a truss form of a torque arm for use in a breasting dolphin structure;

FIG. 6 is a side elevation of the torque arm of FIG. 5;

FIG. 7 is a plan view of an alternate arrangement for securing a torque arm to a pile in a dolphin structure; and

FIG. 8 is a plan view of a mooring facility utilizing a pair of two sided breasting dolphins. Briefly, and in general terms, the dolphin of the present invention in its basic form consists of a pair of pipe piles embedded in the sea floor at a mooring sight or alongside a structure requiring protection against ship impact. Mobilization of the elastic energy in the torsional mode also can be achieved by a single-pile dolphin having secured thereto a horizontal torque arm which extends essentially parallel to the structure to be protected. Further advantages of the combination are achieved, however, by combining such single piles in pairs, with the torque arm of each pile extending beyond the other pile. In one modification, at least one rigid torque arm is secured in a cantilever manner to each pile and is deployed in the direction from which energy absorption is desired. The torque arms preferably extend parallel to the surface of the water and at an acute angle with respect to the other pile in a pair of piles. The torque arms terminate in load-receiving end portions which are extended parallel to the line of the piles and beyond the pile other than the one to which are arm is secured. That is, the torque arms have lengths sufficient to span at least the distance between the outer vertical surfaces of the pair of piles.

More than one torque arm may be attached to each piling depending upon the loads which are anticipated to be applied to a dolphin structure. All the various torque arms are vertically off-set from each other so that each arm or each pair of arms can slip by the other and ultimately contact the other pile. This provision brings the contacted pile into bending action and causes it to share the pile bending associated with the applied load. Thus, the overload capacity of the dolphin is increased.

Fendering may be attached to the torque arms either singly on each arm or on a structure supported jointly by two or more arms but in such a manner as to not interfere with the rotation of the piles. Thus, when a ship impacts against the fendering the torque arms connected to both piles can rotate the respective piles under the applied load and such rotation is resisted by a torsional stiffness of the individual piles. When the load is above normal level, each torque arm is free to contact the companion arm and, thereafter, the bending strength of such piles can be utilized in assisting in absorbing the increased load.

Referring now to drawings, FIGS. 1 and 2 schematically illustrate a simplified two torque arm, one-sided breasting dolphin embodying the present invention. It willl be seen that the overall structure includes a pair of spaced pipe piles 11 and 12 embedded in the sea floor in a conventional manner as mentioned hereinbefore. These piles preferably should be positioned at the mooring sight or alongside the marine facility which is to be protected against ship impact so that the line of the piles extends parallel to the facility.

Each pile has a single torque arm 13 and 14 secured thereto in a cantilever manner and extending at an angle from its respective pile so as to terminate in a portion parallel to and spaced a selected distance from the line of the two piles. Thus, pile 11 has torque arm 13 secured to it, and pile 12 has torque arm 14 secured to it. Torque arms 13 and 14 have ends that are substantially planar as indicated at 16 and 17 to present a linear face against which a ship may abut. Fenders 21 and 22 are added to increase the area of impact of a ship, however, it will be appreciated that other fendering means may be installed within the concept of the invention.

It would be pointed out that each torque arm, no matter what its particular shape, is connected such that a horizontal force acting against its free end in a direction towards the protected structure develops torsional and bending stresses in the pile which supports it. Additionally, each torque arm is arranged such that this free end portion when sufficiently deflected by an overload, contacts the companion pile of the dolphin. The angled arms of FIGS. 1 and 2 secured to their supporting pilings on the ship approach side of the dolphin, have a short parallel length extending horizontally past their companion pile. This overlap perhaps best can be seen in FIG. 2 and is indicated by numerals 25 and 26. An equivalent construction is shown in FIG. 8 where L-shaped torque arms are secured by their short arm length to the respective supporting pilings and with their longer arms extending parallel to the respective line of piling pairs to provide a convenient base for a buffer structure which is either part of the fendering or serves as the mounting means for the fendering.

At the seabed, indicated at 27, the piles have secured to them horizontally extending countertorque arms 29 and 30 which also extend beyond the companion pile. These countertorque arms are operative under heavy loading of arms 14 and 13, respectively, to distribute the loading and reduce pile loosening, among other uses.

In some cases, it may prove desirable to use only a single arm from one pile and to mount the fendering on a single beam spanning between the far end of this torque arm and the far end of at least two torque arms extending from the other pile. Such an embodiment is shown in FIGS. 3 and 4 wherein a single arm 35 projects from a pile 36 and two torque arms 37 and 38 project from a companion pile 39. All of the arms have their end portions, indicated at 41 and 42, horizontally disposed in a common vertical plane. Arms 37 and 38 provide support points for a cross member such as a beam 44 to support fendering means such as vertical bars 45 which preferably are pivotally held against beam 44 by U-bolts 46. Beam 44 preferably is mounted on the dolphin torque arms so as to have some flexibility of movement. This is accomplished in the embodiment shown by securing one end of the beam to arm 35 by a metal bracket 50 which may flex toward and away from pile 39 and attaching the other end of the beam to a plate 51 whose bottom surface rests on and is slidable on a horizontally extending surface such as that provided by an L-shaped bracket 52. Bracket 52 is suspended from arms 37 and 38 by attachment to a vertical beam 54 which is secured to arms 37 and 38.

Where the fenders and the fender support structure may exceed the weight desired to be imposed on the supporting torque arms, supplementary vertical support thereof may be provided by transverse support members, such as indicated at 55 and 56, upon which the torque arms may slide.

The lengths of torque arms 35, 37, and 38 are such that they also extend horizontally a short distance beyond their companion pile. The single torque arm 35 and the pair of torque arms 37 and 38 together support

the fendering. Vertical bars **45** although tightly held against beam **44** may be pivoted by heavy loading applied against them. This permits the vertical fender members to conform somewhat to the surface which applies load to the dolphin structure. Flexible bracket **50** and the sliding plate combination **51–52** provide for freedom of movement in order that the structure can absorb loads without damage such as undoubtedly would be sustained if a rigid interconnection of the vertical support beam and the torque arms were utilized.

Although only three torque arms are shown in this embodiment and two in the embodiment of FIGS. **1** and **2**, it will be appreciated that under certain conditions additional torque arms may be added within the concept of the invention to present a larger fendering area where applicable. Whether two or more torque arms are employed, all of the various arms are vertically off-set from each other so that there is no interference between them when they are deflected by an applied load.

When a ship impacts against the fendering, the fendering transmits the force to, in the embodiment of FIGS. **3** and **4**, the outer end of arm **35** and vertical beam **54** which secures the outer ends of arms **37** and **38** together. The amount of force transmitted to each torque arm or combination of joint torque arms is dependent upon the relative impact force at each of the supporting points of the fendering means. For example, as the ship impacts midway along the length of horizontal beam **44**, half of the impact force is imported to each end so that the beam force transmitted to vertical beam **54** is further transmitted from that beam to torque arms **37** and **38**, and by these torque arms is transmitted into pile **39** as torque and bending moment in that pile. Torque arms **37** and **38** are displaced toward the facility protected by the dolphin structure due to twisting and bending of the pile **39** and rotate clockwise due to torsional strain in that pile. Torque arm **35** is displaced toward the protected facilities due to bending and twisting of pile **36**, rotating counterclockwise due to torsional strain in that pile.

Within the normal loading range, displacements of torque arms **37** and **38**, where they pass pile **36**, is not sufficient to bring these torque arms into contact with pile **36**. Under overload, the displacement of torque arm **37** and/or **38**, due to bending strain and torsional strain of pile **39**, and, to a much lesser extent, due to bending strain in the torque arms, may be sufficient to bring either or both of these arms into contact with pile **36**. Correspondingly, under normal loading, torque arm **35** will not come into contact with pile **39** but under overload may contact pile **39**.

Provision for contact of arm **37** and/or **38** with pile **36**, or for contact of arm **35** with pile **39**, under overload conditions, achieves a sharing of the ship impact force between the two piles. For ship impact at a point on the fendering midway between the two piles, the impact force would be shared equally by the two piles even without contact between torque arms and piles. However, for ship impact at a point on the fendering opposite pile **36**, all of the force will be resisted by pile **39** until, and unless, overload contact of arms **37** and/or **38** with pile **36** is provided. Similarly, for ship impact at a point on the fendering opposite pile **39**, all of the force will be resisted by pile **36** until, and unless, overload contact of arm **35** with pile **39** is provided. In summary, the provision for contact of torque arms and piles results in substantial assistance from the contacted pile in resisting ship impact force, under overload conditions, for the typical case of an impact at a location other than on the fendering midline.

For some seabed soil conditions, the pile torque corresponding to acceptable pile torsion stresses may exceed the torque which can be transmitted into the soil over a reasonable embedment length. If the pile torque that can be transmitted into the soil is sufficient to accommodate the normal range of dolphin loading, torsional slip of the pile relative to the soil can be permitted under occasional overload. When such slip is anticipated under overload, the connection of each torque arm to pile can be designed with a reset capability so that the torque arms can be re-adjusted to their proper no-load positions after the overload event.

This condition is illustrated in the embodiments of FIGS. **5, 6,** and **7**. FIG. **5** is a plan view of a torque arm in truss form **60** constructed of longitudinal angle iron members **61** and **62** and diagonal cross members **64, 65,** and **66**. The longitudinal members are secured at the pile end to plates **67** and **68** which conform along curved surface **69** to the outer dimensions of a supporting pile **72**. Longitudinal members **61** and **62** are joined at the end remote from the pile to form a load receiving surface **73** which in the initial unloaded condition at installation is parallel to the dock or combination of dolphins. As shown in FIG. **6**, which is a front elevation of the truss of FIG. **5**, pile **72** has a pair of flanges **75** and **76** secured to it preferably by welding and spaced apart to receive plates **67** and **68** of the pile end of the truss. Both plates **67** and **68** and flanges **75** and **76** are provided with a plurality of equally spaced holes **80** into which bolts, not shown, are inserted after the truss has been mounted between the flanges. The foregoing embodiment provides a reset capability so that when pile **72** has been rotated in the seabed and fails to return to its initial condition, the bolts joining the truss and the flanges may be withdrawn and the truss reset to position surface **73** in the desired plane. FIG. **7** is a plan view of a portion of an alternate truss torque embodiment wherein a box section **83** forms the torque arm and is joined to a pair of plates **84** and **85**. A flange **86** and its companion, not shown, are attached in such a position that flanges **84** and **85** will conform to and rest along the upper and lower surfaces of the flanges.

In the embodiment of FIG. **5–7**, fendering may be attached to the remote ends of the torque arms only as in the embodiments of FIGS. **1** and **2**. Also, the truss form of torque arms may be used on a single pile where conditions of surface loading and bottom restraint on the pile are appropriate.

FIG. **8** illustrates an application of the torsion-mode dolphin of the present invention in a long mooring facility which provides for ship mooring along both sides. Here two parallel rows of piles are located in spaced pairs such as **90** and **91, 92** and **93** in a first row and **96** and **97, 98** and **99** in a second row. Each pair of piles is part of a single-sided breasting dolphin of the type shown in FIGS. **3** and **4** but employing L-shaped torque arms instead of angled arms. There also are differences between the arrangements of FIGS. **1** and **8**, namely, the distance between any pile and its counterpart pile on the adjacent line is less than the distance to its associated pile on the same line. Thus, the distance between pilles **90** and **96**, for example, is less than the distance

between pile **90** and **91**. Because of this, the counter-torque arm at the seabed, if needed, terminates on the counterpart pile of the other line, that is, the counter-torque arm secured to pile **90** terminates at pile **96** rather than pile **91**. Also, and of greater importance, both one-sided dolphins of each two-sided structure are cross-connected with bridging struts. Thus, pile **90** is interconnected to pile **96** by strut **100**, pile **91** to **97** by strut **101** and so forth. These cross-connections permit an increase in the breasting force capacity of each line. The bridging struts preferably are not rigid in compression but have some flexibility so that when a ship **110** is already berthed the impact of berthing a ship **111** will not be directly carried to ship **110** by the struts. Struts formed of flat metal stock which are installed at an acute angle to the horizontal are desirable.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings.

What is claimed is:

1. A breasting dolphin comprising:

a pair of pipe piles embedded in the bottom a chosen distance apart;

means secured to and extending away from individual ones of said piles toward the other of said piles for transmitting to said piles impact forces of a docking ship; and

fender means supported from the free ends of said means secured to said piles so that loading forces in a first mode of operation resulting from a ship impacting said fender means are transferred to and develop stresses by torsion and bending in either one or both of said piles depending upon the point of application of these loading forces with respect to said piles.

2. A dolphin comprising:

a pair of pipe piles embedded in the sea floor a chosen distance apart;

means secured to and extending away from individual ones of said piles beyond the other of said piles for transmitting to said piles impact forces of a docking ship; and

fendering supported from said means secured to said piles so that loading forces against said fendering produced during routine docking of a ship develop stresses by torsion and bending in both piles when the point of impact is between said piles and in one of the piles when the point of impact is in front of one pile or beyond the piles pair.

3. An arrangement as defined in claim **2** in which said stresses are developed by torsion and bending in that pile of the pair which is more distant from the point of impact.

4. An arrangement as defined in claim **3** wherein whenever said loading forces exceed a selected maximum, the excess loading force additionally develops stresses by bending only in one or the other pile of said pair.

5. A breasting dolphin comprising,

a pair of pipe piles embedded in the sea floor a chosen distance apart;

one or more rigid torque arms secured to each pile in a cantilever manner and deployed to intercept broadside an impacting ship; and

fender means supported from the free ends of said torque arms.

6. An arrangement as defined in claim **5** wherein the free ends of said torque arms are disposed a selected distance from the pile other than the one to which the torque arm is secured,

said selected distance being that which the end of a torque arm may be displaced to impose the maximum permissible torsion stress on its supporting pile.

7. A breasting dolphin comprising:

a pair of pipe piles embedded in the sea floor a chosen distance apart;

one or more rigid torque arms secured to each pile in a cantilever manner and deployed to intercept broadside an impacting ship;

fender means supported from the free ends of said torque arms;

means connecting the free ends of oppositely extending torque arms,

said connecting means adapted to accomodate relative movement between torque arms supported by opposing piles due to displacement of said torque arms,

the free ends of said torque arms disposed a selected distance from the pile other than the one to which the torque arm is secured,

said selected distance being that which the end of a torque arm may be displaced to impose the maximum permissible torsion stresses on its supporting piles,

said fender means mounted on said connecting means.

8. An arrangement as defined in claim **7** wherein said fender means are pivotally mounted on said connecting means so that said fender means may generally conform to the contour of an impacting ship or object.

9. An arrangement as defined in claim **8** wherein at least two torque arms are secured to one of said piles and one torque arm is secured to the other;

a vertically oriented support member connecting the free ends of said two torque arms,

said one torque arm disposed intermediate said two torque arms;

flexible means connecting said fender support means to the free end of said one torque arm; and

means accommodating relative movement connecting said fender support means to said vertically oriented support member.

10. A breasting dolphin comprising, in combination,

a pair of pipe piles embedded in the sea floor a chosen distance apart;

one or more rigid torque arms secured to each pile in a cantilever manner;

fender means; and

means for supporting said fender means from the free ends of said torque arms such that a ship impact force directed against said fender means is transmitted by certain of said torque arms to either one or both of said piles to develop stresses therein by torsion and bending depending upon the point of application of said ship impact force with respect to the location of said piles.

11. An arrangement as defined in claim **10** wherein each torque arm spans the distance between said piles.

12. An arrangement as defined in claim 10 wherein each torque arm extends in front of the pile to which it is not secured.

13. An arrangement as defined in claim 10 wherein each torque arm is horizontally disposed.

14. An arrangement as defined in claim 10 wherein torque arms secured to different piles extend in opposite directions.

15. An arrangement as defined in claim 10 wherein all torque arms are positioned at different heights from the sea surface,

whereby angular displacement of said arms in response to impact forces may take place without interference.

16. The method of protecting structures from impact forces comprising:

absorbing a first level of impact forces in torsion in a pair of elongate parallel members which are flexible in both bending and torsion and are secured to a foundation; and

absorbing impact forces above said first level in bending of said members,

said first level forces received in transverse extensions of said members which extend beyond and are spaced from the nonsupporting member,

absorbing forces above said first level in bending of said elongate members upon the transverse extensions of one member contacting the other member.

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