CHAPTER 74

HI-DRO CUSHION CAMEL-a new floating fender concept

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ABSTRACT

A new floating fender devise designed to absorb berthing energies of ships against piers or harbor structures is described The principles governing the design and operation of the Hi-Dro Cushion Camel are reviewed The materials used in construction and the results of testing on the prototype are also explained and illustrated. Cost data and other information are given to permit evaluation and economic comparison with other systems. The Hi-Dro Cushion Camel consists of rectangularly arranged thin-walled plastic cylinders grouped in clusters in a sandwich between two structural diaphragms The cylinders are submerged in water and are completely enclosed except for an air vent hole and pressure regulating orifice The orifice controls the pressure build up and water release as the tube walls are pushed together at varying velocities. The ability of the device to adapt to variations in vessel displacement, pier flexibility and berthing velocities, is also discussed

HISTORY OF DEVELOPMENT

In November and December, 1967, a new floating fender system called a Hi-Dro Cushion Camel was constructed and tested at Treasure Island U.S Naval Station in San Francisco Bay. Encouragement for development of this new device came from officers at Treasure Island after witnessing the effectiveness of the Hi-Dro Cushion cells (see Figure No 1) attached in a single row on 12-inch centers to a small-boat marina pier. The cells effectively cushioned a five-ton liberty boat being berthed at speeds which normally are unsafe, without causing damage to the boat or pier Previous to the Treasure Island Boat Marina demonstration, reviews and studies of literature on berthing and mooring forces of ships (3,4,5) available to the writers and coupled with experience obtained in highway safety experiments on this new system (1,2) confirmed that a heavy marine application of the Hi-Dro Cushion cell system was feasible both structurally and economically Adding to this the interest of U.S Naval officers, a prototype was developed which is shown in Photo No 1. The prototype diaphragms were constructed from available timber pilings bolted together at the centerline position of the clusters. To these bolts, 3/8-inch diameter wire cables were strung in a diagonal lacing pattern to resist the longitudinal stresses that would be transmitted from

the ship to the pier. The Hi-Dro Cushion Camel prototype contained eighty-four (84) 36-inch long cells grouped in four clusters. No provisions were made in this camel to overcome the bouyancy so as to completely submerge the cell cluster chambers; however, allowances were made in the orifice design for air voids in the cells. Ideally for most efficient use of the cells, they should be completely submerged without air voids. The prototype was designed to absorb the energy of a 100 ton vessel berthing at a velocity of 6 feet per second or a 1,000 ton vessel berthing at 2 feet per second. Tests on the Hi-Dro Cushion Camel revealed that this objective was reached.

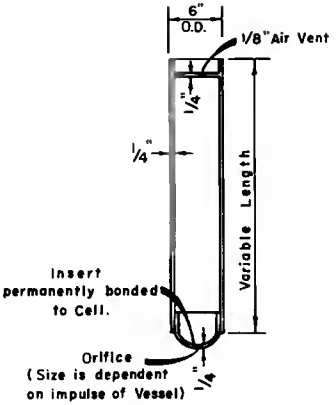


Figure 1 - HI-DRO CUSHION CELL DETAIL

THE WATER-FILLED PLASTIC CELL

The use of a plastic cell filled with water and containing orifices to absorb energy was originally developed under patent by John W. Rich of Sacramento, California for use on automobiles. The automobile water bumper is essentially a horizontally mounted Hi-Dro Cushion cell mounted at front and rear of a car to provide energy absorbing protection. The effectiveness of this system to reduce damage and injuries in automobile collisions is presently becoming more clearly established.

The plastic material makes an ideal container in that it can be molded or extruded in various shapes and sizes. The six-inch diameter cylinder was found to be well suited for use in clusters formed to protect rigid highway hazards such as lighting poles, bridge piers and abutments. The wall thickness and

Photo No. 1.-Hi-Dro Cushion Camel Prototype.

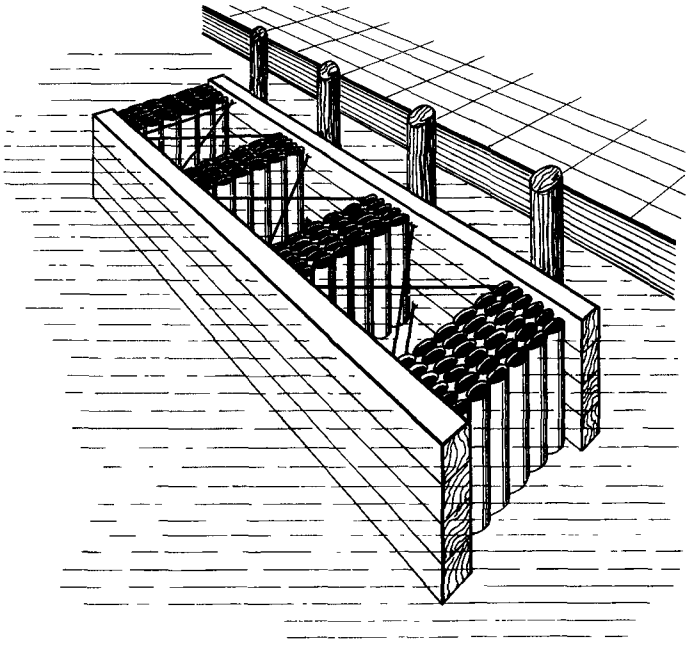


Figure No. 2.- The Hi-Dro Cushion Floating Fender system.

diameter can be varied to suit the stress capability of the plastic material for a specified dynamic pressure The plastic material used in the prototype camel is made from high quality vinyl resins of a high-molecular weight homopolymer combined with totally primary plasticizing systems This plastic possesses the ability to remain plastic at low temperatures and resist distortion at high temperatures The plastic contains stabilizers that inhibit ultra-violet hardening and permit long life under exposed atmospheric conditions. The plastic resists barnacle attachment and attack of marine organisms.

The vinyl plastic has demonstrated its capability to withstand numerous impacts without suffering damage. If failure does occur, however, additional energy is absorbed and the plastic cell is inexpensive to replace. The six-inch diameter cells tested and designed for highway applications are capable of sustaining short-duration (300 millisecond) pressure peaks over 200 psi. In marine uses, however, the impulse periods are longer (4 to 10 seconds). Because the plastic is quite strain-rate sensitive, the ultimate strength of the plastic reduces with increasing load time. This requires the exercise of judgement in assigning allowable design pressures in marine applications

The testing on the prototype demonstrated the distinct capability of the plastic cell clusters to restore to their original shape The reforming force of the cells refilled the clusters within a five to seven second time period after the collapsing load was released

THEORETICAL CONSIDERATIONS

Figure No. 2 is a drawing of a Hi-Dro Cushion Camel that incorporates one major improvement over the prototype. The diaphragms provide a flat surface to bear against the cell clusters. This inhibits the buildup of uneven pressures in the cell ranks and makes the stresses more uniform. Because the cells are constructed with a given size orifice, the pressure impulse of the clusters will vary with the berthing velocity of the ship. The impulse equals the product of internal cell pressure times the area of the cell clusters in contact with the diaphragm times the change in time or.

$$\text{Impulse} = T/g \int_{V_1}^{V_2} dV = \int_{t_1}^{t_2} pA\, dt$$

Where T is the displacement weight of the vessel, dV is the change in velocity of the vessel, g is the gravitational constant, p is the pressure, A is the area of contact between the cells and diaphragm and dt is the change of time. The kinetic energy formulas can also be used to make analysis for a given set of conditions. Further simplifications are possible by assuming constant accelerations and applying an impact or dynamic factor to account for the force-time variations in the equation. The dynamic factors can be verified through experimentation.

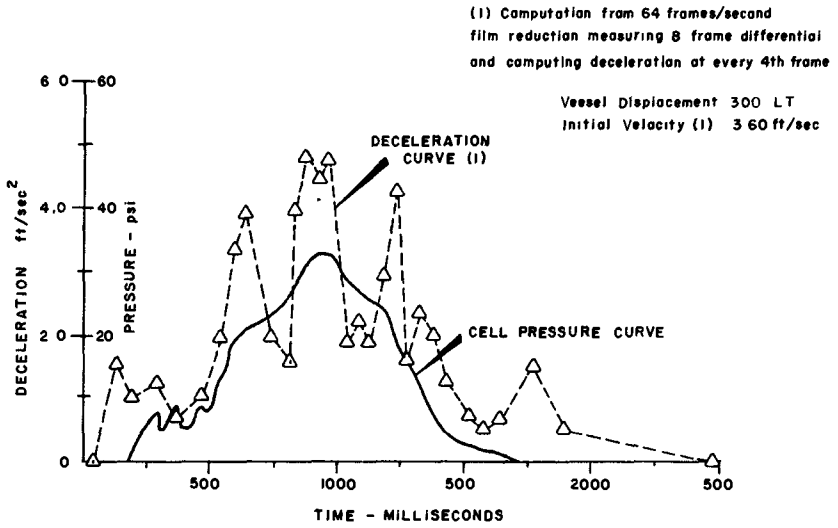


Figure No. 3.- Test No. 9-Hi-Dro Cushion Camel
April 19, 1968- Treasure Island.

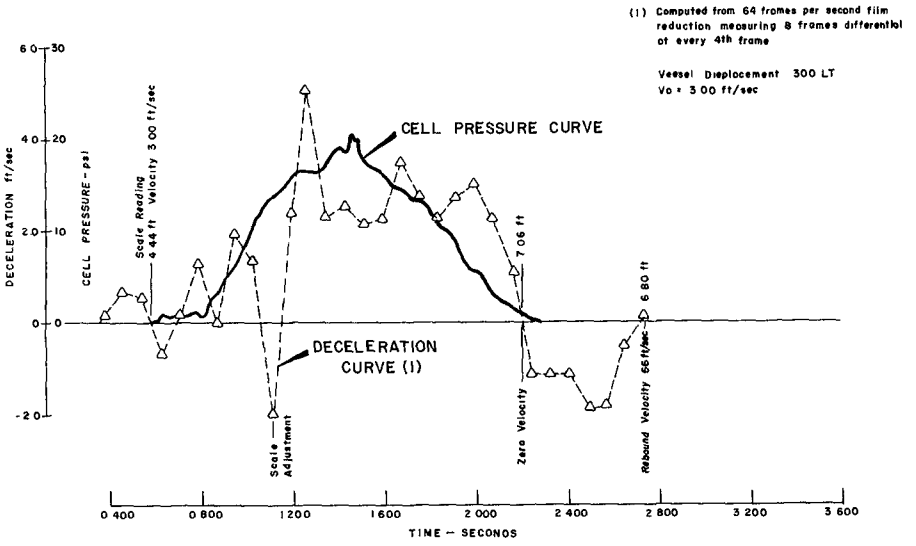


Figure No. 4.- Test No. 8- Hi-Dro Cushion Camel.

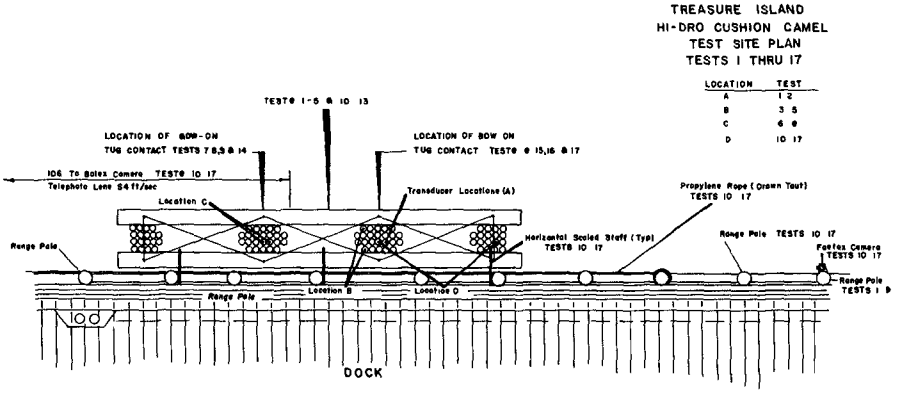


Figure No. 5.- Test Site plan.

HI-DRO CUSHION CAMEL TESTS

Figure No. 5 illustrates the layout of the pier section at Treasure Island Station where two series of tests were conducted on the Hi-Dro Cushion Camel. Photo No. 1 shows pier construction which is identical to the test site.

Tests 1 thru 9 were run on April 19 1968 using a 300 long-ton vessel impacting bow-on into the camel. Velocities into the camel varied between 1.5 and 3.6 feet per second. Acceleration data were measured and computed from 16 m.m. film shot with a Bolex Camera operating at 64 frames per second. Pressure measurements in the cell clusters were recorded on Polaroid film using a C-30 camera mounted to the face of a Tektronic Oscilloscope (2 channels) Type 422 manufactured by Tektronic, Inc. of Portland, Oregon. The pressure transducers were Teleflight Series 185 manufactured by Taber Instrument Corp. of North Tonawanda, New York. The transducers were located in the same cluster and in adjacent cells (See Figure No. 5). Although the cell clusters contained two sizes orifices, nearly identical pressures were recorded in the cells. The orifice sizes were distributed in a checkerboard pattern.

Tests 10 thru 17 conducted on May 13, 1968 used a 400 long-ton displacement vessel. Velocities at impact varied between 1.6 and 3.2 feet per second. Acceleration and pressure measurements were recorded similar to the previous series. Additional Fastax film data was recorded on several hits to measure the fender pile deflections. Transducers were installed in separate units to determine the magnitude of dampening from cluster to cluster due to flexing of the diaphragms.

The fender pilings were 12-inch nominal diameter and extended 30 feet from the deck to the mudline. The water depth was about 18 feet for the first series of tests and about 22 feet for the second series.

In both series of tests the bows of each vessel had smooth receding curvatures that would cause the camel to sink under the bow except at the slower velocities. The override occurred, however, only after the camel had taken most of the energy out of the impact. The tug operator during test 1 thru 6 had difficulties in controlling the ship due to wind conditions. The quartering winds tended to cause the tug at times to hit off-center from the intended target. Tests 7 thru 9 were made on target (See figure No. 5 which shows the locations that the vessel bow initiated contact with the camel). In the second series, the tug was under good control; however, separation of transducer connections at the cells, caused some failures in pressure readings.

TEST RESULTS

Figure No. 3 shows the graphic results of Test No 9. The tug impacted the Camel at an initial velocity of 3 60 feet per second. The computed deceleration curve exhibited some noise or oscillations which are also characteristic to film reduced decelaration data obtained by Warner in Brigham Young University experiments (2). Warner suggests that the noise can be filtered by applying a regression analysis. The deceleration curve plotted in Figure No. 7 (a) did recognize that a computed negative peak did occur even though the magnitude was insignificant. No attempt was made to make special curve fits for the computed deceleration curves. It was interesting to observe that the area under the Deceleration-Time curve of 3.63 fps compared closely to the initial velocity of the tug measured from the film data. In analyzing the curves shown in this paper, please note that the pressure and deceleration curves are shown together for convenience. The time correlation of the two

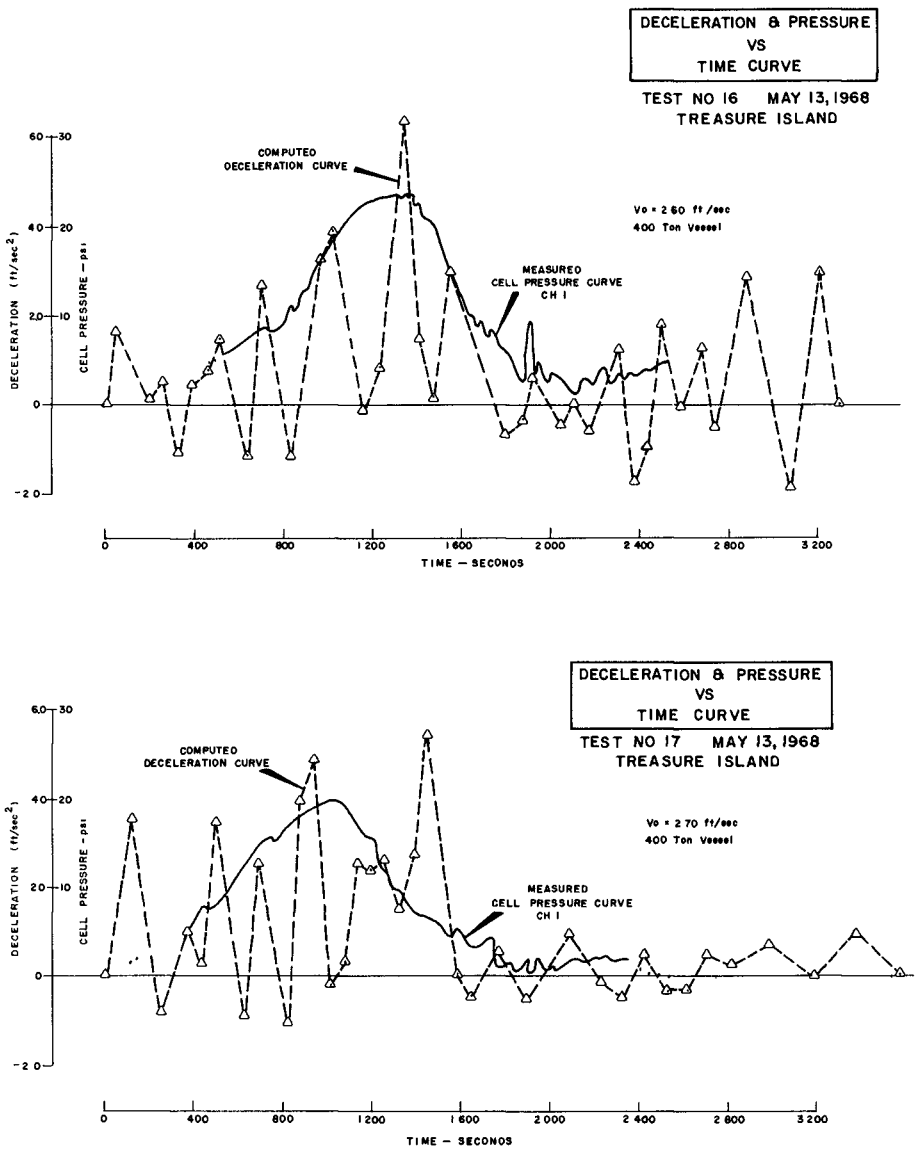


Figure No. 6 - Tests No 16 and 17- Hi-Dro Cushion Camel

curves is not exact, however, it does permit a comparison of the shapes and lengths of the curves.

Figure No. 4 shows a similar set of curves for Test No 8. At a time 1.100 seconds in the event an extreme negative deceleration is shown followed by an almost equally excessive positive peak which indicate how parallax adjustments of the operator in measuring the film data affected the curve It is noted that the pressure wave on the oscilloscope ends near the point of maximum penetration of the tug against the pier Beyond this point in time the tug accelerated away from the pier. The acceleration was caused by stored energy in the pier, and the vessel reached a maximum rebound velocity of 0.66 feet per second. The percentage of stored energy is equal to 100 times the squared ratio of rebound velocity to initial velocity. For Test No. 8, the percentage of rebound was about 5 percent of the total energy. This ratio, however, ignores the influences of hydrodynamic mass. It is characteristic that a slight mass-inertia effect takes place in the early stages of the pressure readings as the camel is suddenly accelerated by the vessel and brought to bear against the pier. The magnitude of the force is small because of the large mass of the tug compared to the mass of the camel However, in other tests where the mass of the cushion system equals the weight of the moving mass, the mass-inertia considerations influence in a large measure, the magnitude of the forces that stop the vehicle. In the marine application, the pressure-resistance effects of the Hi-Dro Cushion Cells are primary.

The deceleration and pressure time curves in Figure No. 6 (Tests No 16 and 17) are similar to those obtained in Tests No 8 and 9. There was, however, a delay in the oscilloscope trace after triggering, before pressure readings showed itself on the scope. This resulted in a loss of measurements of the mass-inertia wave mentioned previously. In these tests, only channel 1 was recorded due to failure in the transducer connection to Channel 2. The curves do correlate in location in time of the recorded peaks. The oscillations of the deceleration curves after pressure effects are over can be explained largely by the sinking of the camel as the bow of the tug rides over the camel and penetrates closer to the pier face. This condition will not exist when most ships are being berthed along a pier. Most ships have sides nearly vertical at the waterline where the loads are taken. The loads will normally be uniformly distributed in a horizontal direction and without a significant vertical component.

Comparisons can be obtained in Figure No 7 in the plot of deceleration and pressure vs time or distance. The oscilloscope pressure readings and acceleration measurements were assumed to correlate on the time base curve and this correlation was platted on the distance base recorded on the film data. The areas under the time based curves are a measure of the change in momentum while the areas under the distance-based curves are a measure of the energy. It can be noted that most of the energy is absorbed before the pressure in the cells is zero. The area under the deceleration-distance curve between 0.25 and 3.50 feet is 6.12 ft.^{2} per sec.^{2} which is 95 percent of the theoretical area. This area can be computed from the measured velocity of impact, i e. $A = \frac{1}{2} V^2$ or $\frac{1}{2} (3.6)^2 = 6.50$ ft.^{2} per sec.^{2} The assumption that the remaining energy would be absorbed in the pier agrees with the comparison made above in Test No. 8.

Test No. 15 shown on Figure No. 8 provided some very interesting data about the flexibility of the round timber diaphragms. This was the only test in this series in which both pressure readings were recorded without a connection failure. Figure No. 5 shows the location of the "bow-on" impact relative to the location of the transducers. The bow of the tug struck the camel at the unit where the Channel 2 transducer was placed and the pressure in this transducer

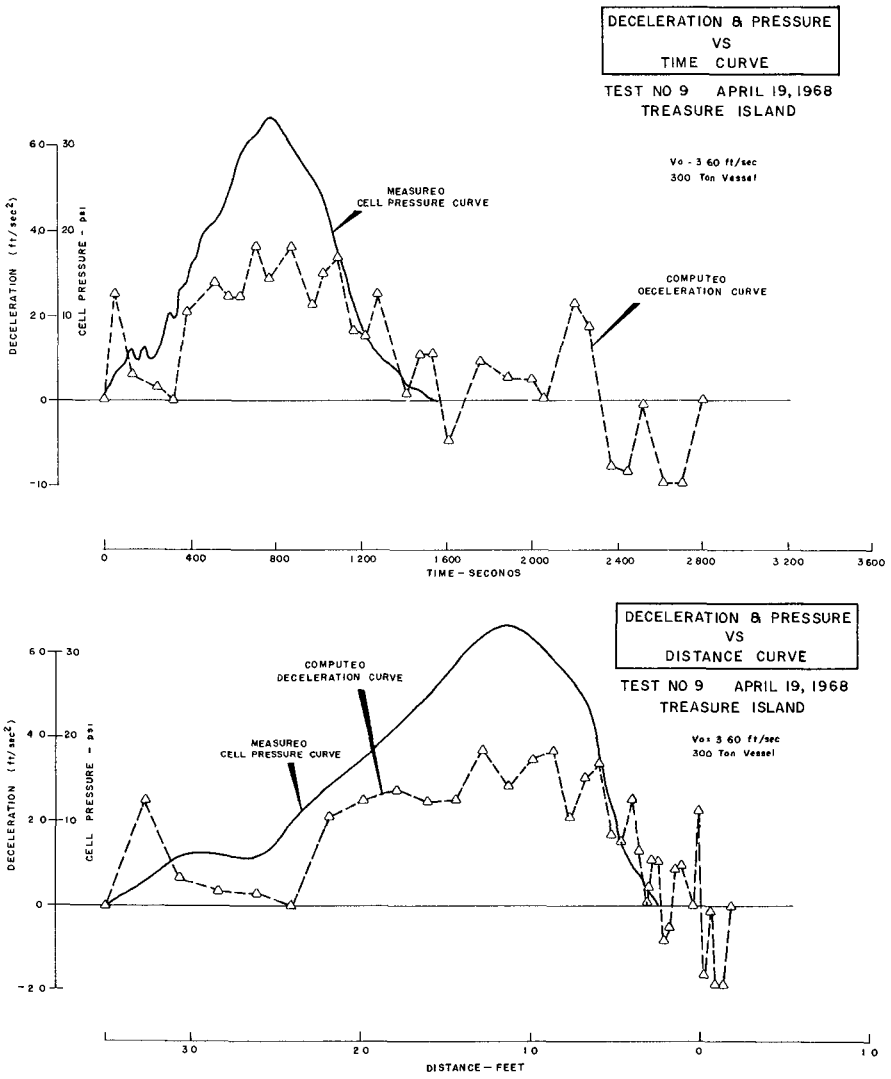


Figure No 7 - A comparison of time and distance curves for Test No 9- Hi-Dro Cushion Camel.

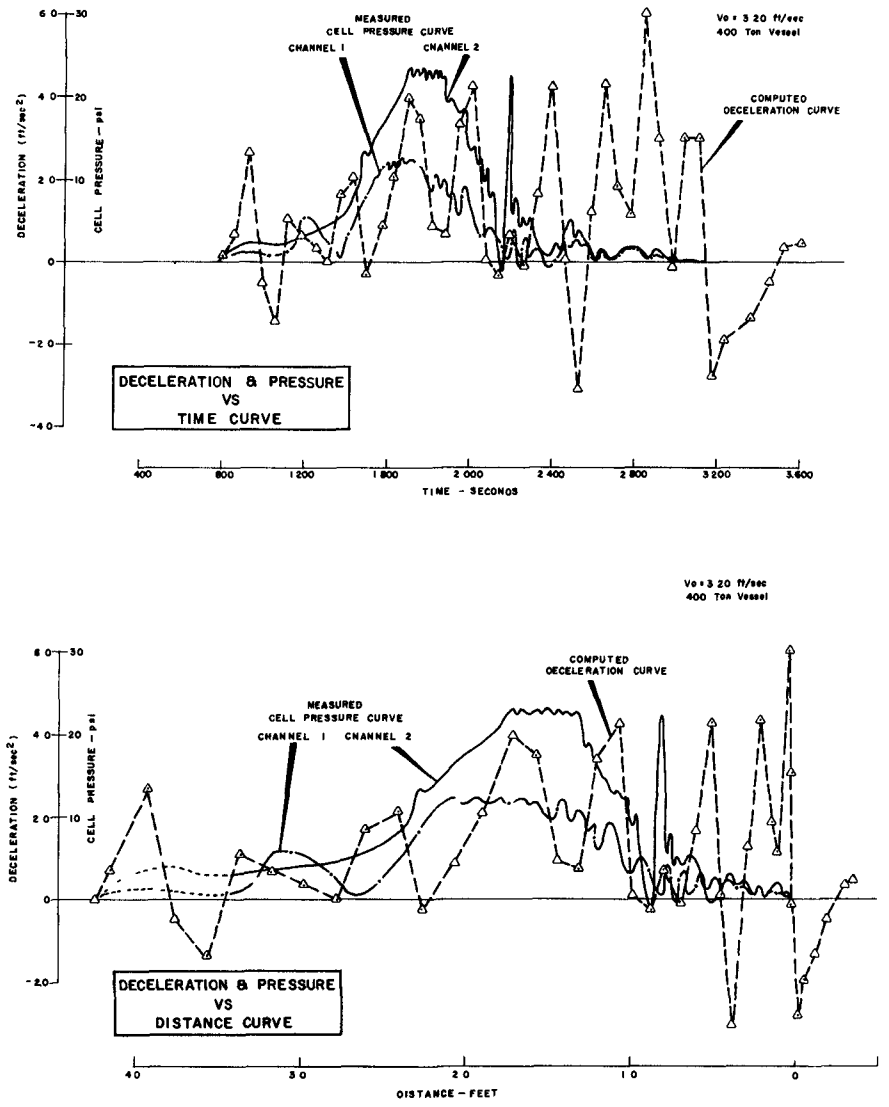


Figure No. 8- Test No 15, May 13, 1968, Treasure Island. Comparison of pressure distribution between adjacent clusters

was measured at 23 psi The impulse pressure recorded on Channel 1 was about 60 percent of the value obtained in the Channel 2 cluster The clusters were spaced uniformly on the camel.

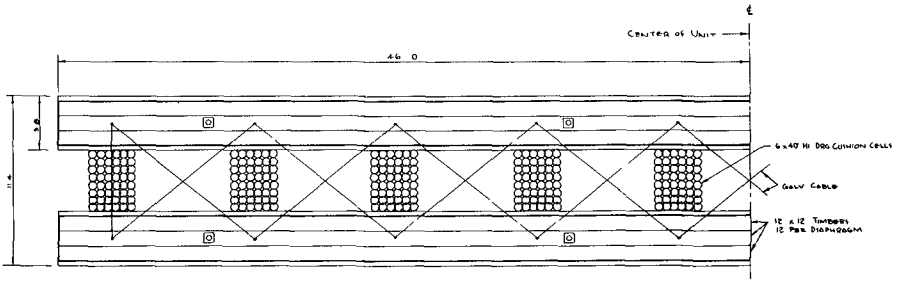
UNIT COSTS

Based upon experience and data gained from installation of the Hi-Dro Cushion Camel tested at Treasure Island, a 45 foot camel, as shown in Figure 2 has been designed with an energy absorbing capability of 3,455 inch-tons The total cost of this camel is estimated at $4,500.00 installed. The cost in place then equals $1 30 per inch-ton per lineal foot The plastic cell clusters comprise 49% of this total cost.

OTHER APPLICATIONS

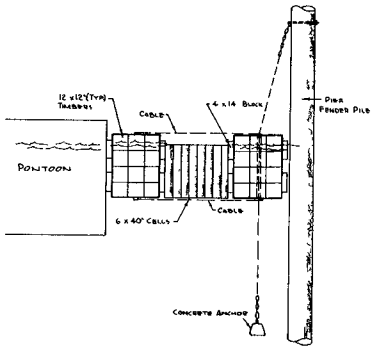
Figures No 9 and 10 show what can be done to use existing fender material, reconfigured and assembled, to overcome a present fendering problem for a carrier breasted out away from the pier. Figures No 11 and 12 also show how an existing submarine camel can be adapted to receive the increased protection provided by Hi-Dro Cushion Cells. A solution for a breasting or turning dolphin is shown in Figures No 13 and 14

Extensive use in Europe of retractable fender systems has been noted in the literature and many otner types of fender devices are being developed or have been tested (7,8,9.). Some of the disadvantages of these systems can be overcome by using the Hi-Dro Cushion system. Energy absorbing capabilities of some devices can be complimented by adding Hi-Dro Cushion Cells to make the existing fendering system less sensitive to varying ship displacements.



PLAN VIEW
OF
HI-DRO CUSHION CAMEL FOR AIRCRAFT CARRIER

Figure No. 9- Hi-Dro Cushion Camel Layout- Half Plan
(See Fig No. 10 for side view)



SIDE VIEW
OF
HI-DRO CUSHION CAMEL FOR AIRCRAFT CARRIER

Figure No 10- Aircraft camel detail

AREAS OF INVESTIGATION

The promise of this new floating fender system has opened areas of research that are important from an economic standpoint. Plastics are relatively new materials. Many plastic materials and systems with varying strength properties are being investigated for use in marine applications. There are many plastics that can be produced less expensively than the plastic materials used in the Camel at Treasure Island, however some are prone to harden and stiffen by ultraviolet deterioation when exposed to sunlight. If the cells can be kept submerged and removed from the sunlight, the use of less expensive materials is possible

Research is now in progress on strength and durability of the various plastic materials, especially the fatigue characteristics. It is known that plastics can endure many short duration high peaks without damage. These limits are now being investigated at Brigham Young University

CONCLUSIONS

The tests indicate that the impulse period is lengthened and the forces are reduced during impact on flexible fenders protected by the Hi-Dro Cushion Camel. The benefical effects of the system become apparent. The plastic celled system has a high degree of adaptability to velocity variations and changing masses. This is a distinct advantage when considering piers with multiple use requirements. The Hi-Dro Cushion Camel is economical to construct Maintenance is not expected to be costly.

Development of high strength plastics will also prove to be advantageous. As design pressures can be increased, costs will decrease also.

The construction of larger vessels makes it necessary to develop economical fendering systems. The Hi-Dro Cushion Camel system will most certainly fulfill some of these needs. Harbor structures constructed without fender systems that are adequate to prevent damage to ships, can now be inexpensively

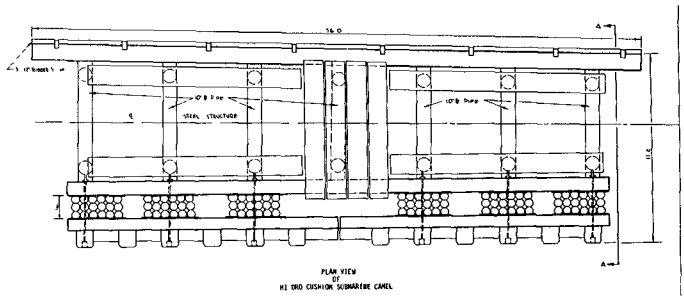
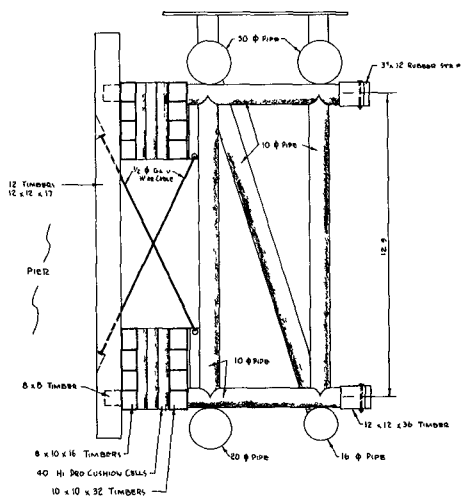


Figure No. 11,- Submarine Camel



SECTION VIEW
OF
HI-DRO CUSHION SUBMARINE CAMEL

Figure No. 12 - Submarine Camel

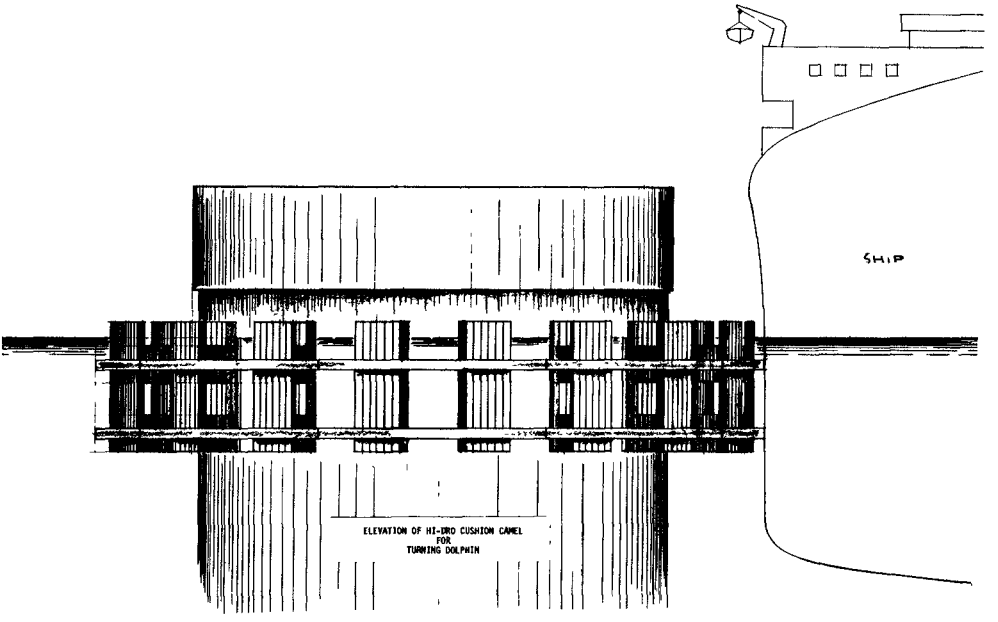


Figure No 13- Turning dolphin details.

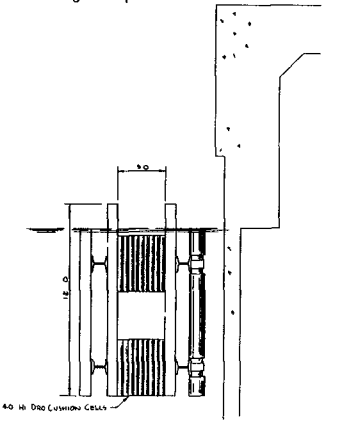


Figure No 14- Turning dolphin details.

and effectively protected This effect alone can reduce shipping rates by inviting commerce from shipping interests that avoid hazardous ports

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