R-315

Technical Report

AN INFLATABLE CAUSEWAY

18 August 1964

U. S. NAVAL CIVIL ENGINEERING LABORATORY

Port Hueneme, California

CONTENTS

INTRODUCTION

The present-day floating causeway consists of NL pontoon sections connected end-to-end. Usually, these sections are side-carried on a Landing Ship, Tank (LST) to the site, launched, and connected end-to-end into a causeway of the desired length. The current LST side-carries four 3 x 15 pontoon sections, each about 85 feet long and weighing 70 tons. An increase in the side-carrying capacity of an LST would enhance operations. One method of increasing the capacity is to side-carry the causeways double-tiered: four inboard sections loaded onto the side of an LST, and four outboard sections loaded onto the inboard sections.

In certain operations, pontoon causeway sections are transported to or from the site in the well deck of a Landing Ship, Dock (LSD). LSD's with a nominal 48-foot-wide well deck can load the pontoon sections two abreast, and may easily carry a total of seven (three pairs in tandem and one section forward in the tapering length of the well deck). Those with a nominal 44-foot-wide well deck cannot accommodate the pontoon sections two abreast; thus, their carrying capacity is normally limited to three or four sections in tandem. Increasing the number of causeway sections that can be delivered by an LSD would likewise be a logistic advantage. Here again the solution is multiple tiering, but in this case, stacked — one on top of the other in the normal afloat orientation. Because the depth of NL pontoons precludes double tiering in side-carrying and their buoyancy precludes stacking, another causeway concept is necessary.

One approach to the solution is an inflatable causeway. The task for the development of such a causeway was assigned to the Laboratory by the Bureau of Yards and Docks. The intent of this task was to provide a shallow structure having the utility of a pontoon causeway, but capable of being double-tiered on the side of an LST. Although the capability of stacking causeways in an LSD was desirable, it was only a secondary objective.

The prototype section of a modular design was the beach or onshore section, fabricated, assembled, and tested by NCEL. Subsequently, three intermediate sections were procured under Contract N160-30791.

This report describes the development of the NCEL-designed inflatable causeway and its capability. It includes the engineering tests, the fleet operational evaluation, findings, conclusions, and recommendations.

DESIGN AND CONSTRUCTION

Basic Design

The causeway was to consist of inflatable sections connected end-to-end to provide a floating roadway from an LST to the beach, and was to be capable of resting on all types of sand beaches and littoral sea bottoms. The causeway sections were to have a minimum length of 60 feet and a minimum roadway width of 18 feet 6 inches, with a maximum overall width of approximately 21 feet. The causeway was to be capable of supporting 62-ton vehicles spaced at 240 feet and maintaining traffic in a 40-mph wind, a lateral current of 3 knots, and a 6-foot surf.

The inflatable causeway designed by NCEL was produced in accordance with the criteria furnished by BUDOCKS.* The engineering details are represented on Y&D Drawing Nos. 879036 through 879053 and 879076 and 879077 (see Appendix A).

As designed, the inflatable-causeway section represents one unit of a 21-foot-wide causeway system. Basically, each section consists of a steel superstructure with self-contained inflatable cells. The cells, when deflated, are drawn into the superstructure; when inflated, they fill their storage cavity and extend approximately 2-1/2 feet below the superstructure to provide buoyancy.

Each causeway section is made up of 24 modules, two wide by 12 long. Twenty basic modules plus four end modules make up a section. The end modules of one type of section may be interchanged with those of another. The types of sections are as follows:

1. Beach section. Consists of basic modules plus the onshore beach-ramp modules and the open end-connection modules for an overall length of 87 feet; weight is 42 tons.

2. Intermediate section. Consists of basic modules plus the open and closed end-connection modules for an overall length of 85-1/2 feet; estimated weight is 44 tons.

3. LST end section. Consists of basic modules plus the closed end-connection modules and the LST end modules for an overall length of 88 feet; estimated weight is 44 tons.

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* U. S. Naval Civil Engineering Laboratory. Technical Report R-136, Prototype Inflatable Causeway, by J. J. Hromadik. Port Hueneme, California, 12 June 1961.

Superstructure

All modules are of mild-steel (ASTM A7) construction, 3/16-inch plate, with structural shape framing. All basic modules, Figure 1(a), are identical. Each has an underneath cavity to accommodate the inflatable cell. The end-connection modules, Figure 1(b), are similar to the basic modules except for an added length at one end to accommodate the end connections and to provide a roadway from one section to another. The end-connection modules are left and right units with open or closed connectors and, therefore, are not interchangeable within a section. The beach end-ramp modules, Figure 1(c), are enclosed, watertight steel pontoons with a tapered ramp. All end-ramp modules are identical, i.e., no left or right. They have no inflatable cells.

The six longitudinal load-carrying girders that assemble the modules into a causeway section are high-strength, low-alloy steel (ASTM A342) angles, 6 by 8 by 1/2 inches, with cover plates. One of the deck angles includes a hinge bar, while the bilge angle on the same side forms a hinge rail. The causeway centerline angles are welded together with cover plates to form a tee section. A cross-sectional makeup of the angle-girders is illustrated in Figure 2.

All angle-girders are connected to the modules with 1-1/2-inch-diameter high-strength steel bolts and flange nuts. The "turn-of-nut" method* was used to tighten the assembly bolts.

Flotation System

The inflatable pontoon cells are of 2-ply, high-tensile-strength synthetic rubber-coated nylon fabric. Each weighs about 240 pounds. The cells have essentially a rectangular cross-section and are designed for a 2-1/2 psig internal working pressure. When inflated, the upper portion of the cell fills the formed cavity of the module, and the lower portion extends about 2-1/2 feet below the structure. When deflated, as during side-carrying, the lower portion of each cell is drawn up into the cavity.

Each cell is secured in the module by ten hanger straps located near the top around the cell periphery, and by five restraining straps which encircle the lower portion of the cells. The hanger straps retain the cell when it is deflated, and the restraining straps hold the cell when it is inflated. All straps are 3-inch-wide Dacron webbing with looped ends to engage locking pins.

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* American Institute of Steel Construction. Specifications for Structural Joints Using ASTM A325 Bolts. Approved by the Research Council on Riveted and Bolted Structural Joints of the Engineering Foundation, March 1960.

Figure 1. Typical inflatable-causeway modules.

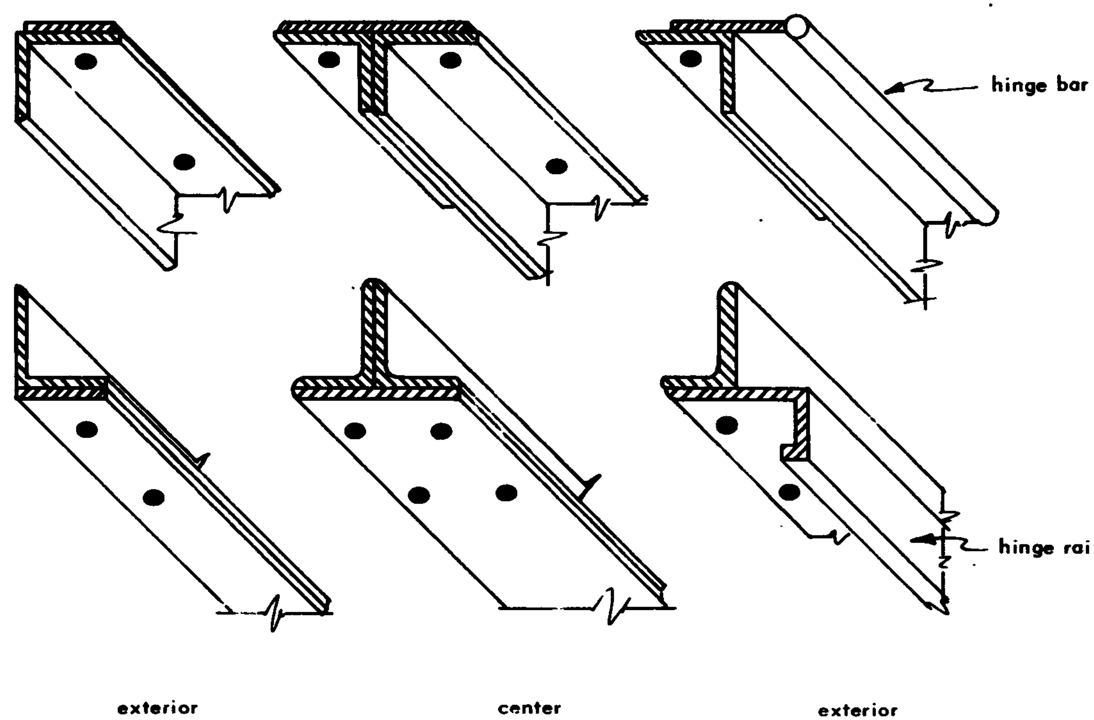


Figure 2. Cross-section of longitudinal assembly-angle girders.

Air Supply

The air supply and evacuation piping is schematically shown in Figure 3. The main header extends the full length of the causeway section, within the modules of one of the strings. It is made of pipe segments joined with articulated couplers. A side header branching off the main header at the center of the section extends between modules to the outboard edge. Air entry or evacuation is possible from either end of the main header or from the side header. The tandem connection of all causeway-section air systems is possible with short hoses between section end ports. Thus, air may be supplied to any section of an assembled causeway from any point in the system.

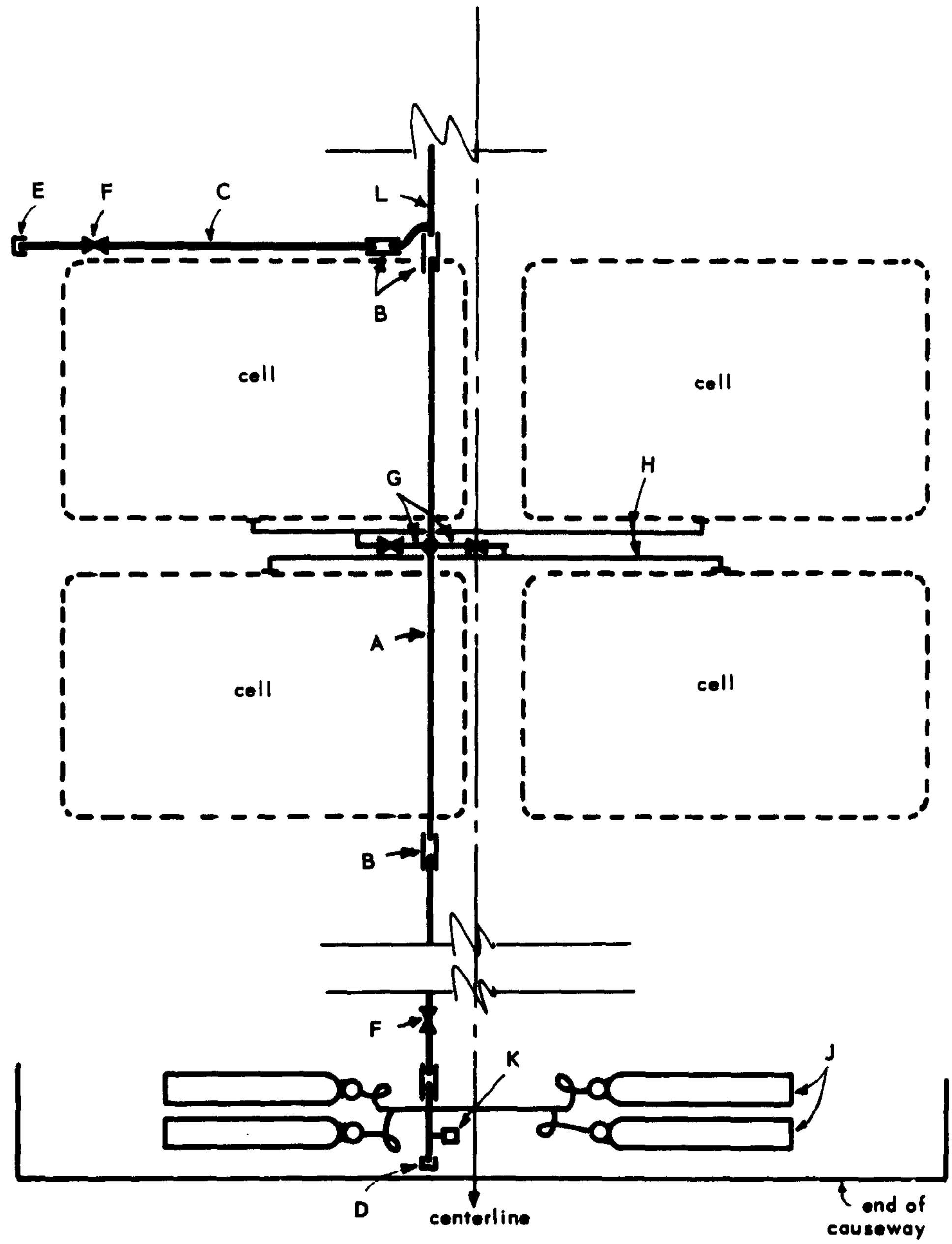
At six points along the main header, every other space between modules, two lines branch off, each through a quick-opening valve. Beyond each valve, the branch line divides to service two transversely adjacent cells, Figure 4(a). Quick-disconnect couplers are used at the cells. The quick-opening valves are controlled with universal-jointed reach rods that extend to the outboard edge, Figure 4(b). The same system is used for inflation or deflation of the rubber cells.

Air is supplied to the cells by an engine-blower combination external to the system. The engine-blower unit is rated 2100 cfm, 70" sp at 3570 rpm and was designed to inflate four causeway sections simultaneously in 20 minutes or less. Air is evacuated by reversing the blower intake and exhaust ports.

An emergency air-supply unit internal to the system consists of two standard high-pressure air or nitrogen cylinders. Each end-connection module houses one auxiliary air unit valved directly to the main header. An intermediate causeway section is supplied with four units (eight cylinders), the onshore and offshore sections with two units each (four cylinders). One cylinder (275 cubic feet capacity at atmospheric pressure) can partially inflate one cell. Although inflation is below normal working pressure, it will maintain buoyancy.

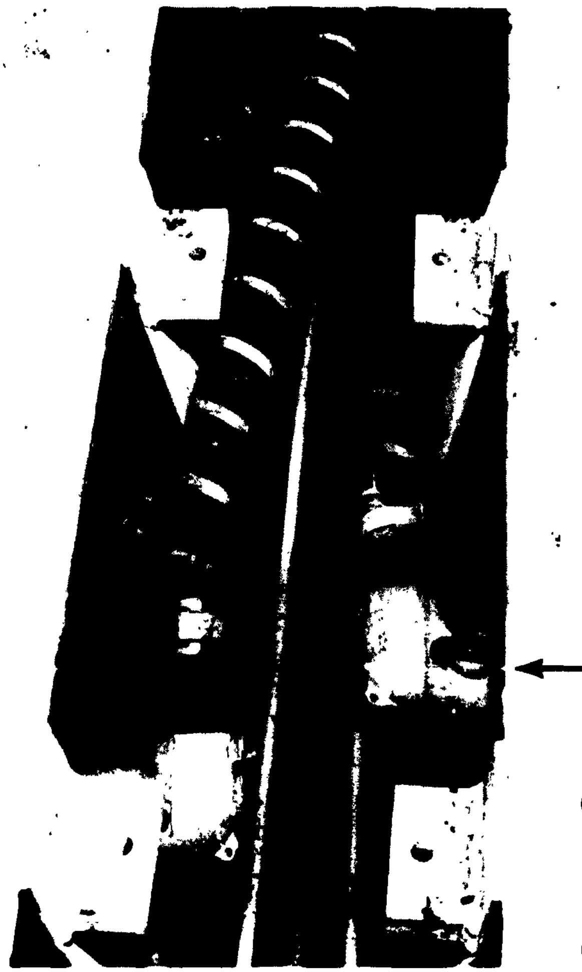
Section Assembly

The method of assembling the superstructure is similar to that employed with the NL system. Alternate methods have been evaluated. Available handling equipment will normally dictate the method used. One method is to assemble all modules into longitudinal strings, transversely on end, as shown in Figure 5. Strings may then be combined, as shown in Figure 6. It may be noted in Figure 6 that the centerline deck tee member is connected to one string while the bilge tee member is connected to the other. This method will require hoisting equipment of at least a 22-ton capacity.

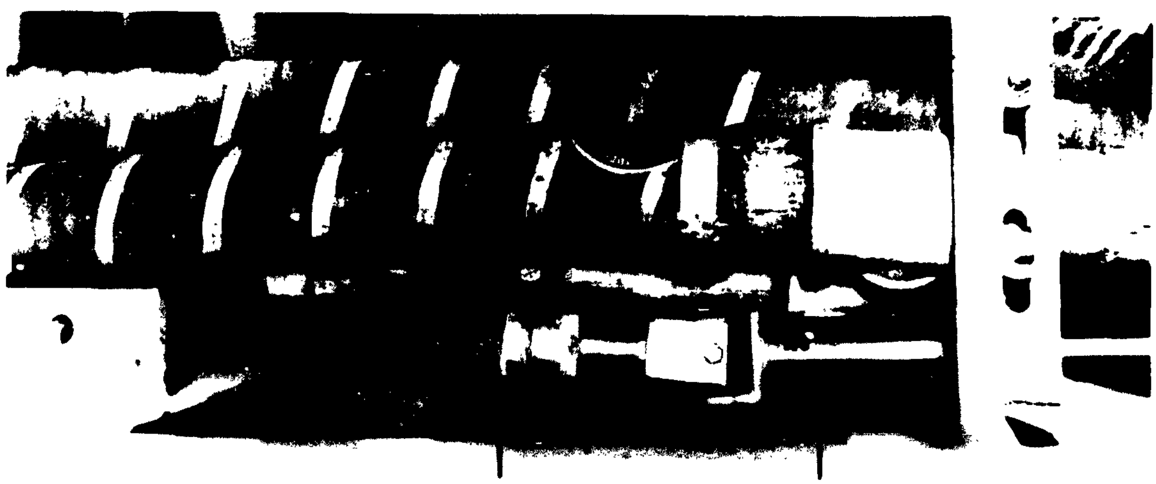


A	Main header	G	Branch lines
B	Couplers	H	Air hose to cell
C	Side header	J	High-pressure-air cylinders
D	End port	K	Safety valve
E	Center port	L	Main header segment with midsection side header
F	Quick-opening gate valve		

Figure 3. Schematic of air-supply system.



(a) Two-inch air hose from main header to cells



(b) Valve with reach-rod control

Figure 4. Air-supply control system.

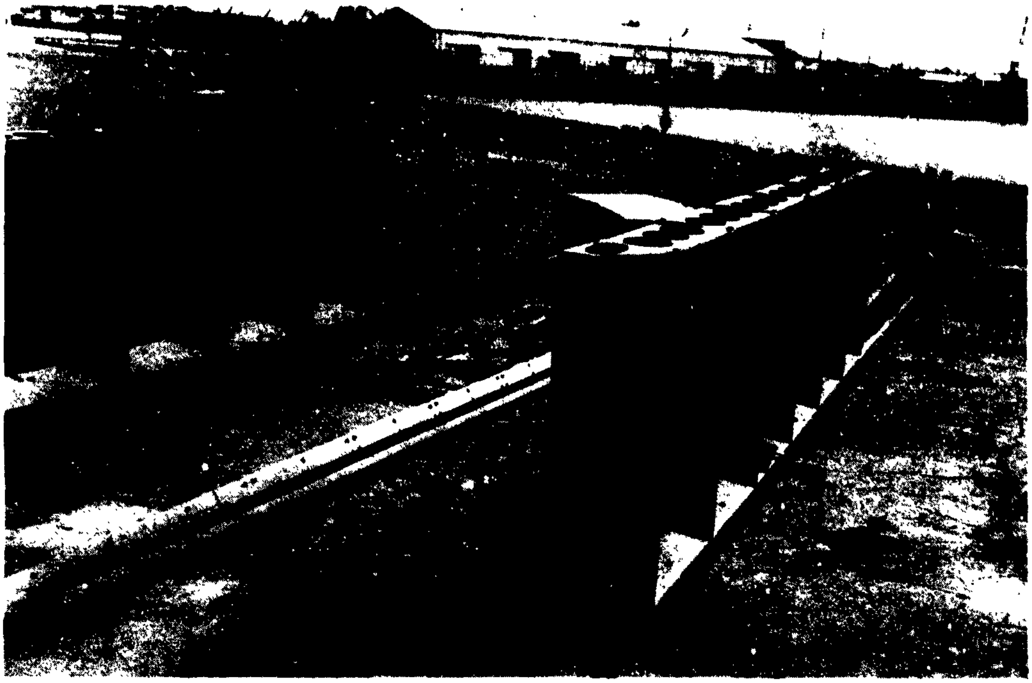


Figure 5. Assembling of modules into strings.

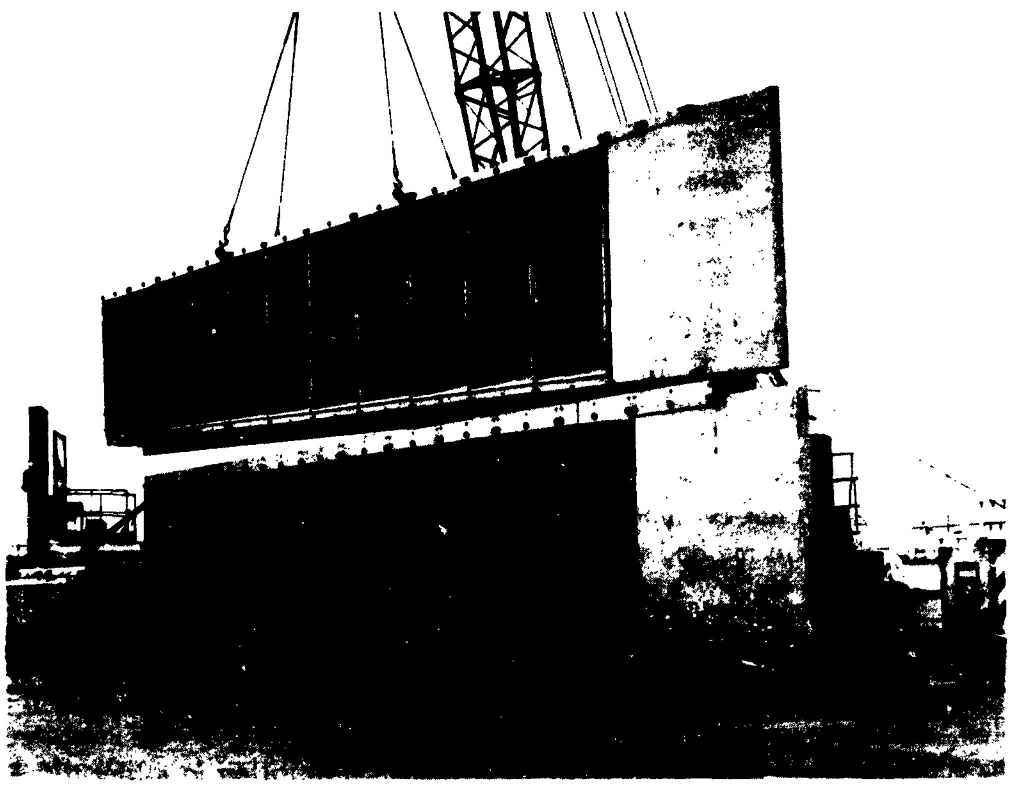


Figure 6. Combining strings.

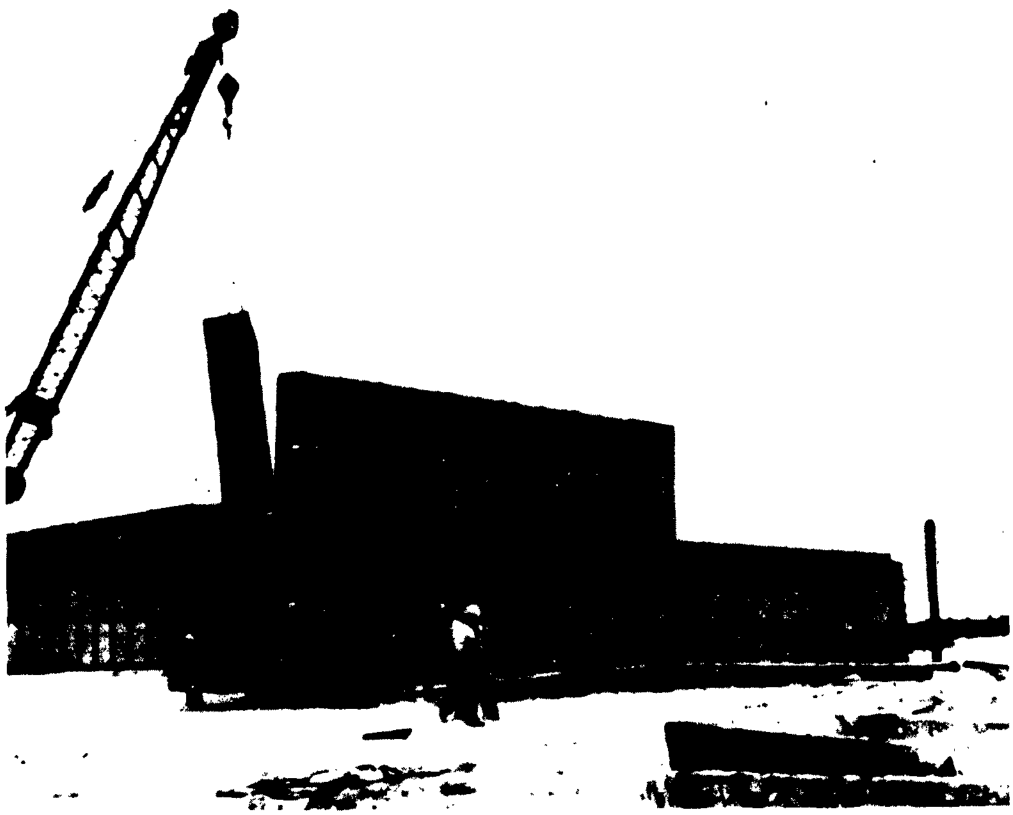


Figure 7. Alternate method for causeway assembly.

An alternate method is to use a module-by-module buildup of the entire section, as shown in Figure 7. The maximum single weight handled by this method would be the tee assembly member. Thus, hoisting equipment having a 3-ton capacity would suffice.

A third method, not evaluated, would be to assemble the sections horizontally, module by module. This method would presumably be employed at advance bases where launching from ways was necessary.

The air system may be installed in a completed string before that string is combined with a second string, or it may be installed after the superstructure is assembled. The emergency air-supply units and the inflatable cells are installed after the superstructure is completed. The cells may be installed in either the vertical or horizontal orientation of the completed assembly.

ENGINEERING TESTS

All engineering tests were performed on the prototype beach section. These included dry-environment tests to establish structural and air-system adequacy and functional tests of operational aspects.

Structural (Dry Environment)

These tests were to check the structural behavior in conformance with criteria for conditions of resting on the sea bottom. The structure was simply supported on a 75-foot span. This span was comparable to supporting the structure on each end pair of cells only. SR-4 electric strain gages were bonded to the surface of the assembly angles at or near critical locations; mechanical gages were used to measure deflections.

A test was performed to obtain maximum dead-load stresses and deflections at the center. The structure was temporarily supported at intermediate points, theoretically determined to result in a zero stress at the center. The temporary supports were shimmed as nearly as possible to a zero deflection at the center, relative to the supports. In this condition, the zero strain and deflection readings were recorded. The supports were then removed to obtain dead-load values.

Two static live-load tests were made to 80 kips with concrete weights distributed on a load frame. The overall size of the frame was 23 feet long (tracks or runners) with a 10-foot center-to-center spacing between the tracks. This arrangement of load was compatible with vehicle dimensions specified in the criteria. Longitudinally, the load was centered for both tests; transversely, the load was centered for one test and shifted off center for the other.

The 75-foot simple span structure was also tested under a moving-wheeled-vehicle load, as shown in Figure 8, using three traffic lanes, one on either side of the longitudinal center and one straddling.

The structure performed satisfactorily under these tests. A comparison of theoretical and observed static live-load values, other results, and test details are contained in Appendix B.

A retraction test was performed to simulate beaching, where the lead causeway section grounds on the front cells. The structure was supported at one end only on the end pair of cells. The initial pressure in the unloaded cells was 2.5 psig; the pressure increased to 3.9 psig under a dead load of approximately 21 tons. The load was held for 20 minutes without any noticeable damage to the structure.

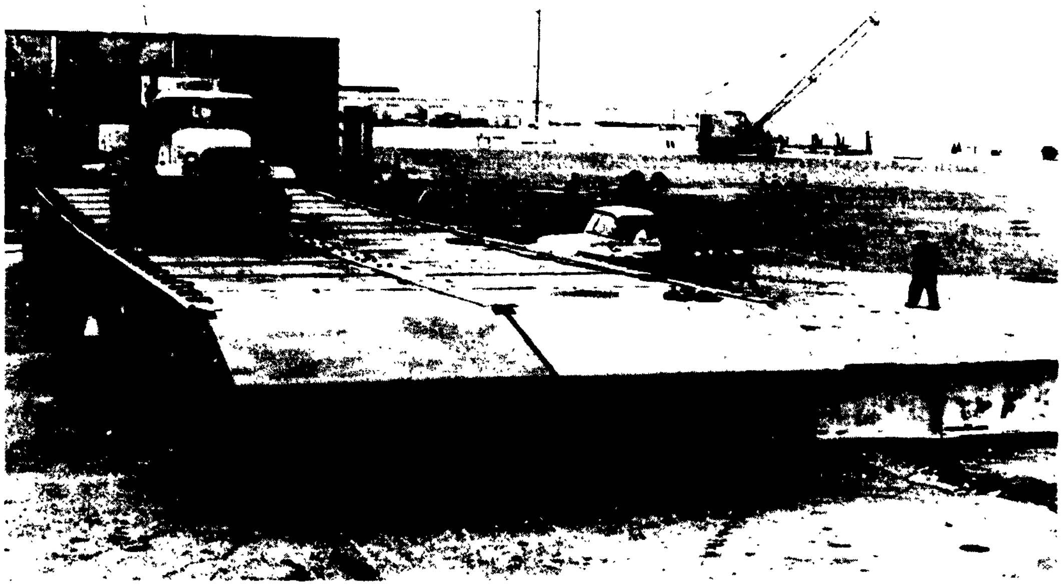


Figure 8. Test with moving vehicle.

Inflation and Deflation (Dry Environment)

Various tests were conducted to ascertain the functioning of the air-supply and evacuation system (main and emergency) and to obtain inflation-time data. In the studies, cells were inflated from two conditions:

1. Vacuum-collapsed (as the cells would be in transit) to 2.5 psig.

2. Free hanging at atmospheric equilibrium to 2.5 psig.

Studies on deflation were the reverse of the first inflation-test condition, i.e., from a pressure of 2.5 psig to the vacuum-collapsed condition. The time required to inflate all cells from the vacuum-collapsed condition was 8 to 8-3/4 minutes; deflating to the same condition required about 11 minutes. Details and results of the inflation — deflation tests are contained in Appendix B.

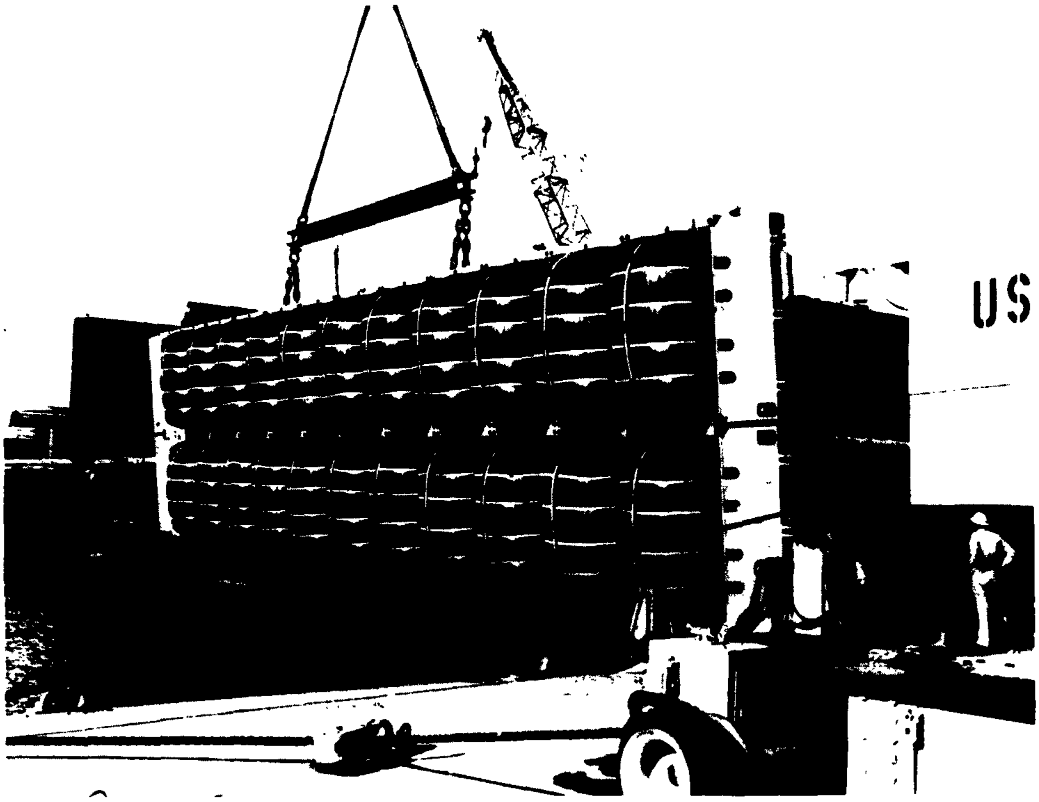


Figure 9. Loading section for launching.

Operational Aspects

The causeway section was launched 13 times from a simulated LST side-carrying position using a dock-mounted frame. Figure 9 shows the section being loaded into the launching frame. The height of the launching rail above water varied from 5 feet 7 inches to 11 feet.

The first 12 launchings were made with all cells inflated to a working pressure of 2.0 to 2.4 psig, while the pressure for the 13th launching was limited to 1.5 psig. Data obtained during the launching tests consisted of continuous recordings of decelerations, strains in the assembly angles at critical locations and changes in the cell pressure in the two outboard end cells, i.e., furthest from launch rail.

In general, 80 percent of the impact deceleration values were in the 20- to 30-g range; 10 percent were above and 10 percent below this range. The median of all values was 26 g. The launching stresses, based on recorded strains, reached peaks of 20 to 30 ksi at time of impact. These stresses were of less than 0.1-second duration. The superstructure performed satisfactorily under repeated launching impacts.

Pressure increases averaged 9.5 psig for the cell at the connection end and 7.6 psig for the cell at the ramp end; median values were respectively 9.6 and 7.9 psig. The cells sustained no apparent damage from the launchings. Some straps failed; 12 failed on the initial launching. The failure was in the stitching of the straps girding the short dimension of the cells. After the second launching test all straps were removed and resewn to alter the end loops. During the remaining 11 launching tests, only three of the modified straps failed, but not in the stitching. A summary of results of the launching tests is presented in Appendix B.

Flotation and stability studies were conducted in the harbor where calm waters prevailed. The section was pushed longitudinally and laterally, both unloaded and with a 65-ton static load centered amidships. Stability in motion and maneuverability were good. The section was also tested stationary with various load positions and initial inflation pressures. The stability and freeboard were judged satisfactory under all test conditions. With an initial inflation pressure of 1.0 psig, freeboard was reduced only three inches from that obtained with an initial pressure of 2.4 psig. Results are detailed in Appendix B.

To evaluate the section as a lighterage barge, an 06DH propulsion unit was mounted at the connection end, and the section was maneuvered about unloaded in the harbor. The section rode well with very little vibration, had quick response to steering, was easy to dock, and had good speed, estimated at about 6 knots. It was possible to make a 360-degree turn with the section in a distance of approximately 100 feet, or slightly more than the length of the section.

Two series of tests of four beachings each were made with the unit as the lead section of a two-section causeway. The sections were maneuvered with a pontoon warping tug. The first series of tests was conducted in a sheltered area inside the breakwater of the Port Hueneme Harbor; the second was made in an unprotected area outside the breakwater.

In general, the beachings were made with a varying number of lead cells deflated; no auxiliary beach equipment was used to assist the beaching. The sections rode in on the beach on the ramp pontoon until the inflated cells bottomed. In a majority of the beachings, access to the beached section was possible without a transitional sand ramp. In retreating, the causeway was pulled off the beach with comparative ease. Results were satisfactory. The beachings are described in greater detail in Appendix B.

In operation at sea and enroute to and from the second beaching site, the action of the causeway section in the ocean was very satisfactory; the cells acted as shock absorbers, and the section was sufficiently flexible to resist pounding by quartering swells.

Double-tiering tests were performed to study LST self side-loading and the gear involved to accomplish it, the behavior of the cells in their deflated state when being transported, and launching of the double-tiered sections. Two 2 x 4 sections of basic modules were used for these. Primary interest was focused on the deflated state in transport. It was noted, during the deflation study, that with the section in its vertical side-carrying position and the cells deflated, the deflated cells overhung the bilge assembly angle and laid in the hinge rail. This was undesirable for the inboard section, as the overhanging cells could be damaged on self side-loading the outboard section.

DISCUSSION OF ENGINEERING TESTS AND RESULTS

Structurally, the superstructure was satisfactory for flotation, beaching, launching, and spanning the 75-foot unsupported length under full load. For the latter, its behavior was reasonably close to that predicted by design calculation. For the extremely severe condition of full load (62 tons) on a 75-foot span, the stresses will have a factor of safety of 1.1 or greater on the yield point, as shown in Table V, Appendix B. As may be noted in the table and in Figure B-3 of Appendix B, discrepancies existed between the test and theoretical values. In the dead-load values, the difference was largely due to the methods employed in approximating the zero-load values. Since the point of zero-dead-load strain was not possible to attain electronically, this point was arbitrarily arrived at mechanically and established as the electronic zero strain.

The discrepancies in the live-load values were less; their presence was probably due in part to the method employed in distributing the loads analytically to arrive at theoretical values. Because of the remote probability of attaining the 75-foot span and a maximum design load at the same time, the small margin of safety is considered to be sufficient. If greater safety is desired, the assembly members may be strengthened by additional cover plates, with only a slight increase in weight and minor additional fabrication. The factor of safety for the afloat condition under maximum load is in excess of two. With regard to the launching stresses in the assembly angles, values to 30 ksi are not critical for the extremely short duration.

The flotation system functioned satisfactorily. The cells were adequate for stability; the causeway section could be maneuvered by auxiliary craft and under its own power as a lighterage barge with comparative ease. Adequate freeboard was maintained under all normal conditions of load. The sections were capable of operating at initial cell-inflation pressures of 1.0 to 2.5 psig.

The causeway beached successfully, presenting no problems. The beachings were most satisfactory when the proper number of lead cells were deflated to match the beach gradient. The cells showed no abrasive damage or wear as a result of the limited number of beachings. In all cases where the section beached with the lead cells deflated, the ramp was accessible to traffic without additional preparations.

In the side-launching tests, the inflated cells served as shock absorbers, reducing impact forces to values which have no adverse effect on the structure. A majority of the launchings were from heights in excess of 9 feet, where the most severe impacts were experienced. Except for the initial strap failures, the structure showed no sign of damage. No apparent mathematical correlation was found between the launching heights and the recorded data for impact forces, pressure changes, or strains; nor was there any significant correlation between one measured parameter and another. Presumably, this is due to unmeasured factors, such as angle of entry, freedom of escape from the launching rail, orientation of section on impact, and the like.

Studies from double-tiering tests indicated that the difficulties encountered with cell overhang could be solved with a minor cell redesign and the use of a mechanical device to assist in drawing the cell into the cavity during deflation. This was accomplished with an elasticized strap installed within each cell.

The gear necessary to double tiering functioned satisfactorily; launching from the double-tiered position presented no problems. However, a more satisfactory test of the handling, loading, lashing, and carrying of double-tiered sections was indicated, such as an operational evaluation.

FLEET OPERATIONAL EVALUATION

Upon completion of engineering tests, NCEL recommended a fleet operational evaluation. For economy it was decided to provide only a four-section causeway. This was to consist of the prototype beach section plus three intermediate sections. The latter were procured from Pascoe Steel Company, Pomona, California, under Contract N160-30791, and embodied the latest design modifications determined by the engineering tests. The primary change was to the cells to effect a shallower profile and to add the self-contained elastic straps.

The contractor chose to preassemble the modules into strings at his plant. These were truck-transported to the final assembly area at NCEL, Figure 10, and then combined into sections, Figure 11. The air systems, cells, and miscellaneous deck gear were then installed.

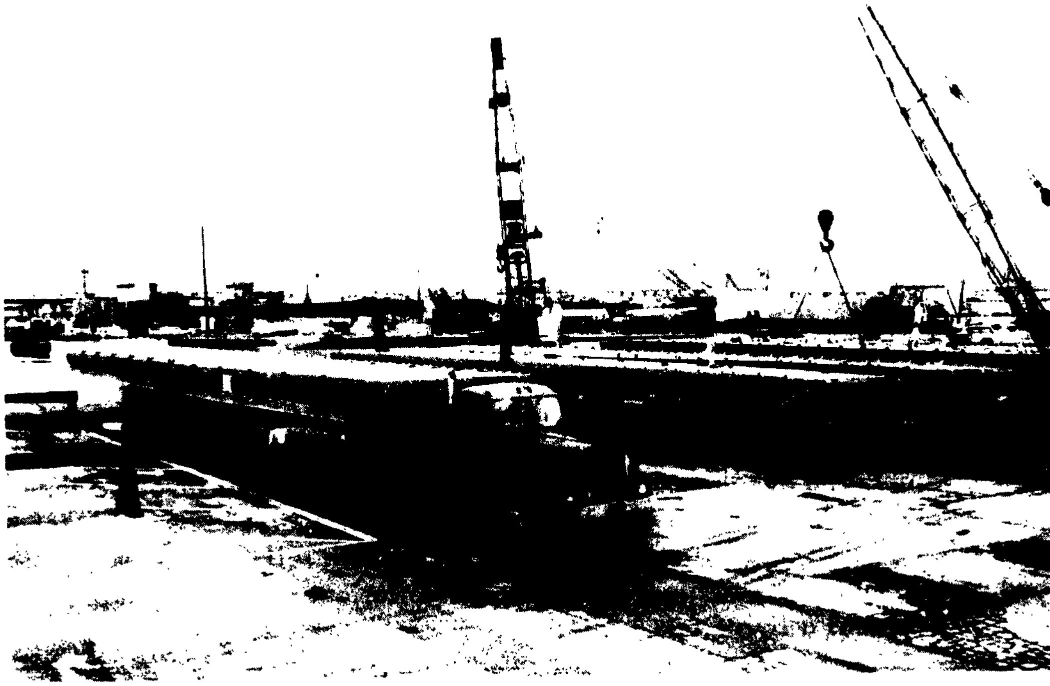


Figure 10. Preassembled strings arriving at final assembly area.

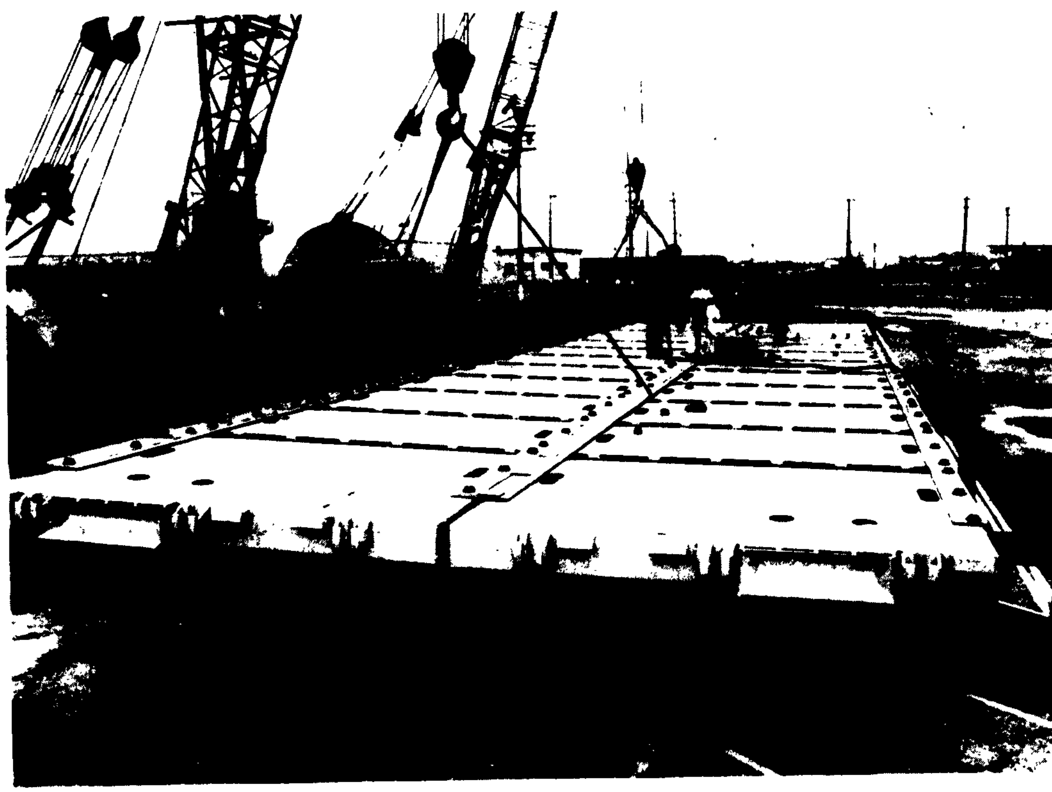


Figure 11. Strings being combined into complete sections.

Subsequently, Chief of Naval Operations Project Plan for CNO Project O/S77 FY 63, "Conduct an Operational Evaluation of an Inflatable Causeway Modular Design" was issued. The Deputy Commander Operational Test and Evaluation Force Pacific (DEPCOMOPTEVFORPAC) was designated as the prosecuting activity. Amphibious Construction Battalion One (ACB One) was instructed to furnish services of a standard NL pontoon causeway crew for the tests, as directed by DEPCOMOPTEVFORPAC. USS Polk County (LST 1084) furnished support equipment and personnel services to provide a realistic fleet environment, and NCEL provided technical and logistic support as required.

The operational evaluation was conducted in two phases: Phase I at NCEL, Port Hueneme, California, and Phase II at the Amphibious Base, Coronado, California. Phase I tests were planned primarily for indoctrination, determination of personnel training and safety, and development of operational procedures. It involved the USS Polk County and the ACB One crew. Physical testing included removal, repair, and installation of cells; mating of causeway sections; both self- and crane-assisted side-loading in double tier; lashing; inflation and deflation; side launching; and the use of a section as a lighterage barge.

The Phase II tests were conducted in an operational environment to better determine the causeway's ability to meet the specified operational requirements and its overall suitability for service use. These tests included side launching of sections, assembly of a causeway in an open sea, beaching the causeway, trafficability, retraction from the beach, and assembly of a causeway section. In addition, all Phase I tests were repeated under the more realistic operational conditions. A detailed schedule of the tests is contained in Appendix C. The results of the operational evaluation, including conclusions and recommendations are contained in the OPTEVFOR Final Report.*

Discussion of Operational Evaluation

The discussion of the operational tests is based on NCEL observations, the OPTEVFOR Final Report, and a report by ACB One that is contained in Appendix D.

Double-tiered side-carrying is operationally feasible. The four sections were transported double-tiered on the side of an LST for 65 continuous hours through seas ranging from calm to moderate (sea state 1 to 3). Wave action had little effect on the superstructure, and no damage to the deflated cells was noted. The elastic strap was effective in drawing the cells into the module cavity, as may be noted in Figure 12.

* Operational Test and Evaluation Force. Final Report on Project O/S77 FY 63, Operational Evaluation of an Inflatable Causeway — Modular Design, by Commander, Operational Test and Evaluation Force, December 1963.

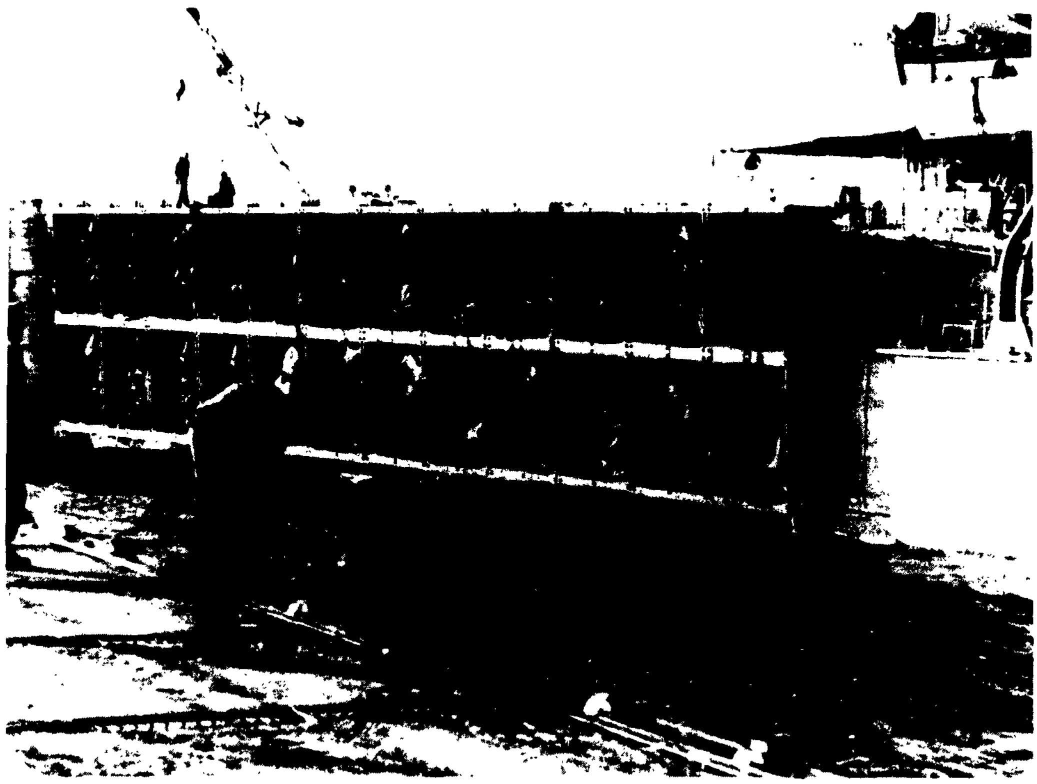


Figure 12. Side-loaded section. Note excellent cell-retention in modules.

Standard tie-down and lashing gear was used for the inboard section. For the outboard section, the gear included tie-back lines over the inboard section to the LST deck, tie-down hooks to secure the outboard section in the inboard-section hinge rail, and cross-tie lashing between the outboard and inboard sections. Figure 13 shows the four inflatable sections double-tiered and secured forward, ready for transporting to Coronado; two NL sections are aft. In transit, and during the 65-hour shakedown cruise, the tie-down and lashing gear functioned satisfactorily, but rather mild seas failed to provide an environment to fully evaluate the gear.

Self side-loading can be accomplished with lighter lifting gear than normally used for NL-type causeways. Because of the lighter weight involved, a twofold rather than a threefold purchase on the lifting lines is possible. For self side-loading the outboard section, two portable rollers were mounted on the secured inboard section, as shown in Figure 14, to pass the lifting lines over the inboard section. The weight of the rollers made it necessary to use the ship's mobile crane for placement, as they were too heavy to be positioned manually. A portable davit, fabricated later for handling and positioning the rollers, improved the method of handling. A lighter roller would be a further improvement. Repeated attempts to self side-load the outboard section in an open seaway were unsuccessful. This problem will require further study, but a solution appears feasible.

Side loading in double tiers with a floating crane can be achieved in calm waters with little difficulty. However, care should be exercised to avoid excessive swinging of the outboard section when positioning it in the inboard-section hinge rail. All cell damage during the evaluation occurred with crane loading.

During one operational test, the four inflatable sections were back-loaded into the well deck of an LSD and transported "piggyback." Sections were loaded by deflating the bottom ones, allowing them to rest on the deck. The upper sections were then floated in and positioned over the sunken sections. When the ship deballasted, the upper sections, still inflated, were carried on top of the lower sections.

From the LST, the inflatable sections were side-launched from a double-tiered position nine times with no apparent difficulty. The standard chopping-block method of releasing the section to free fall was used. But removal of the lashing gear before launching the inboard section appears to compromise the safety of the operating personnel, since the removal cannot be made from the deck. Placement of hold-back lines convenient to deck handling and removal would eliminate this hazard. No damage to the superstructure or to the cells resulted from launching impacts. Launching of an outboard section is shown in Figure 15.

The inflatable sections were successfully beached through surf ranging from zero to six feet on beaches with gradients ranging from 1:20 to 1:60. Nine beachings were made using NCEL-suggested techniques; i.e., deflating the lead cells of the beach section until the ramp just cleared the water. In the majority of the beachings, the causeway rode well up onto the beach, as shown in Figure 16; no transitional sand ramp was required. No cell failures due to beaching were reported. A ten-section causeway with inflatable units making up the first four sections is shown in Figure 17.

The causeway provided an adequate roadway for all types of vehicles. During the evaluation period, a total of over 200 wheeled and tracked vehicles were driven on the causeway. The vehicles ranged in size from 1-1/2-ton jeeps to 62-ton M103 tanks. Note that the 62-ton tank in Figure 18 is fully supported, without benefit of flotation by the grounded cells. Stability of the inflatable sections during trafficability was good, and the vehicles negotiated on and off the beach ramp with comparative ease.

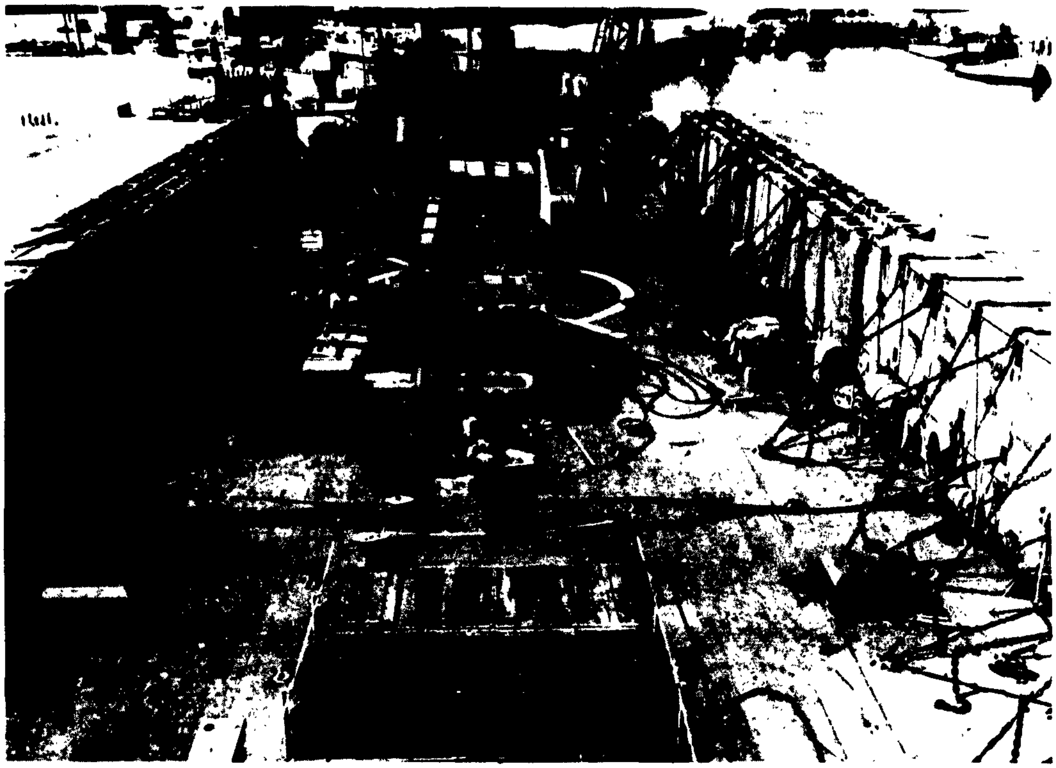


Figure 13. Four inflatable sections lashed for LST side-carrying.

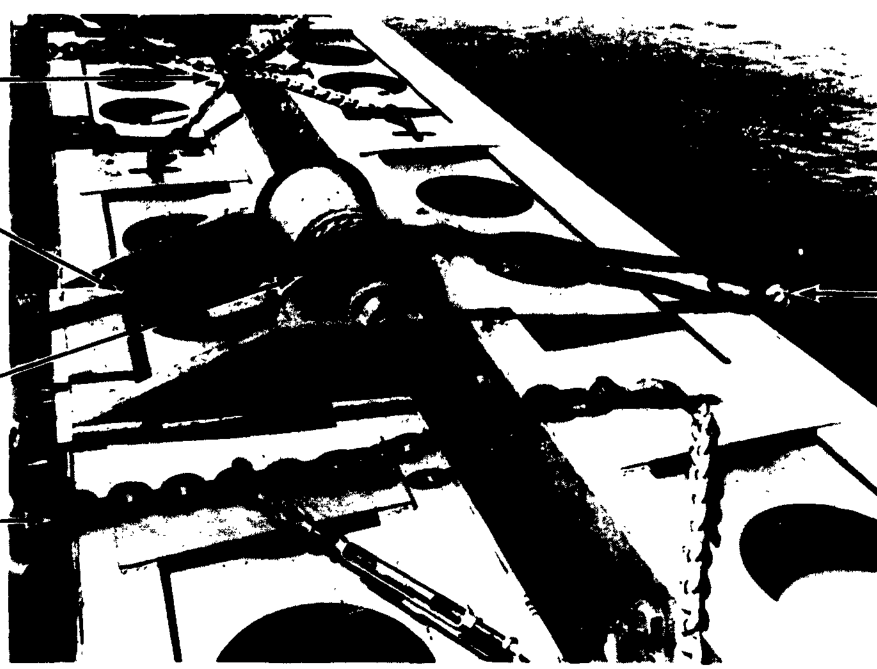


Figure 14. Inflatable causeway lifting and lashing gear.

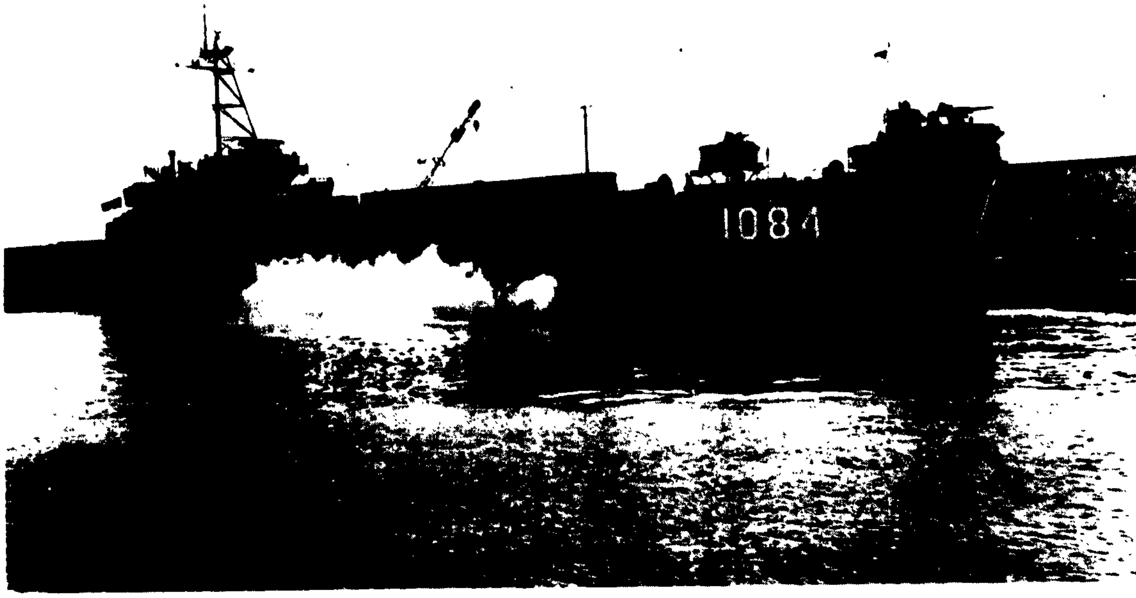


Figure 15. Side-launching of an outboard section from double-tiered position.

Figure 16. Beaching test with leading cells deflated.

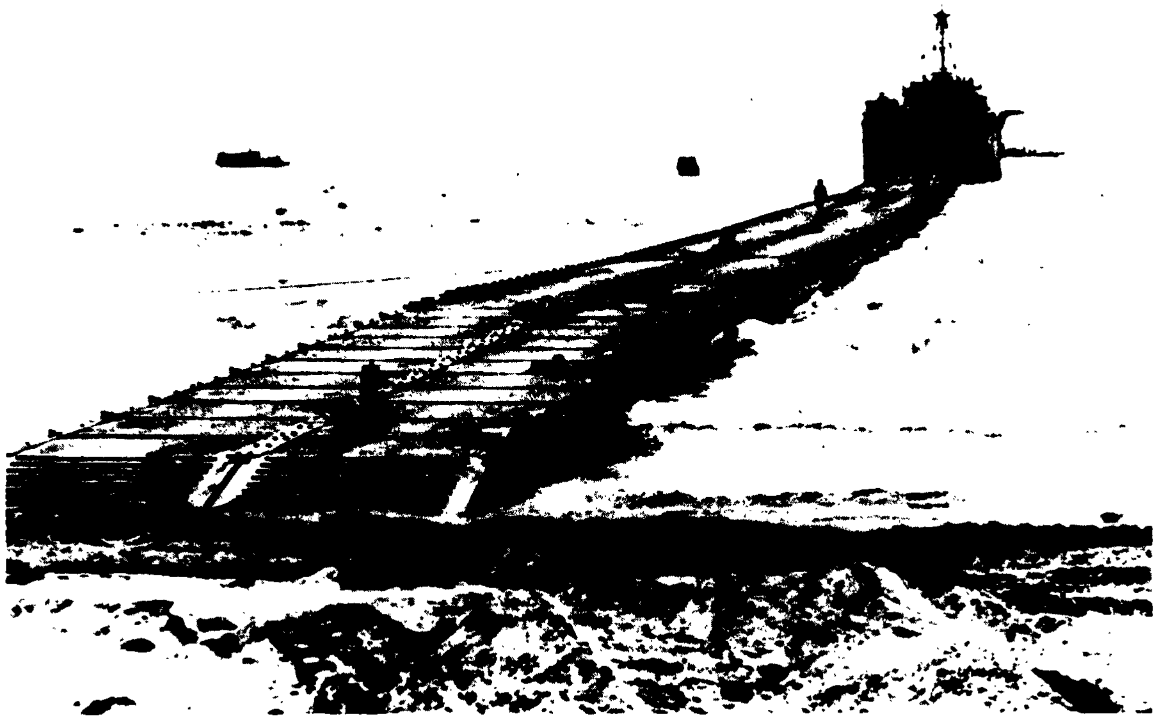


Figure 17. Ten-section causeway made up of four inflatable and six pontoon sections.

Figure 18. Sixty-two-ton tank traveling causeway.

The inflatable sections were easily retracted from the beach under all normal conditions imposed during the tests. Under one abnormal condition, a causeway with three inflatable sections firmly grounded was retracted from the beach at low tide in 1/2 hour using three warping tugs pulling and two tractors pushing. While this was a most severe test on the cells, the abrasive damage was not sufficient to effect air retention.

Comments on Evaluation Findings

Generally, the overall performance of the inflatable causeway was satisfactory, although some deficiencies were detected by the evaluation. Those specifically mentioned in the OPTEVFOR report follow. NCEL comments pertaining to each are included.

1. Points for attaching hold-down chains that can be reached by men standing on the deck of the ship are required to ensure safety of personnel while launching inboard sections from the side of an LST.

Comment: Changes to the lashing gear will be made to rectify this hazard.

2. The end-connectors provided with the intermediate inflatable sections are unsatisfactory for assembly to NL pontoon sections.

Comment: In calm waters, some difficulty was encountered in end-to-end mating of the intermediate inflatable sections to the NL sections during the Phase I tests. An investigation indicated that the problem did not lie entirely with the inflatable causeway connectors, but was due to several causes, such as minor differences in flotation between the two sections, fabrication tolerances, and the use of different model connectors. The end-to-end connectors on the inflatable sections were of a later design. No problems were experienced in end-to-end mating of inflatable sections. No future problems are anticipated, as end connectors on both types will be identical. It was possible to mate the inflatable sections to NL sections in rougher waters that permitted the sections to pitch.

3. The inflatable sections are difficult to control under any wind condition and require adequate provisions for mooring warping tugs alongside.

Comment: Provisions for mooring warping tugs alongside will be incorporated in the design drawings.

4. The patching kits evaluated are operationally unsatisfactory, because the patches are too small and require excessive time to apply (repair time plus 24 hours drying time).

Comment: The repair kit furnished was for rips or tears up to six inches long. It does not appear to be practical to effect an on-the-spot repair of anything in excess of six inches. Agree that curing time is excessive. In discussing this with the manufacturer, it was determined that the curing time could be reduced if heat were applied to the patch. The manufacturer indicated that a curing time of an hour is possible if a temperature of 280° F is maintained on the patch. This would be very difficult under most field emergency conditions, but could easily be done under more favorable shop conditions. The mechanical clamp-type patch furnished with the repair kit should be used for emergency repairs in the field on the larger tears. This type of patch will be adequate for tears up to six inches long until a permanent repair can be made. Side launching with cells repaired with mechanical clamps is not recommended.

5. All hardware (i.e., closure-plate hinges and locking devices, bolt head, etc.) installed along the roadway portion of the inflatable sections should be recessed into the decks to prevent damage by heavy tracked vehicles.

Comment: Agree. Changes to the design will be made to render these items less vulnerable.

6. The internal bungee system installed in the air cells is unsatisfactory in that it did not fully retract the cells into the module cavities on deflation.

Comment: The failure was investigated on completion of the operational evaluation. An appreciable quantity of water was found in those cells that did not fully retract. The source of the water was traced to a deflation operation. During this operation, two of the cells had previously been removed for patching indoctrination. The open ends of air hoses to these cells dropped into the water. Consequently, during deflation, water was drawn into the system. Although this condition was soon discovered and remedied, sufficient water was retained in the cells to present a problem. No change is contemplated in the cell retraction system.

7. The air-cell-retaining straps require strengthening, and all sharp edges around the module-access holes should be eliminated.

Comment: A total of 74 cell-retaining straps failed. The source of this failure was traced to strap abrasion on the sharp contours of the grommet around the strap openings in the module. The fact that all strap failures occurred in the three intermediate sections confirmed the finding. The grommets on the prototype beach section were split-pipe, having a full round with no sharp edges; those on the other sections were fabricated into a simulated round by a series of machine breaks. The edges of the break concentrated the wear along a single line and induced a sawing action. Future drawings will specify only the split-pipe grommets.

8. Inflatable sections cannot be self-loaded, double-tiered, on the side of an LST in an open seaway using present procedures.

Comment: It has been determined that the initial LST list was increased with the added weight of the inboard section (44 tons), thus reducing the height of the hinge rail above the water. This reduction in height is believed to be the major cause for the outboard section's "jumping" out of the hinge rail. This problem will require further study by NCEL.

CONCLUSIONS AND RECOMMENDATION

The NCEL inflatable causeway is technically sound and operationally feasible. The resolution of the deficiencies brought out by the operational evaluation is possible. Additional in-transit tests of double-tiered side carrying are required to evaluate tie-down gear. The inflatable causeway is recommended for fleet use.

Appendix A

INDEX OF DRAWINGS OF A MODULAR INFLATABLE CAUSEWAY

Y&D Drawing No.	Description
879036	Pontoon Cell Plan, Elevation and Details
879037	Piping Assembly
879038	General Assembly
879039	Basic Module, General Assembly
879040	Basic Module, Details
879041	Basic Module, Details
879042	Basic Module, Details
879043	End Module, General Assembly
879044	End Module, Details
879045	End Module, Details
879046	End Module, Details
879047	End Module, Details
879048	Beach End Module, General Assembly
879049	Beach End Module, Details
879050	Beach End Module, Details
879051	Beach End Module, Details
879052	Causeway, Details
879053	Piping, Details
879076	Launching Rail, Assembly and Details
879077	Lifting Roller and Lashing Gear, Assembly and Details
879078	Plan for Lashing Causeway to LST 1173 and 542
879079	Engine Blower Unit, Assembly and Details

Appendix B

ENGINEERING TESTS

Table I. Dead-Load Stresses and Deflections of Girders[1]

Trial No.[2]	Dead-Load Stresses (ksi)						Deflection (inches)		
	E-1	E-2	C-1	C-2	E_R-1	E_R-3	$E_{℄}$	$C_{℄}$	$E_{R_{℄}}$
1	10.8	-9.9	12.3	-9.0	16.5	7.8	1.43	—	2.41
2	11.4	-9.7	12.9	-9.3	15.9	8.4	1.62	2.00	2.59
Average	11.1	-9.8	12.6	-9.2	16.2	8.1	1.52	2.00	2.55

1/ Girders are assembly angle girders identified as follows: E, exterior; C, center; E_R, exterior with launching rail. Gage locations are shown in Figure B-2.

2/ Readings were obtained at different times before each static test. Trial No. 1 reading before test with live load centered; No. 2 before test with live load shifted.

Table II. *Static Live-Load Stresses and Deflections of Girders*

Live Load[1] (kips)	Live-Load Stress (ksi)						Live-Load Deflection (inches)		
	E-1	E-2	C-1	C-2	E_R-1	E_R-3	$E_{℄}$	$C_{℄}$	$E_{R℄}$
Center									
30.4	6.3	-6.8	7.5	-3.6	5.7	4.2	0.91	not recorded	0.90
58.2	13.5	-11.4	13.8	-6.9	11.4	8.1	1.72		1.65
80.0	—	-15.8	19.5	-9.9	16.2	10.8	2.50		2.37
Shifted									
30.4	8.2	-7.5	6.8	-3.6	5.4	3.3	1.16	0.91	0.57
58.2	13.8	-13.2	12.2	-6.5	9.3	5.7	2.13	1.66	1.10
80.0	20.4	-17.1	17.1	-9.2	12.8	8.1	3.07	2.31	1.53

[1] Live load was at midships (center of span) for both tests; transversely centered for one test, shifted 3 feet 7 inches toward E girder for other.

Table III. Structural Test Results (Moving Live Load)

Traffic Lane	Vehicular Load 1/ (kips)		Maximum Live-Load Stress (ksi)					
	Total	Rear Axle	E-1	E-2	C-1	C-2	E_R-1	E_R-3
C-E_R			1.4	-1.3	3.2	-2.1	5.3	—
Ctr	15.2	9.4	2.8	-2.5	3.2	-2.0	3.1	2.6
C-E			4.2	-4.2	3.2	-2.3	1.7	1.4
C-E_R			2.8	-2.7	6.8	-4.3	11.3	7.1
Ctr	29.6	23.4	5.5	-5.5	6.8	-4.6	6.7	4.9
C-E			8.7	-8.7	6.5	-4.1	3.6	3.1
C-E_R			3.0	-3.5	9.1	-5.4	14.3	10.4
Ctr	40.0	33.1	7.6	-7.3	9.0	-6.3	9.7	6.3
C-E			12.6	-12.7	9.0	-6.6	4.6	3.7

1/ Vehicular load was obtained at a later date by weighing duplicated load combinations.

Table IV. Distribution of Static Live Load to Girders for Theoretical Analyses[1]

Live Load (kips)	Proportion to Girder		
	E	C	E_R
Centered			
30.4	.239	.473	.288
58.2	.243	.475	.282
80.0	.242	.477	.281
Shifted, E			
30.4	.316	.495	.189
58.2	.313	.490	.197
80.0	.320	.485	.195

1/ Distribution was based on stiffness, as related to girder moment of inertia and measured deflections.

Table V. Girder Stresses[1]

Load	Stress (ksi)		
	E	C	E_R
Dead	10.0 (11.1)	10.0 (12.6)	11.7 (16.2)
Live (80^k)	17.7 (21.0)	17.5 (19.5)	20.1 (16.2)
Live (128^k), Extrapolated	28.3 (33.6)	28.0 (31.2)	32.2 (25.9)
Dead & Live, Maximum	38.3 (44.7)	38.0 (43.8)	43.9 (42.1)
Factor of Safety on f_{yp} = 50	1.30 (1.12)	1.32 (1.14)	1.14 (1.19)

1/ Stresses in parenthesis are based on test values; the others are theoretical.

Table VI. Inflation and Deflation Time Study, All Cells

Condition	Test No. 1/	Time (min)	Remarks
Inflation			
From vacuum-collapsed to 2.5 psig	1C 2C 3E 4E	7.9 7.9 8.5 8.7	Cells were fully extended after 6 to 6-1/2 minutes. Pressure at this stage was 0.75 psig.
From free hang to 2.5 psig	1C 2C	4.5 4.5	Cells were fully extended after 2-1/2 minutes. Pressure at this stage was 0.75 psig.
Deflation			
From 2.5 psig to vacuum-collapsed	1C 2C 3E 4E	7.9 9.3 11.5 11.5	Cells were at the state of free hang in approximately 3-1/2 minutes

1/ In the tests marked "C," the blower was connected to the center port of the causeway air supply header; in those marked "E," the connection was to the end port.

Table VII. Inflation Tests With Auxiliary System

No. of Cells Open to System 1/	No. of Cylinders Discharged	Pressure in Cells Open to System (psig)
2	1	1.1
4	2	1.7
6	3	1.6
8	4	1.6
10	4	0.6

1/ All cells were free hanging at atmospheric equilibrium. It is estimated that volume and pressure would be about 50% less where cells would be initially in collapsed state.

Table VIII. Launching Tests

Test No.	Launch Rail Height	Impact Deceleration Point Indicated 1/ (g)			Pressure Increase in Cells Indicated 2/ (psig)		Stresses 3/ (ksi)				Remarks
	(ft-in.)	No. 1	No. 2	No. 3	A	B	E-1 (comp)	C-2 (tension)	C-1 (comp)	E_R-1 (comp)	
1	9-2	27.0	28.3	31.0	9.3	8.2	22.5	—	21.3	—	12 restraining straps failed on the first launching; 1 additional on the second. Straps modified thereafter. 2 modified straps failed on the fourth launching. 1 on the fifth. No strap failures thereafter.
2	5-9	25.6	23.1	20.0	10.2	4.9	—	—	28.8	—	
3	10-8	28.6	32.5	33.3	7.2	7.8	36.3	20.2	24.1	12.6	
4	10-10	24.6	26.2	27.5	8.7	8.0	31.1	28.3	35.8	13.6	
5	11-0	25.1	26.7	26.7	9.4	6.8	—	15.3	23.6	9.8	
6	11-0	28.3	27.1	26.0	11.1	6.9	—	15.7	23.9	—	Initial pressure in cells 2.0 to 2.4 psig for tests 1 through 12; 1.5 psig for test 13.
7	5-7	22.9	19.1	18.5	9.2	8.2	—	21.8	23.7	—	
8	5-11	25.2	23.6	18.7	9.8	7.9	—	22.4	29.6	—	
9	6-6	30.8	26.2	19.7	9.6	8.6	—	22.8	30.8	—	Strain gages E-1 and E_R-1 failed after tests 5 and 6 respectively due to loss of waterproofing.
10	8-3	26.0	26.7	21.7	9.2	7.7	—	19.4	27.2	—	
11	9-8	28.4	28.9	21.7	9.8	7.9	—	19.4	25.7	—	
12	10-1	24.8	28.4	21.7	10.4	7.3	—	20.1	26.0	—	
13	11-0	22.8	29.7	22.0	10.8	8.0	—	20.5	26.9	—	

1/ Accelerometers mounted on outboard deck angle: No. 1 at connection end, No. 2 at midships, No. 3 at ramp end.

2/ Pressure transducers mounted to record pressure change in outboard corner cells: "A" at connection end, "B" at ramp end.

3/ Strain gage locations given in Figure B2.

Table IX. Flotation and Stability Tests[1]

Initial Inflation Pressure (psig)	Condition of Load	Comments
2.4	Unloaded 65-ton static load centered at midships	Section pushed longitudinally and laterally in calm waters. Stability in motion and maneuverability good. No problem in handling section. Approximately 1-1/2-foot draft for 65-ton load. No change in cell pressure with addition of load.
2.4	54-ton static load shifted outboard at midships	List approximately 11-1/4 degrees.
2.0	65-ton static load centered at connection end 54-ton static load centered at ramp end	Center of load on 23-foot load frame approximately 14 feet from connection end. Freeboard: minus 6 inches at connection end. Load centered approximately 14 feet from top of ramp. Deck just awash (minus 1 inch freeboard) at top of ramp.
1.5	Unloaded 65-ton static load centered at midships 54-ton static load centered at ramp end	Freeboard in unloaded condition same as for 2.4 psig test. Freeboard in loaded condition from 0 to 2 inches less than for previous tests with pressures at 2.0 to 2.4 psig. Cell pressure increased to 1.6 psig under 65-ton load.
1.0	Unloaded 65-ton static load centered at midships	Loss in freeboard from 2.4 psig test about 2 inches for unloaded conditions to an average of about 3 inches for loaded condition. Cell pressure increased to 1.6 psig under 65-ton load.

1/ Tests were conducted with unit stationary except as otherwise noted.

SUMMARY OF BEACHING TESTS IN SHELTERED AREA

Weather: Clear and calm.

Sea: Calm, no surf.

Beach: Uniform foreshore gradient approximately 1:10; fine sand.

Approach: Normal to beach, estimated at 4 to 6 knots.

First Beaching: First three pairs of cells were deflated. Resulting freeboard at ramp was 25 inches. The section skidded up high onto the beach in a near perfect landing. The ramp plowed a bit of sand. A jeep was driven up onto the section without any additional preparation. General evaluation of operation: Good.

Second Beaching: First four pairs of cells were deflated. Resulting freeboard at ramp was 17 inches. As the section rode in toward the beach, the ramp had a tendency to nose under, with water coming to the top of the ramp. On beaching, the ramp dug in like a dozer and did not ride up high onto the beach; however, the section was accessible to vehicular traffic without additional preparations. General evaluation of operation: Fair.

Third Beaching: Conditions and results same as for second beaching.

Fourth Beaching: First two pairs of cells were deflated. Resulting freeboard at ramp was 28 inches. Results were similar to first beaching, except for fact that section did not ride as high up onto the beach due to bottoming of third pair of cells. As on each of the previous beachings, the section was accessible to practically any traffic, excepting cranes, without additional preparations. In all cases the section retreated without difficulty.

SUMMARY OF BEACHING TESTS 'N UNPROTECTED AREA

Weather: Cloudy, some wind.

Sea: Slight to moderate, with 4- to 5-foot waves. Surf variable as indicated below.

Beach: Foreshore gradient approximately 1:3 at waterline, changing to approximately 1:10 thereafter; fine to coarse mixture of sand.

Approach: Normal to beach at estimated speed of 4 to 6 knots.

Fifth Beaching: Surf at 3-1/2 to 4 feet. Valves to first three pairs of cells were opened to allow deflation on the approach to the beach. Due to offshore currents, the section did not land normal to the beach. Also, failure to open main header valve allowed the cells to deflate only partially. As a result, the section beached and rode up onto the 1:10 sloping foreshore on partly deflated cells with the ramp remaining some 6 inches above the beach. Section retreated with lead cells still partially inflated. General evaluation: poor.

Sixth Beaching: Surf at 4 feet. First three pairs of cells were deflated. Again, offshore currents caused the section to hit the beach at a slight angle. Contact with the beach was made at low point of a swell causing the ramp to plow into the 1:3 foreshore slope and come to rest on the 1:10 slope, but not clearing the surge-water area. A tracked vehicle was driven up onto the section without additional preparations, but had to traverse a portion of surge-water area. General evaluation: Fair.

Seventh Beaching: Surf at 4 to 5 feet. Other conditions and results similar to sixth beaching, but section rode in normal to beach.

Eighth Beaching: Surf at 4 to 5 feet. First two pair of cells deflated. Causeway rode in well and high up onto the 1:10 sloping foreshore to afford immediate access to traffic. General evaluation: Good.

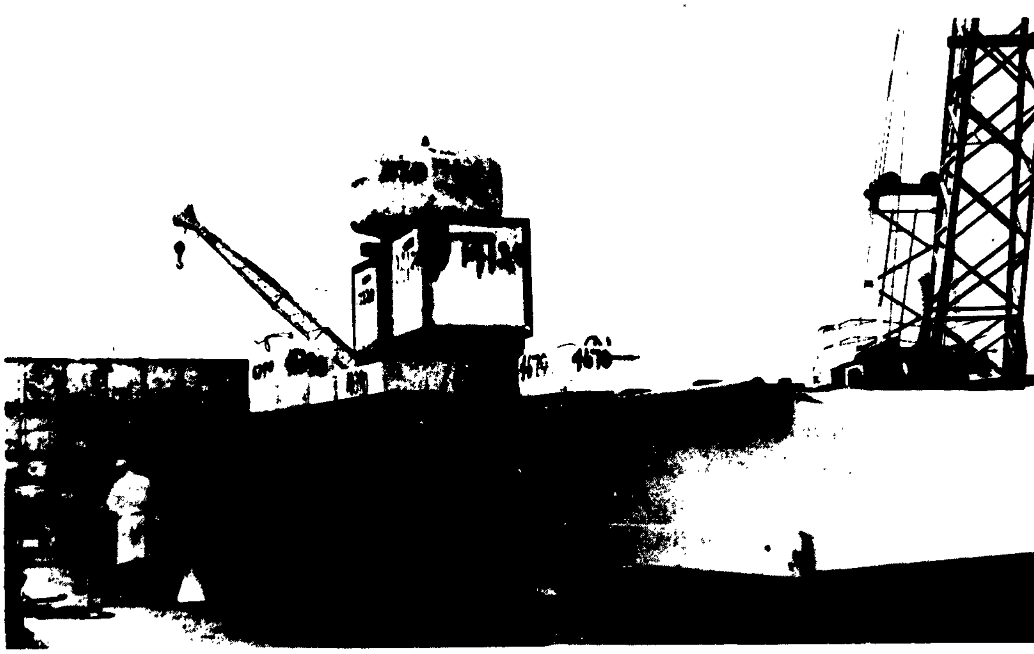
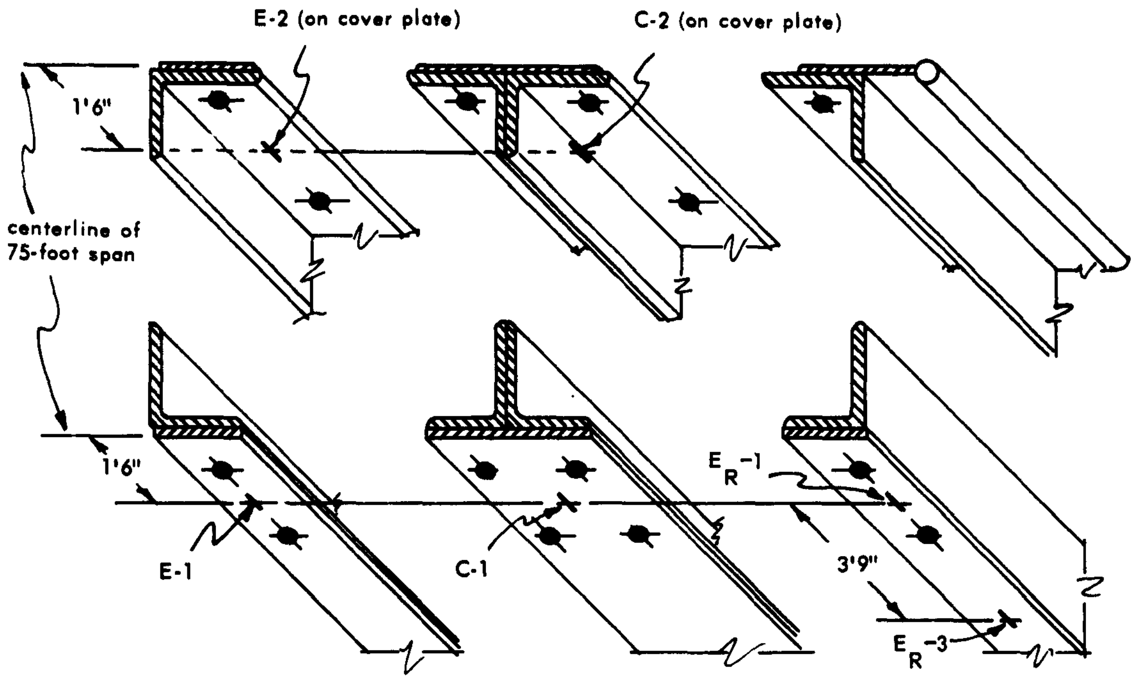


Figure B-1. Static test, 75-foot simple span.



Plane section at centerline of 75-foot span
no scale

Property	E	C	E_R
Assembly	8x6x1/2	8x6x1/2	8x6x1/2
Cover plate			
Top	6x1/2	12x1/2	8x5/8+2-1/2pipe
Bottom	6x1/2	12x1/2	6x1/2
Moment of Inertia (Net)	3290	6580	4000
Section Modulus			
Top	208	416	305
Bottom	197	394	205

Notes:
1. Girder notation E, C, and E_R refer to assembly angle girders: exterior, center, and exterior with launching rail respectively.
2. Strain gages are referenced by represented girder and numbered even at the top, odd at the bottom. Gages 1 and 2 are on the girder proper in the space between modules; gage 3 is on the girder proper in the space within a module.
3. Properties listed in the table are in units of inches.

Figure B-2. Assembly angle girders.

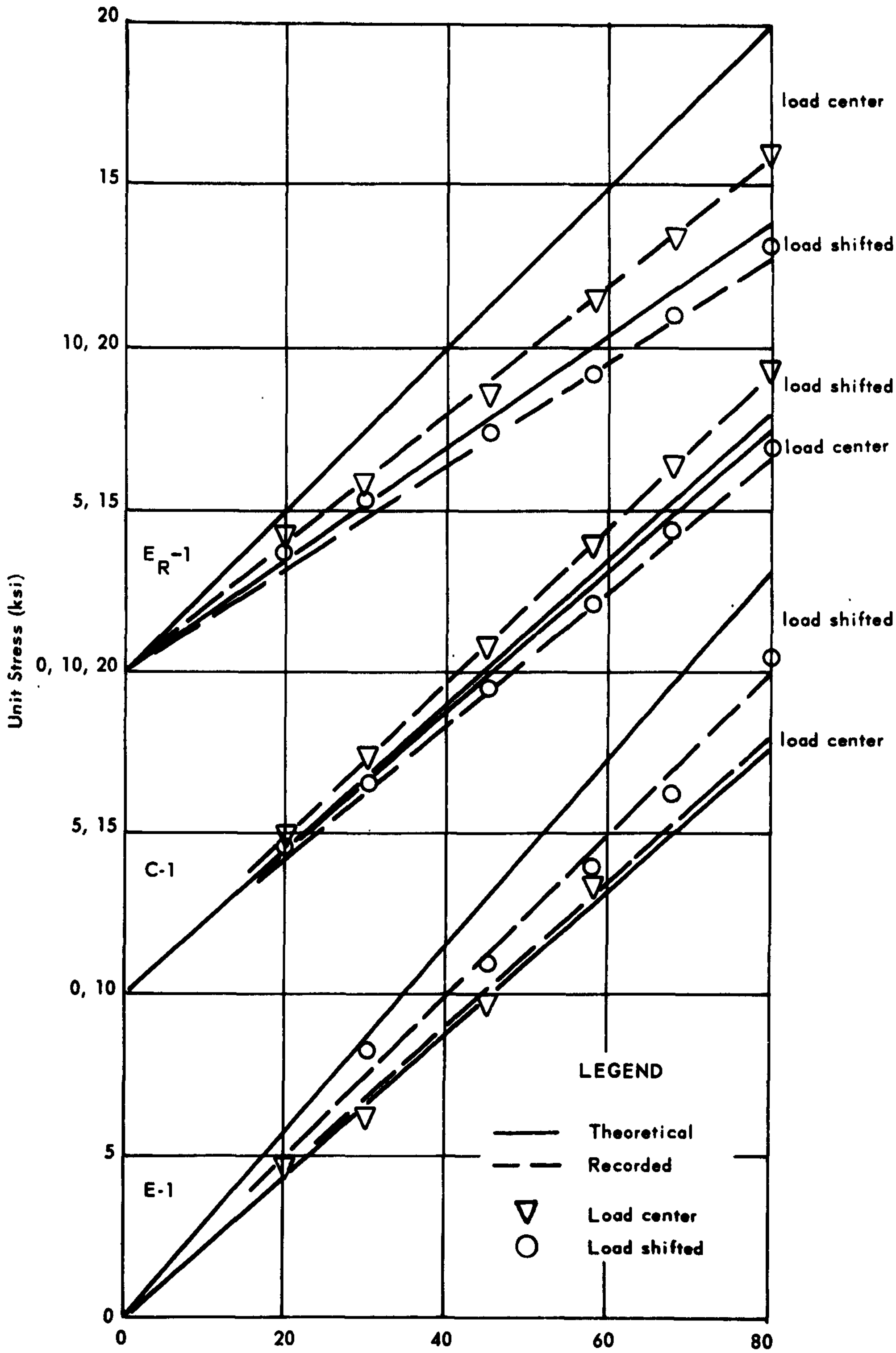


Figure B-3. Live-load stresses, theoretical versus observed.

Initial impact is assumed at first pressure rise; this is followed by a high rate of pressure increase and deceleration. Peak pressures and decelerations were coincidental, occurring approximately 0.08 second after initial impact, followed by peak strains about 0.05 second later, or 0.13 second after initial impact. Thereafter, the pressures and decelerations decay rapidly, while the strains go through a series of three pronounced reversals over about a 0.6-second period, with each cycle dampening in turn (section flexing after impact).

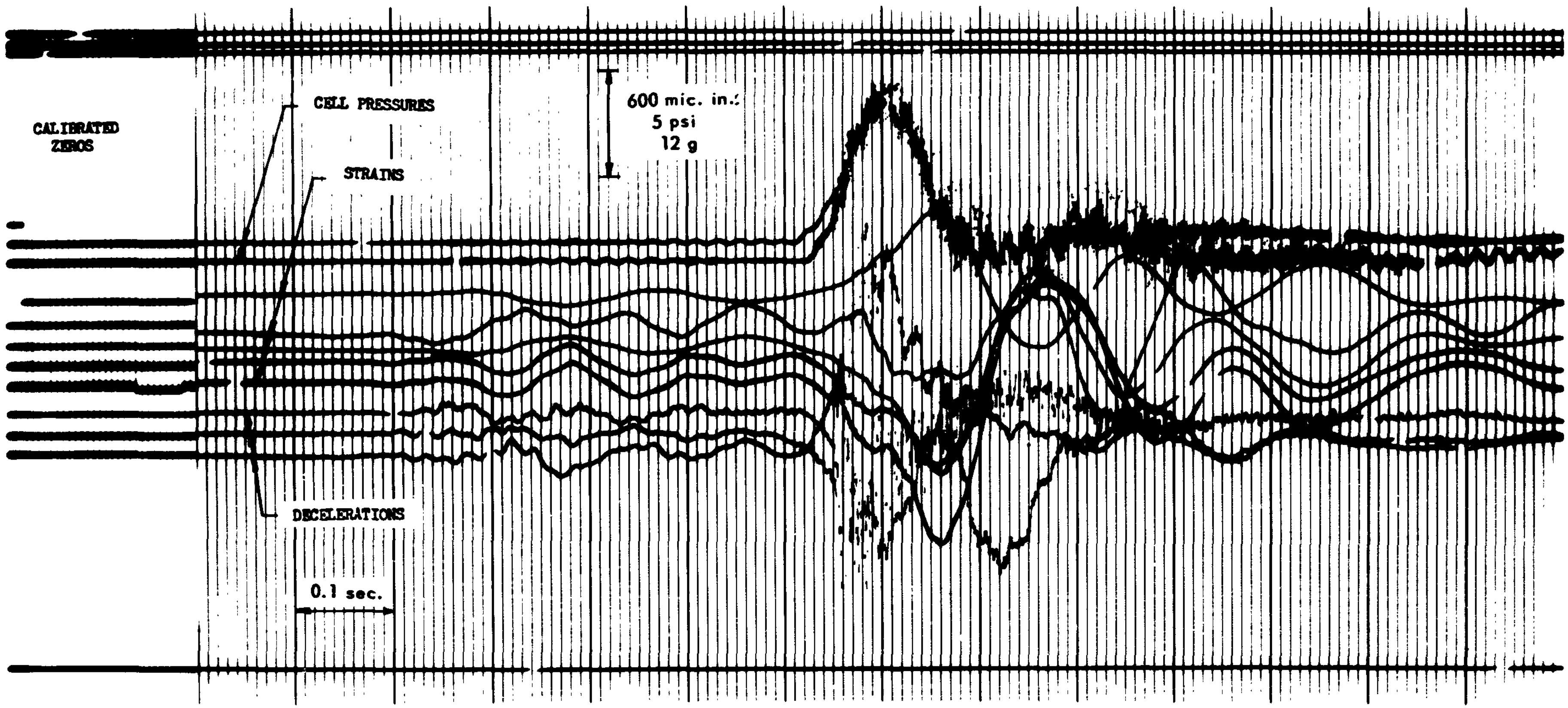


Figure B-4. Photo reproduction of recorded data.

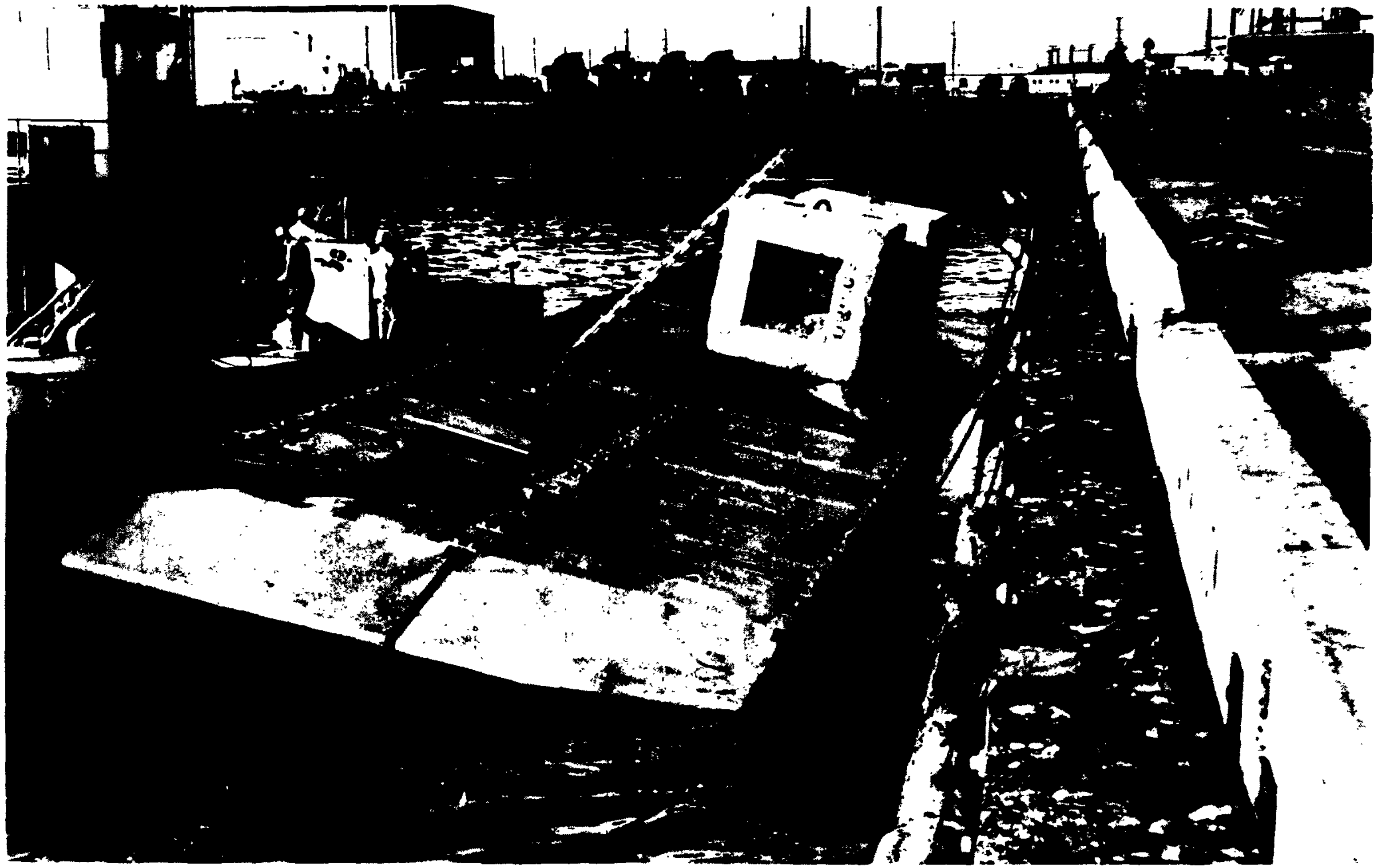


Figure B-5. Stability test with 54-ton load shifted. List is approximately 11 degrees.

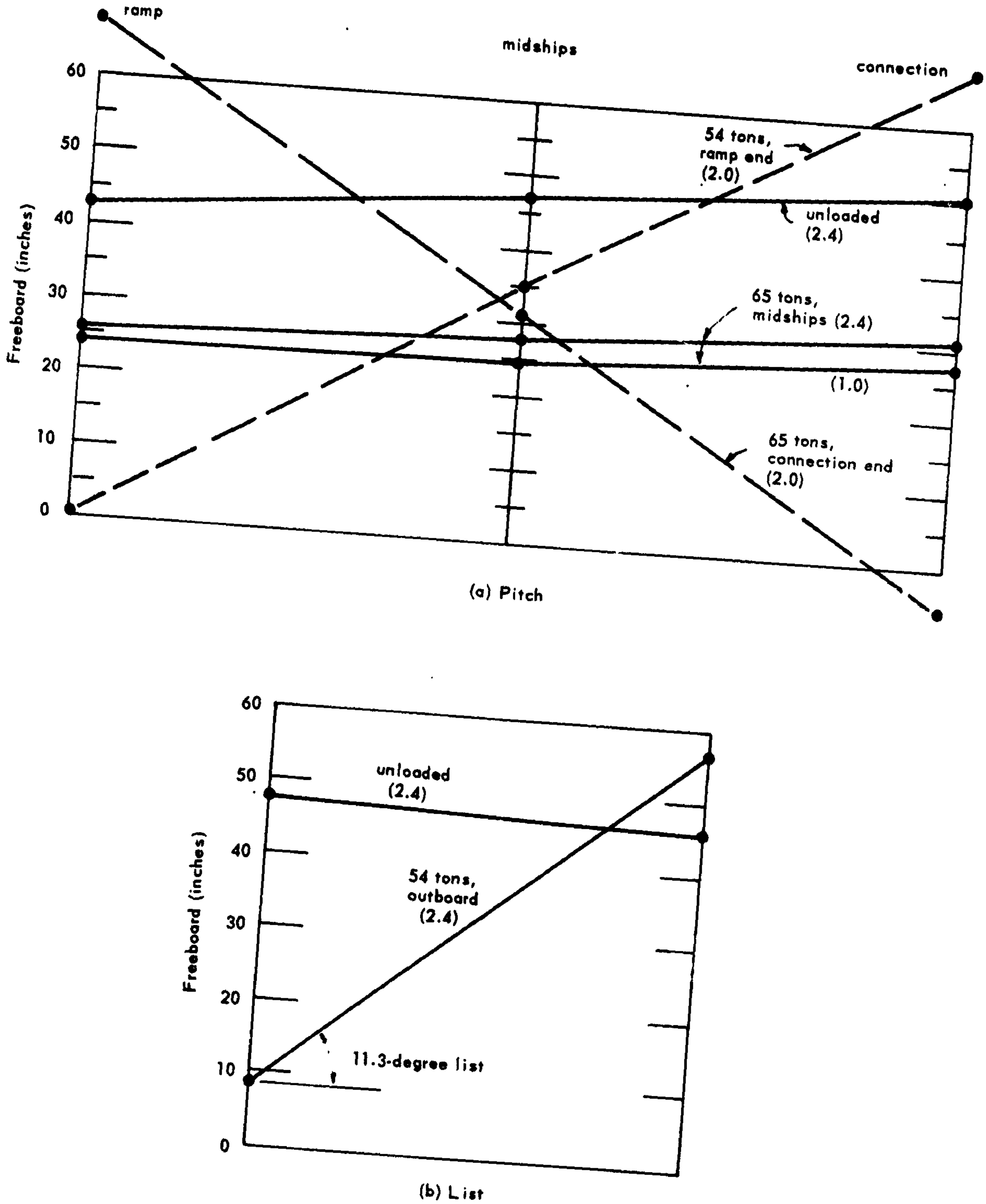


Figure B-6. Freeboards for various conditions of load. Initial cell pressures in psig are given in parentheses with each curve.

Appendix C

OPERATIONAL EVALUATION TESTS

Test 1, replacement of damaged air cells in the inflatable-causeway beach section, was conducted tc determine the maintainability of the inflatable causeway in the operational environment and to evaluate the auxiliary air supply which is installed internally in each inflatable section. Two auxiliary air bottles were expended to inflate the affected pair of cells after each new cell had been installed. Times to replace the cell and to inflate it with auxiliary air were determined by stopwatch.

Test 2, repair of damaged air cells using patching kits provided, was conducted to determine the extent of air-cell puncture or tear damage which can be repaired in the field; time required to effect this type of repair; and the reliability of the patched cell in the operational environment. Manufacturer's instructions provided with the kits were followed in applying patches to damaged cells. Time to repair was determined and was measured from commencement of the actual patching operation until the cell was ready in all respects for reinstallation in a causeway section. This time included a 24-hour drying period recommended by the manufacturer. All repaired cells were reinstalled in a causeway section and periodically inspected throughout Phase II of the evaluation for patch wear and retention of air in the cell.

Test 3, loading inflatable causeway sections on the side of an LST, was conducted to determine the capability of double-tiering these sections. The methods of self side-loading and loading with a 100-ton floating crane were used. Time to load sections was determined and was measured from commencement of rigging the equipment required for side-loading and continued until the sections were completely lashed down.

Test 4, inflating or deflating causeway sections simultaneously, was conducted to determine the time required to inflate and deflate inflatable sections and to evaluate the engine-blower unit and the air-supply system installed within the sections. The center ports were used when inflating and deflating sections. Time to inflate and deflate was determined and was measured from the time the manifold on the engine-blower was opened until all cells were fully extended or completely retracted into the modules.

Test 5, launching inflatable sections from the side of an LST and assembling these sections into a causeway, was conducted to determine if these sections can be side-launched from the double-tiered position; to what extent they are capable of withstanding the impacts of side-launching; and whether or not they can be connected one to another and to NL pontoon sections.

Test 6, using an inflatable causeway section as a lighterage barge, was conducted to determine the load capacity, stability, speed, and maneuvering characteristics of an inflatable section being utilized to transport cargo. A 06DH propulsion unit was mounted on the seaward end of the beach section for the conduct of this test. Speeds were determined by timing the section between two sets of range markers placed 150 yards apart on nearby piers. The course was run in both directions, and the times were averaged to offset the effects of wind and current. The propulsion unit was operated at full speed during all measurements. Advance and transfer were measured by commencing a full turn as a set of markers placed on a pier was passed (advance) or approached (transfer) and marking the barge's position from the pier after completing a turn of 90 degrees (advance) or 180 degrees (transfer). The distance between these two points on the pier was then measured with a steel tape measure.

Test 7, transport of the inflatable sections, double-tiered, to an operational site, was conducted to determine if the lashing and tie-down scheme is adequate to withstand the action of wind and sea over great distances and to determine what effect this action has on the deflated air cells. The four sections were side-loaded, double-tiered, on an LST for these tests. Lashings and tie-downs were in accordance with Y&D Drawings 879077 and 879078. All cells were vacuum-deflated before getting underway. An underway transit of 65 hours was conducted, during which rough weather was sought. During this transit, the sections were double-tiered, two to a side, in the forward positions on the LST.

Test 8, beaching the inflatable causeway, was conducted to determine the capability of these sections to land on various types of beaches under different surf conditions and to evaluate the resultant ramp as an access for vehicular traffic from sea to shore. Causeways were composed of from 4 to 12 sections, with the inflatable sections assembled in various combinations with NL pontoon sections. The inflatable beach section was always used as the shore end of the causeway. Beaches ranging in gradient from about 1:20 to 1:60 were used for this test. From 0 to 3 pairs of leading air cells in the inflatable beach section were deflated on the approach to the beach.

Test 9, trafficability, was conducted to determine the capability of the inflatable causeway to provide a roadway for vehicular traffic from ship to shore. Various vehicles, ranging in size from a 1-1/2-ton jeep to a 62-ton tank were used during these tests. Speeds were determined by timing the vehicle for the length of the causeway. Spacing was maintained by instructing the drivers to maintain a particular number of causeway sections between themselves and the vehicle ahead.

Test 10, retracting the inflatable causeway, was conducted to determine the capability of the causeway to be retracted from different types of beaches under various conditions. Retracting tests were conducted at all states of the tide and with the leading cells in the inflatable beach section both inflated and deflated.

Test 11, assembly of an inflatable section, was conducted to determine an amphibious construction battalion's capability to construct these sections in the field, utilizing their normally available personnel and equipment, and the manhours required to complete a single section.

Appendix D

SUMMARY OF ACB ONE REPORT

1. Overall, the inflatable causeways are capable of doing the job of the present NL-type causeways with the exception that they will not endure the damages incurred during everyday training exercises. They will do the job for one or two landings, but for day in and day out operations, they will not stand up under the pounding of shifting berth spaces, etc., by warping tugs and barges. If it were feasible to put them in and take them out of the water during operations, their lifetime might be increased.

2. Ease or difficulties encountered while conducting the tests are as follows:

Side Loading. The lifting gear falls are to use twofold instead of threefold purchases in order to afford adequate deck travel for the stern anchor wire. The anchor engine is capable of lifting a section in high gear. Portable fair-lead rollers used to double-tier are too heavy for two men to position. Back-loading outboard sections in rough sea is damaging and dangerous and not recommended. Side-loading with a crew can be accomplished, but when outboard sections are positioned on inboard shelf-bracket, the swinging motion will pinch inboard deflated cells.

Launching. Due to the additional lashing gear, more time is required to prepare for launching.

Lashing Gear. The lashing gear was nor tested adequately because of calm seas in the area at the time of the test. Up-and-over "A" chains to outboard sections should be rigged through inboard cell modules to give a straight lead to the deck clover leaf and eliminate going over the inboard section.

Inflation and Deflation. Valves could be more accessible through closure plates; otherwise, no problems for this test.

Cells. Cells stood up well during tests; however, restraining-strap ports in module edges should be rounded off, because the present sharp surface cuts the straps.

Replacement and Installation of Cells. All cells are easy to change except the end cells, which, because of the contour of the end-can modules, makes them vary hard to remove or install.

Trafficability. Trafficability was excellent for all tests, but protruding hinges and closure-plate brackets must be recessed.

3. For training requirements, providing an LST is available, the inflatable causeway can be made ready in one work week.

4. The same safety precautions currently used for NL causeways apply to the inflatables. Hold-back chains must be placed on the causeway so they can be reached from the LST deck instead of from the top of the causeway.

5. Specific comments are as follows:

a. Damaged cells can be replaced successfully in 2 hours on a beached causeway in a 3-foot surf.

b. The emergency air-supply system is adequate, but compressed-air-bottle valves have a tendency to freeze up. This can be corrected by using an inert gas (e.g., nitrogen).

c. The cell-repair kit is practical for tears or holes up to six inches. However, the 24-hour application time appears too long.

d. All classes of LST's are capable of double-tiering, with minor adjustments to side-loading rigs. The lashings appear to be adequate in the tests conducted; however, rough weather was not encountered to allow full evaluation of the lashings.

e. The engine blower unit is more than adequate to inflate and deflate four sections simultaneously.

f. The air-supply system performed adequately during all tests.

g. The inflatable sections can be launched successfully from an LST, and they can be assembled to each other and also to NL types.

h. The inflatable section can be rigged as a lighterage barge and has carried 62 tons at a speed of 5.8 knots, with the load evenly distributed.

i. Inflatable sections performed exceptionally well during beaching and retracting.

j. It was found that, for ideal beaching, the beach-end cells should be deflated until the lower edge of the ramp is skimming the surface of the water. In retracting, if the beach-end cells were inflated, the causeway came off easier; however, it also came off fairly easy when cells were not inflated.

k. Inflatable sections provided an adequate roadway for vehicular traffic up to 62 tons, the heaviest vehicle tested.

l. The only time a sand ramp will be required on the beach is to ensure the landing of low-slung missile trailers. Again, dunnage could replace the sand ramp.

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