ST. ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

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EVALUATION STUDIES OF THE UNITED STATES RUBBER COMPANY WAVE BLANKET AND WAVE TRAP

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PREFACE

The evaluation studies described herein were designed to establish the effectiveness of certain types of mobile floating structures in providing protection against ocean-type waves. The moored structures were intended to provide an artificial harbor of a temporary nature.

Two separate types of structures were evaluated. One type called the "wave blanket" consisted of a moored, permeable, flow-resisting structure floating just below the wave surface. A second type called the "wave trap" consisted of a moored, surface-floating, horizontal sheet supporting a deeply submerged, horizontal anchor sheet.

Both structures were tested in the Laboratory at about one-eighth of full scale. The tests under a range of wave conditions involved determinations of: attenuation of wave height, magnitude of wave reflection, and magnitude of mooring forces.

The tests served to show that either of the structures could effectively attenuate the wave height if the extent of the structure was large relative to the length of the wave. The report makes no attempt to evaluate the economic aspects or total feasibility of the test units. A documentary motion picture film serves as a supplement to this report.

The tests discussed in this report were undertaken in the facilities of the St. Anthony Falls Hydraulic Laboratory during the period February to June 1960 and were sponsored by the United States Rubber Company.

The scope and objectives of the study were established initially by conference with Vice Admiral C. B. Momsen (Ret.) and Henry F. Miller for the United States Rubber Company and subsequently by mutual agreement of the Rubber Company and the Laboratory. The program was under the general direction of Lorenz G. Straub. John F. Ripken was in direct charge of the experimental work and preparation of this report and a documentary film of the studies.

Special credit is due to Charles E. Bowers for his guidance relative to nearly all aspects of the program and to Goffe J. Erickson for his help in the execution of the program. Credit is also due to John A. Almo, Alvin G. Anderson, Roland H. Daugherty, Meir Pilch, and Floyd E. Thomas for their varied contributions. Loyal A. Johnson edited the manuscript with the assistance of Marjorie Summers.

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I. INTRODUCTION

Inherent in man's use of large bodies of water is the need for sheltered area protected from the destructive force of gravity waves. In natural harbors this protection is provided by structures which absorb or reflect the energy of these waves. The structures vary from long sloping beaches of fine sand to vertical cliffs of massive rock. The sloping beach largely dissipates the wave energy in viscous fluid action whereas the bluff structure serves mainly to reflect the wave energy back toward the source.

In the development of man-made harbors of a permanent character, breakwater design has generally paralleled the designs of nature with a trend toward rigid structures having a front of maximum steepness consistent with the economy of available materials. The inherent energy of large waves usually leads to the control breakwater being a structure of formidable cost.

In modern marine activities there is a growing need for wave absorbers or reflectors offering temporary or short-lived protection at less cost than would be required for a permanent breakwater. These units would be of value in protecting anchorages and loading operations, in permitting military amphibious landings, in rescue and salvage operations, in offshore marine construction, in offshore drilling and mining, and for small boat marinas.

In addition to the described shore protective works there is also a limited need for floating absorbers which can provide quiet water conditions in the open ocean. In an attempt to provide an answer for these needs the U. S. Rubber Company has developed new structures which adapt existing materials of their manufacture to the wave control problem. The development has led to two distinctly different types of wave absorbers--notably a shallow moored floating structure and a moored floating structure of substantial depth. These units were subjected to a variety of mild field tests during their development and to limited laboratory tests at the David Taylor Model Basin, Department of the Navy [1].* In light of these tests it was decided to conduct

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*Numbers in brackets refer to the List of References on p. 39.

additional evaluation tests at the St. Anthony Falls Hydraulic Laboratory under more severe and more controlled conditions with the intent of better determining the mechanism and end usefulness of the proposed designs.

Because of the wide variation in natural conditions and the very limited history of operations with floating wave absorbers, design criteria for these units are not as yet formulated. In light of this the tests which were conducted at the St. Anthony Falls Hydraulic Laboratory and which are described herein are quite general in character.

II. THE WAVE BLANKET--CONSTRUCTION AND ASSEMBLY

The wave blanket is a proprietary design of wave absorber developed by the United States Rubber Company. It consists of a moored blanket of permeable material designed to float just below the surface of waves. The design concept of the wave blanket assumed that the orbit and translation velocity of the wave water would force a flow through the permeable structure of the blanket. The flow resistance occasioned by the dense permeable structure was intended to provide an energy loss sufficient to dissipate the wave strength.

The blanket units supplied by the U. S. Rubber Company were assembled from sheets of a new type of three-dimensional fabric woven from stiff plastic fibers varying from 0.014-in. to 0.020-in. diameter. The fabric employed in the tests was designated as 4-ply Trilok and was about 1/2 in. thick. The nature of the fabric construction is shown in Fig. 1. The fabric is inherently slightly buoyant in fresh water.

The blanket assembly consisted of two sheets of Trilok fabric. The upper sheet had a corrugated or sine wave form and the lower sheet lay flat. The two sheets were stitched and lashed together with plastic cording to form a unit 8 in. thick as shown in Fig. 2.

The unit blanket assembly was edge and cross stiffened by the addition of white polyethylene tubing of 1/2-in. outside diameter and 3/8-in. inside diameter. The tubing was securely lashed to the fabric as shown in Fig. 2.

Blanket assemblies tested in the Laboratory consisted of basic units slightly less than 9 ft wide and 8 ft 4 in. long. These basic units were lashed together to form test assemblies of the lengths of 16.6, 25, 33.4, and

50 ft. The leading edge of the entire blanket assembly was additionally stiffened by lashing on a metal tube which served to spread the load of the mooring cable across the blanket as shown in Fig. 2.

Initial tests demonstrated that, with waves having a length greater than the blanket length, the blanket was subjected to substantial alternate tension and compression along its length. Marked buckling occurred at the joints between blanket units during the compressive phase of the cycle. In later tests additional stiffening was achieved at these joints by providing additional 1/2 in. diameter splice tubes at the top of the blanket to give continuity to the longitudinal stiffener tubes.

In tests which involved multiple layers of the basic blanket unit the individual layers were securely lashed at close intervals around the outside edges of the stack of blanket units and at spaced intervals in the interior. Mooring stiffeners were provided across the front of the top and bottom layers of these stacked units. Tests were made on a two-layer blanket of 16-in. total thickness and a three-layer blanket of 24-in. total thickness. Additional tests were run on a stepped blanket which was three layers or 24 in. thick at the front end, two layers or 16 in. thick at the midsection, and one layer or 8 in. thick at the trailing end. In this three-step blanket each thickness had a length of 16.6 ft thus providing a total length of 50 ft.

III. THE WAVE TRAP--CONSTRUCTION AND ASSEMBLY

The wave trap is a proprietary design of wave absorber developed by the U. S. Rubber Company. The trap consisted of a large, thin, rather impermeable, floating sheet fitted with numerous pendant cords supporting a large, thin, horizontal weighted valve sheet in a position slightly above the water bottom. The valve sheet was positioned in the lower water and was thus subject to only minor vertical oscillations. The float sheet was positioned in the surface water and was thus subject to the large vertical oscillations or full amplitude of the waves. The tie lines between the two sheets served to exert a lift on the valve sheet, a resistance to the upward motion of the float sheet, and a consequent damping force on the surface wave. The numerous flap valves in the valve sheet permitted this weighted sheet to settle down during passage of the wave trough, yet permitted valve closure and a retarded upward movement during passage of the wave crest.

The details and assembly of the wave trap are shown in Fig. 3.

The float sheet of the trap was made of 18 in. wide unit strips which were lashed together to form one large, rather impermeable sheet. The basic float sheet strip consisted of a 1/2 in. thick layer of flotation material stitched to a nonporous coated synthetic fabric which served as the load carrying sheet. The flotation layer was a flexible foamed plastic. The coated fabric strip was reinforced by rubber hoses stitched to its edges and by metal rods which spanned between the hoses in a stitched pocket in the fabric. These rods were anchored in the hoses. The hose was a fabric reinforced rubber of 5/8-in. outside diameter. The transverse metal rods were 1/4 in. diameter stainless steel and were spaced at 6 in. centers along the strip.

The 18 in. wide float sheet just described was fitted along each edge with pendant cords on 6-in. centers. In the test unit these lines were 40 in. long and supported the 18 in. wide valve sheet at their lower ends. The lines were of woven plastic fibers.

The valve sheet consisted of a coated, synthetic fabric, edge stiffened with hose, and transversely stiffened and weighted with metal rods in a manner similar to the float sheet. In the valve sheet two rods were placed in each stitched fabric pocket. Only one of these rods was anchored in the edge hoses; the second rod was slightly shorter and was simply confined by the fabric stitching. In this sheet, however, were closely spaced holes of 1-5/8-in. diameter fitted with 2-3/4-in. by 3-in. coated fabric flaps which served as check valves. The holes were arranged in a staggered pattern with only about 1/2 in. of fabric between holes. The valve flaps readily opened to permit upward flow but closed against downward flow. The valve sheet unit strips were 18 in. wide and were lashed together at their edges at about 12-in. intervals to form one large valve sheet.

For the tests described herein the assembly consisted of six 18 in. wide strips lashed together to make a single wave trap just slightly narrower than the 9-ft inside width of the test channel. The assembly was tested in the single length of 20 ft.

A metal stiffener tube of length slightly less than 9 ft was lashed to the front of the float sheet assembly to serve as a load distributor for the attached mooring cable.

Initial tests with the above described construction led to a request by the sponsor that additional flotation be added to the float sheet and additional weight be added to the valve sheet. The additional flotation was provided by attaching one additional layer of 1/2-in. foamed plastic to the underside of the float sheet. The addition was made for the full 9 ft of width but for only the central 10 ft of the 20-ft trap length. The additional weight consisted of forty-one 1/4-in. round steel bars of 9-ft length which were attached at 6-in. centers along the 20-ft length of the valve sheet. Additional lashing was also provided between the unit strips of the assembly. The former spacing of about 12 in. was reduced to about 3 inches.

IV. WAVE GENERATING FACILITIES

All of the wave tests described in this report were two-dimensional in character and were conducted in a smooth concrete channel of 9-ft width, 6-ft depth, and approximately 220 ft of effective length. A 20-ft length near the midportion of one side wall of the channel was equipped with glass windows which permitted visual and photographic observations of the full water depth and of the far wall of the channel which was marked with a grid system having 10-ft increments of length and 0.25-ft increments of height. The channel was filled with fresh water from the municipal supply. The water had a temperature of about 50 degrees F during the tests. The still-water depth in the channel was maintained at 4.5 ft. A 50 hp, bottom-hinged, flat plate wave generator of variable speed and stroke as shown in Fig. 4(a) originated waves at one end of the channel as typified by Fig. 4(b). A permanent high efficiency wave absorber of sloping permeable construction was located opposite the wave generator to minimize any wave reflections from the far end of the channel.

The test wave absorbers were moored with their front edge at a consistent distance of 110 ft shoreward of the wave generator and 110 ft seaward of the permanent absorber.

Because of a lack of specific design criteria for prototype floating wave absorbers, the test waves were varied over the maximum practical range permitted by the Laboratory facilities. In the case of wave length (distance between two successive crests) the values varied from 5 to 40 ft. In the case of wave height (vertical distance between crest and trough) the values varied substantial factor in the practical consideration of the absorber for deep water conditions is the problem of mooring or stabilizing. It should be noted that mechanically generated waves do not exactly duplicate the random characteristics of natural wind-generated waves but the differences are considered minor in the general effect on the character of the test examined herein.

V. WAVE MEASUREMENTS

The effectiveness of a given wave absorber can be arbitrarily evaluated by the extent to which the wave height is reduced or attenuated as it passes over the absorber. While it would be possible to evaluate the attenuation in terms of the reduction in energy, steepness, sea state, or some other parameter, the wave height is a directly measurable quantity that may be readily converted to most other parameters.

In the subject tests the wave heights were measured by an instrument which was mounted on a reference datum above the water surface and detected the surface height variation acoustically. The instrument employed a sound head which both emitted a sound signal and received the sound reflected from the water surface. The transit time of the sound beam from the reference datum to the water surface and back to the datum was electronically measured and converted to a voltage value that was recorded as a calibrated height variation on a standard paper chart recorder. The sonic wave meter, a development of the St. Anthony Falls Hydraulic Laboratory, is described in Reference [2].

In the tests two wave recorders were employed. One was placed seaward of the absorber to measure the incident wave and the other was placed shoreward to measure the transmitted wave. The more seaward of the two heads was placed approximately 10 ft seaward of the mooring force dynamometer which for most tests placed the head about 55 ft seaward of the leading edge of the absorber. The shoreward head was placed approximately 125 ft from the seaward head.

Because of the previously mentioned wave reflections in the channel it was desirable to measure the waves in such a way that the true incident and transmitted waves could be divorced from any obscuring reflections. A technique for accomplishing this consisted of mounting the sonic head on a carriage which permitted traversing in a horizontal plane above the wave channel axis. For a given incident wave and reflection condition the seaward head when mounted stationary would give a wave trace in accord with the left-hand portion of Fig. 5. This record then represented a local variation of wave height and was a superpositioning of the incident wave and the reflected wave. However, if the sonic head was slowly traversed along the channel axis a distance of at least one half wave length the resulting wave trace embraced all phases of the superpositioning of the two waves as shown in the right-hand portion of Fig. 5. If the crests of the latter trace were connected by one envelope curve and the troughs by a second envelope curve, the minimum node distance, H_N, and loop distance, H_L, could be determined therefrom as shown. By analysis of the superpositioning of two curves of equal frequency but differing amplitude it may be shown that the height of the larger or incident wave is approximately given by $H_I = (H_L + H_N)/2$ and the height of the smaller or reflected wave is approximately given by $H_R = (H_L - H_N)/2$. The value of H_I was of prime interest in these tests in order to evaluate the attenuation action, but the value of H_R was also of interest in that it indicated the extent to which reflection was involved in the attenuation process.

The records of the shoreward or transmitted wave height, H_T, were obtained in the same manner as for the incident wave. Reflection values superimposed on the transmitted wave were in general insignificant.

The wave attenuation was represented by the relation $(H_I - H_T)/H_I$ and was expressed as a percentage value.

In the Appendix data the reflected wave height is expressed as a percentage of the incident wave height.

The length of the wave was established by the wave generator settings which had been previously calibrated. The resulting wave was checked visually and by a frequency measurement of the wave generation.

VI. THE MOORING SYSTEM

Stabilization of the horizontal position of a floating wave absorber is necessary to its function. Such stabilization in a large prototype installation requires the application of very substantial forces and consequent consideration of load handling problems both within the absorber structure and in the external mooring system. While it was beyond the scope of these tests to establish or develop optimum mooring procedures an attempt was made to employ model test conditions which would serve to give some insight into the mooring forces which might be encountered. To this end the tests were made with the absorber structure moored by a single cable running at a selected slope angle between the mooring tube lashed to the front of each absorber and a mooring anchor on the channel floor.

The arbitrary slope angle selection for the bulk of the tests was 1:10 which for the 4.5-ft water depth required that the bottom anchor be located 45 ft seaward of the absorber. Limited tests were also run at slopes of 1:6 and 1:4.

The peak forces required to stabilize an actively oscillating wave absorber are inherently related to the mass contained within the absorber boundaries, the motion characteristics of the absorber in a given wave, and the degree of constraint imposed by the mooring system. Since the mass and motion characteristics were presumably to be simulated in these model tests the determination of representative model forces would be dependent on the selection of a mooring system having suitable constraint.

The constraint characteristics of the system may involve the elastic or gravitational extensibility inherent in the materials normally used in an elementary mooring or may involve the addition of special components possessing large elastic or gravitational extensibility. Since neither the sponsor nor the literature provided well established procedures and materials for an end design of mooring it was considered most conservative to conduct the tests with a mooring providing a maximum of constraint through a minimum of elasticity or damping. To this end mooring in the model was supplied by a high strength lightweight cable. The cable selected was a 1/16-in. stainless steel aircraft type composed of a 7 by 7 stranding of wires of 0.007-in. diameter and having a rated breaking strength of 480 lbs. In light of the relatively firm constraint of this cable the observed peak load values are believed to be excessive or conservative if extrapolated and applied to prototype systems which would normally involve greater force damping action than was provided in these model studies. There is, however, a possibility that an excessive freedom of constraint could be provided with resulting forces being even greater than those for a system with maximum constraint as tested.

In all tests with the wave blanket only frontal moorings were required for position stability. However, in the case of the wave trap tests, certain low steepness waves produced a modest forward propelling force. The wave trap was stabilized by providing a rear mooring for these conditions. No force measurements were made for these rear moorings.

Use of a simple sloped cable for providing the necessary horizontal stabilizing force also involves the development of a downward vertical component of force at the junction of the cable with the absorber itself. For most of the test conditions the inherent buoyancy was adequate but in some tests the addition of buoyancy to the wave blanket was required. Early tests with the wave trap also pointed out the need for additional buoyancy. This was added as previously described.

VII. THE MOORING FORCE DYNAMOMETER

The mooring forces were evaluated from a dynamometer which measured the tension in the mooring cable at the bottom anchorage. The elements of this system are shown in Fig. 6. These included a low friction pulley at the base, a streamlined housing covering the riser cable, and a knife-edged cable hanger bearing on a cantilevered load beam. The load beam deflection was converted to an electrical voltage signal by a Schaevitz linear differential transformer consisting of a magnetic core moving with the beam deflection and a stationary mounted transformer coil. The variation in voltage signal was recorded on a Sanborn paper chart recorder.

The instrument was simple and rugged and provided a linear signal which was usually check calibrated at the beginning of each day's run or when changing beam rods. The beam rods could be quickly changed to adjust the instrument sensitivity to a given test range. For the tests the mooring force was found to vary between 0 and 130 lbs.

VIII. WAVE BLANKET--TEST RESULTS

A. Attenuation Studies

1. Influence of Wave Length, Wave Steepness, Blanket Length, and Blanket Thickness

In order to determine the wave height attenuation of the various lengths and thicknesses of blanket when exposed to various wave lengths and steepnesses, wave height measurements were made in the facilities previously described. These measurements are tabulated in Appendix A and typical values are plotted in Figs. 7, 8, and 9. In these plain coordinate plottings the performance is characterized by the wave height attenuation expressed in per cent and the dimensional characteristics of the wave and absorber are expressed by the ratio of wave length to blanket length. Both of the plotted parameters are dimensionless in nature and are believed to be those which are most meaningful in representing the variables involved. The steepness characteristic of the wave, which is also a dimensionless property, has been plotted as a supplement to the principal variables.

Because of the variety of factors that influence both the character of the blanket and the character of the wave, no one simplified plotting of the test data can both detail and summarize the performance. To this end Figs. 7, 8, and 9 contain detailed point plottings of representative tests while Fig. 10 represents a summary plotting of all the tests relating to the wave blanket. For clarity and perspective, individual test points have been omitted from Fig. 10 and the data treated as broad inclusive bands representing significant differences.

2. Influence of Size or Scale

An important requirement of any modelled hydraulic test is the establishment of the modelling laws or basic forces which dominate the occurrence. For model tests of many hydraulic designs previous experience has already defined the dominant force system and the related model laws of similitude. For such tests it is usually adequate to operate at only one suitable size of model and the model data therefrom may then be extrapolated to any desired prototype size by use of the established laws of similitude. However, in the case of the wave blanket there was no precedent which clearly established the force mechanism and the similitude relations. It was then important to operate the tests in such a way as to clarify these relations. Analysis of the physical forces which might dominate the fluid dynamics of the wave blanket action indicate that both viscous and gravity forces may be involved. The original theory in support of the Trilok wave blanket design assumed that viscous action in the permeable blanket structure controlled the attenuation effects. The extent to which gravity was involved was obscure.

For the desired test program neither the blanket fabrications supplied nor the main test channel provided a substantial range of test size for clarification of scaling principles, but a limited variation of size was possible by operating the channel at a reduced depth. Tests 177-188 (see Appendix A) are tests of a single-layer blanket of length 16.6 ft operating in a water depth of 3.0 ft rather than in the 4.5-ft depth generally employed. Since the standard blanket thickness of 8 in. was used for both the 3-ft and 4.5-ft tests it is necessary to compare the tests at the two depths on the basis of comparable thickness to depth ratios. For the purpose of this comparison, in Fig. 11 the new data have been superimposed on the data as previously summarized in Fig. 10. It may be seen in the dimensionless plotting of Fig. 11 that comparable conditions of thickness to depth produce essentially the same attenuation performance even though the tests at 4.5-ft depth are a 150 per cent scale-up on the tests at 3.0-ft depth.

Since the above represented the practical range limits of the large wave channel it was decided to attempt an even wider scale range by auxiliary tests on a smaller scale. These tests were conducted in a smaller available wave channel using a water depth of 12 in. and a width of 24 inches. The wave generator, permanent end wave absorber, wave measuring, and force measuring auxiliaries for this channel were analogous to those of the large channel, and the tests were conducted in the same manner.

The blanket construction for these smaller tests could not be simulated in detail, but other experience [3] indicated that in all probability the interior detail construction of the blanket was far less critical to performance than were the bulk dimensions. In support of this belief two separate models were built for use in the small wave channel.

One of these models consisted of three flat layers of 1/2 in. thick Trilok fabric (the material shown in Fig. 1) made up in a sandwich with narrow rubber spacer strips of 1/8-in. thickness to give a total blanket thickness of 1.75 inches. The blanket was made with a width slightly less than the 24-in. channel width and with a length of 44.5 inches. This blanket then had bulk dimensions which were a 1:4.5 scale model of the 8 in. thick, 16.6 ft long blanket that was tested in the large channel. This model was somewhat less permeable than the regular 8 in. thick blanket but was still essentially a permeable structure. The small model was also relatively stiffer than the large model.

The second small model consisted of a single slab of soft, small pore, foamed plastic, or synthetic sponge. This blanket had the same 1.75-in.

thickness and 44.5-in. length as the Trilok model. For testing, this model was saturated with water by squeezing out the air until its top side floated just level with the static water surface. This model was then essentially impermeable to internal flow under wave action.

The data from these two tests are listed in Appendix A as tests 202 to 229 for the sponge blanket and tests 230 to 256 for the Trilok blanket. These data together with tests 156-166, and 190 for the standard 8-in. blanket are plotted in Fig. 12.

Figure 12 is of considerable importance in that it indicates the following:

a. Attenuation tests conducted in the small facility appeared to yield the same type of performance as tests conducted at a scale 4.5 times as large.

b. Attenuation tests conducted with an impermeable blanket produced essentially the same type of performance as those conducted with a permeable blanket thereby indicating that the viscous energy dissipated within a permeable blanket structure could only be a small part of the total energy dissipation that occurred in the attenuating action of the blanket.

3. Influence of Frontal Wave Reflections

The height of the wave reflected from the wave blanket was evaluated for each test run by the technique previously described in Section V. This height is of interest as an index of the amount of energy reflected by the blanket.

The reflection values were expressed as a percentage of the incident wave height and as such varied from 0 to about 14 per cent. The reflection data were studied in various ways but were found to have substantial scatter and failed to yield fully consistent relations with variation in either the wave dimensions or the blanket dimensions. This inconsistency is believed to be due to the fact that the absolute magnitude of the reflections were quite small and as a result the inherent errors of the measuring system produced a relatively large scatter. The reflection data of Appendix A does not yield a clear graphic trend but a study of the data of Appendix A gives support to the following:

a. An increase in reflected wave height is accompanied by a reduction in wave height attenuation.

b. Increased blanket thickness increased the attenuation of wave height but the range of reflected wave heights was essentially the same for either the single-, double-, or triple-thickness blankets. However, the reflected wave heights for the stepped blanket were only about one half of those for the triple blankets which had the same frontal form and size.

c. The reflected relative wave height generally increased slightly as the wave steepness increased.

d. The reflected relative wave height increased with the wave length.

It should be noted that, if waves are to be compared on the basis of energy, the energy theoretically varies as the square of the wave height. On this basis the energy of a reflected wave having a height of 14 per cent of that of the incident wave (the maximum observed) would have an energy of only about 2 per cent of the incident wave. In view of the low energy content of the reflected waves of these tests it appears that reflection is not a major factor in the attenuation performance of a wave blanket.

4. Influence of Joint Stiffening Tubes

As previously described the wave blanket units consisted of white plastic stiffening tubes tied to the upper and lower planes of the Trilok material. When these units were lashed together in the bottom plane only, the joints were capable of sustaining tension in the blanket but were without significant compressive resistance. The first tests in this program were conducted with blanket joints of this construction and gave evidence of severe buckling at the joints under certain wave conditions.

In Section VIII-B of this report the force system producing the compressive action is separately discussed and a remedial expedient is described relative to the construction shown in Fig. 19. This remedy consisted of stiffening the blanket by splicing supplementary plastic tubes of about 4.5-ft length across the gap between the existing tubes in the top plane of the blanket. The reinforced joints appreciably reduced the buckling action in the blanket and in turn influenced the wave attenuation performance of the blanket. Tests 5-17 were conducted without the additional joint stiffening and all subsequent tests were run with stiffeners. Figure 13 serves to show the comparative difference provided by the stiffening.

5. Influence of Blanket Orientation

Preliminary tests described in Reference [1] indicated that the most effective wave attenuation might be obtained with the blanket corrugations oriented upward and parallel to the wave crests. These tests [1] were not conclusive, so as an early part of the current tests it was decided to test alternate orientations of the blanket. Since the blanket units were made up in lengths of 8 ft 4 in. and the test channel width was 9 ft, it was not considered practical to conduct a good two-dimensional test with the corrugations arranged perpendicular to the wave crests. The only remaining alternate was to test with the corrugations parallel to the wave crest but with corrugations pointed down.

Tests 18-26 with corrugations up and tests 144-150 with corrugations down are plotted in Fig. 14 to demonstrate the comparative difference. It appears that for many wave conditions a slightly better wave attenuation will result with corrugations oriented upward.

The reason for the improved performance of the latter orientation is not clearly evident but the tests described under A-2 give some indication that the prime function of the wave blanket is to provide containment that will immobilize a water mass against orbiting action. With the flat Trilok sheet of the blanket oriented down an effective containment is provided for the water within the corrugations. With the flat Trilok sheet placed on top a considerable portion of the water mass within the blanket outline is not effectively contained against response to orbiting action.

6. Influence of Mooring Line Length or Slope

In the description of the mooring system it was pointed out that the length or slope of the mooring line was to be made a test variable to determine whether this contributed significantly to the attenuation performance.

For the above purpose a single-layer blanket and a triple-layer blanket both of 50-ft length were subjected to a variation of mooring line length under a variety of wave conditions. The comparative single-layer tests 39-49, 120-131, and the triple-layer tests 89-110 are plotted in Fig. 15. It should be noted that the data are generally given in terms of the dimensionless and more generally applicable term of line slope. The data listed in Appendix A use only the dimensionless slope values.

Examination of Fig. 15 indicates that for the range of test conditions the mooring line slope had no significant influence on the attenuation performance of either blanket.

7. Influence of Buoyancy

The Trilok wave blanket material provided for the tests was not equipped with auxiliary flotation material but depended only on inherent buoyancy for maintenance of vertical position during the tests. This buoyancy was sufficient to float the blanket just below a static water surface with the crest of the corrugations projecting slightly above the surface.

In wave action the single-layer blanket, which was tested first, showed no particular evidence of submerging under mooring line pull. However, as the tests progressed through the two-layer, three-layer, and stepped configurations, it was noted that the front edge of the mat was being submerged a progressively greater amount during passage of the wave crests. Toward the end of the stepped layer tests the entire front portion of the mat would remain submerged several inches during tests and would at times settle as low as 1.5 ft below the water. A return to single-layer tests following the stepped tests also gave marked evidence of submergence, lateral tipping, and general vertical instability of the frontal portion of the blanket. It was noted also that the later single-layer blanket assemblies floated statically showing almost no evidence of the corrugations projecting above the water.

All of the foregoing evidence indicated a progressive loss of blanket buoyancy as a function of time. Since the Trilok fibers were essentially a nonwater-absorbing solid plastic it was rationalized that the buoyancy loss must be associated with a progressive loss of attached free air bubbles. Examination of a fresh piece of Trilok sheeting submerged in a beaker of water showed definite evidence of large numbers of tiny free air bubbles attached to the fibers. The sheeting floated high in the water under these conditions and remained thus for days even in the presence of agitation. Addition of a small amount of detergent to the beaker water led to the gradual release of the bubbles and a low flotation level after a period of a few hours.

In light of these secondary observations it is believed that air attachment was significant during the first tests but progressively decreased as chemical change or contamination of the fresh fiber surface altered the surface tension forces which held the bubbles in attachment.

The evident vertical instability of the aged blanket as a result of loss of buoyancy was considered detrimental to a reproducible test program. As a remedy soft wood sticks having a section of 3/4 in. by 1 in. and a length equal to the corrugation length were tied below the crest of each blanket corrugation. This added buoyancy was employed in all of the later tests to provide vertical stability.

The wood sticks were a convenient additive for the tests but other design variations should be examined for future fabrications. These variations might include provision of a buoyancy concentration at the mooring attachment point in order to counter the mooring down pull or the addition of flotation material throughout the blanket. Inclusion of sealed-cell foamed plastic pads in the blanket assembly might serve as a solution.

8. Influence of Sealing Lower Sheet

The original design of the Trilok blanket had assumed that the orbiting motion of the water would cause a flow of water through the blanket which would be resisted by the permeable nature of the blanket. Sustained exposure of the orbiting water to this resistance should then lead to attenuation of the wave energy. However, in the actual tests small particles of paper confetti were added to the water and visual and photographic observations of water motion were made through the side wall windows of the wave channel.

The observations indicated that very little vertical flow occurred through the lower Trilok sheet of the blanket and that the major water movement within the blanket was parallel to this lower sheet and passing back and forth through the folds of the corrugated sheet in an oscillatory manner. For flow of this character it was rationalized that the lower Trilok sheet was actually contributing very little frictional energy dissipation to the total wave attenuation and that substitution of an impermeable sheet might produce a similar performance.

For the examination of the above possibility a lightweight sheet of polyethylene film was placed across the underside of a single-layer blanket of length 25 ft. The film was taped and stitched to the bottom of the lower

Trilok sheet. Tests 151-155 were run under this condition and are plotted for comparison with the data of tests 18-26 which were run under comparable conditions but without the impermeable film. This plotting is shown in Fig. 16.

Study of the limited data of Fig. 16 gives general confirmation to the visual and photographic flow studies with confetti. Together they indicate that the very little flow which occurs through the lower sheet is not significant to the attenuation performance of the blanket and that the lower sheet could be of an impermeable character.

It should be noted that the polyethylene film was present in addition to the Trilok sheet in tests 151-155 and that the tests do not establish that the limp polyethylene film could actually replace the stiff Trilok sheet—ing to yield the same performance.

B. Structural Studies

The orbiting motion of a water particle in an undisturbed wave is the resultant motion of a combination of gravitational and centrifugal forces. The orbiting represents a powerful, conservative, and efficient energy system which can be maintained by only a relatively small energy input. In contrast the water mass which is contained within the structure of a wave blanket is constrained by the structure and its mooring system, and thus free orbiting is not possible even though the blanket is supported by a freely orbiting wave system. As a result the constrained water mass is largely motivated by the gravity force W as shown in Fig. 17. The force W may be resolved into components W_T and W_N which are respectively tangential and normal to the surface.

If attention is now confined to the dominant tangential accelerating force, W_T, it will be apparent that a water mass element will be exposed to an accelerating force in the downslope direction. In the case of the wave blanket this accelerating force is resisted by the corrugated top sheet of the blanket which is in turn restrained by lashings to the lower flat sheet of the blanket and to the stiffening plastic tubes. Since the mooring system confines the flat sheet to a small horizontal motion, the mass under consideration will progressively move from relative position 1 to 3 as the wave crest moves from left to right. In so doing, the mass will experience a change in the direction of the force applied to the restraining corrugations of the blanket. From Fig. 17 it is apparent that the magnitude of this restraining force will vary directly with W_T which in turn varies with the wave slope. Since the wave slope is a function of the wave steepness the restraining forces or structural loadings on the blanket may be expected to increase with wave steepness.

Slow motion pictures of the blanket action during testing were taken through the side window of the channel. Study of these pictures showed marked oscillatory shifting and distortion of the blanket corrugations under gravity action in accord with the sketch of Fig. 18. Observation showed the crown of the corrugations to displace parallel to the flat sheet a distance of 3 in. or more under severe wave action. There was no evidence that this distortion adversely affected the tough, flexible, Trilok sheet. However, at the spaced points where the crown of the corrugations were lashed to the longitudinal plastic stiffening tubes a few lashing failures did occur. This was a failure of the lashing proper due to the repeated shearing force occasioned by the restrained motion of the tube and the tendency toward free movement of the corrugated sheet.

The lashings tying the corrugated Trilok sheet to the flat Trilok sheet at the edge stiffener tubes were also subjected to the oscillatory shearing force sketched in Fig. 18. However, these lashings showed no evidence of failure during the limited duration of the tests.

If Fig. 17 is examined with the idea that the mass element at position 1 is expanded to a blanket of finite extent but confined in length to one slope of the wave, the blanket in general would tend to slide from the crest toward the trough as a unit. If this unit were moored from the left-hand side, the mooring line should then exert zero tension and the internal stresses in the blanket should be minor. However, if the blanket unit were in position 3 the sliding motion would be toward the right and tension should exist in the mooring line. The mooring tension would in turn restrain or tension the lower sheet of the blanket and lead to the distortion and internal stressing indicated in Fig. 18(a).

If we now assume that the blanket extends as a unit from position 1 and across the wave trough to position 3 of Fig. 17, the above line of reasoning would lead to a finding of tension in the left-hand part of the lower Trilok sheet and compression in the right-hand portion of the sheet. If in a similar manner we assume the blanket unit to extend only from position 4 and across the wave crest to position 3 the entire lower sheet of the blanket should be subject to tensile stressing.

The nature of the blanket construction was such that the rigid plastic tubes provided the principal longitudinal load-carrying members as shown in Fig. 19. In the original construction of the blanket individual 8.3-ft lengths of blanket were lashed together to form longer test lengths. This joining system in the lower sheet provided the necessary load structure for internal tensile forces but provided only small stiffness against longitudinal compressive loading. This inherent stiffness was adequate to prevent compressive buckling under modest loads but caused the joint to buckle downward as the compressive load increased with increased wave steepness. This buckling, which reached as much as 18 in., caused severe flexure of the blanket structure near the joints and caused speculation as to the influence of buckling on attenuation performance. In a simplified attempt to reduce the buckling, supplementary plastic tubes of about 4-ft 6-in. length were spliced across the joints by lashing to the existing longitudinal plastic tubes in the upper plane. All tests of single-layer blankets subsequent to test No. 17 (see Appendix A) included this stiffening reinforcement. The stiffeners significantly reduced but did not eliminate the buckling action, and under sustained severe action the stiffener tubes broke in two near the joints. Severest buckling action generally occurred at the joints nearest the front of the blanket where vertical wave action and wave slopes were greatest.

The foregoing rationalization indicates that compression forces should be greatest in the blanket when the blanket length is about equal to the wave length and should diminish as the blanket becomes either longer or shorter than this. The compressive action should also increase with increasing wave steepness. Although no attempt was made to measure internal compressive stresses this analysis of the source of compression is believed to be partially substantiated by the observations of buckling action made during the tests. Test observations relative to buckling are recorded in Appendix A. Tests carrying evidence of modest buckling (3 in. to 6 in.) are labelled B and those with severe buckling (about 9 in. and sometimes more) are labelled B+. A comparative study of the buckling data is quite illuminating.

The foregoing discussion has dealt only with load-carrying action in the single-layer blanket. In the case of the multiple-layer blankets the load-generating mechanism would be the same as previously discussed but would

From the standpoint of establishing structural design values for the mooring system only the maximum values of the mooring force are considered significant. In an effort to organize the test data to best clarify these design load values a dimensional analysis together with empirical curve fitting procedures was employed. The result of this analysis is shown in the summary plotting of Fig. 21 using the comparable data represented by tests 18-79, 111-119, 132-137, 156-166, and 177-190 for the tests in the large channel and tests 230-254 for tests in the small channel. The summary was confined to the data relating to the single-layer and two-layer blankets because of the poorer data fit for the thicker blankets and because all indications point toward the thinner blankets as providing a more practical prototype solution.

It is noteworthy that the dimensional analysis permits the mooring force to be interpreted as a function of the weight volume characteristics of the wave, the wave steepness, and the ratio of water depth to wave length.

The nature of the equations shown in Fig. 21 for the two thicknesses used in the larger model tests may be used for estimate values of the mooring force for larger size installations having similar proportions of length, thickness, and depth. Although the scaling conditions for the small scale model tests are not in close agreement with those for the larger model it is believed that the large scale model test may be used for estimate purposes in dealing with prototype installations which may be five to ten times the size of the larger models. The small scale tests involved a structure which was much less resilient than the larger models or any probable prototype.

The summary data and curves of Fig. 21 are not in good agreement for the waves of very low steepness. It was not established whether this deviation was basically correct or whether it represents increasing errors near the threshold sensitivities of the height and force measuring systems. In any case this deviation is not important for mooring system design studies which are more concerned with the larger forces occurring at higher wave steepness.

The data of Fig. 21 indicate that for a given blanket and wave condition the mooring line slope can be varied from 1:4 to 1:10 without significantly varying the resulting mooring force.

Since the test facility was two-dimensional in nature, the data presumably hold for blankets of any width. However, in an open sea setting abnormal effects near the blanket edges would necessitate some correction. This correction is not established by the current tests but probably would be quite small for wide blanket assemblies.

It is also important to note that the final equation shown in Fig. 21 may be rewritten in terms of the fundamental dimensions and reduced to the expression

$$(\text{prototype force}/\text{model force}) \approx (\text{prototype length}/\text{model length})^3$$

This expression constitutes a Froude model law and confirms that the dominant force involved in the production of mooring loads and structural loading is gravitational in nature. From this it may be presumed that the wave height attenuation effects are also dominated by gravitational forces even though the ultimate dissipation of energy is by viscous friction.

IX. WAVE BLANKET--CONCLUSIONS AND RECOMMENDATIONS

The following statements are believed to be a logical outgrowth of the test results which have been described:

1. The data of Fig. 10 indicate that a moored floating wave blanket is capable of attenuating or diminishing the height of gravity waves to any desired degree. The attenuation characteristics of Fig. 10 are considered applicable to any prototype size of similar proportions provided suitable consideration is given to three-dimensional end effects. The data should apply to sea water as well as fresh water.
2. The degree of attenuation achieved increases as the ratio of wave length to blanket length decreases and as the ratio of blanket thickness to water depth increases.
3. For a thin blanket (a blanket thickness less than about 15 per cent of the water depth) the length should be several times as long as the design wave length. A multiple of about three or more is indicated depending on the attenuation desired.

4. The blanket thickness should be of the order of 15 per cent or more of the water depth. For a very long blanket a thickness of as little as 10 per cent might be effective. The amount of wave height attenuation to be selected for a given blanket application is an arbitrary variable. For most applications a height attenuation of about 80 per cent should suffice since this represents an energy attenuation of about 96 per cent. The influence of blanket thickness on wave height attenuation may be approximated by interpolation between the three test curves of Fig. 10.

5. A blanket constructed with thickness decreasing from front to rear has approximately the same attenuation characteristics as a blanket having the same length and volume but having a uniform thickness.

6. The tests were largely conducted under shallow water wave conditions but the attenuation findings are believed applicable to deep water conditions if the blanket depth is related to the depth of orbiting water rather than to the total depth of water.

7. Axial compression will develop in a blanket element when the element is approaching the wave trough. This compression will be greatest for blankets having a length about equal to the wave length. Selection of a blanket having a small value of the ratio of wave length to blanket length will tend to reduce compressive conditions.

8. The blanket structure may be designed to develop internal stresses to resist the axial compression (stiffening tubes) or alternately to seek compressive relief by omitting the stiffening tubes and allowing the compressive force to either elastically compress the Trilok sheeting along the blanket axis or buckle it perpendicular to the axis. From Fig. 13 it appears that either type of design may provide satisfactory wave height attenuation.

9. The present method of providing compressive resistance with a limited number of widely spaced stiffening tubes leads to stress concentrations in the structure. These concentrations caused some local structural failures during the tests and would probably lead to extensive stiffener failures under prolonged prototype conditions. It is recommended that future designs consider either a greater number and dispersion of stiffeners or their complete omission with structural dependence on only the Trilok sheeting.

10. The front of the blanket moves in approximate unison with the incident wave and the amount of vertical movement of an attenuating blanket diminishes toward the rear. Since the compressive forces result from the vertical motion, compression structure at the front of the blanket is more important than at the rear.

11. Blankets of large extent may involve a fixed orientation of mooring and a consequent rather wide variation of wave approach direction in nature. The tests described permitted only one direction of wave approach. The test data must therefore be used with caution in considerations involving three-dimensional aspects of the structure.

12. Any form of wave absorber or breakwater of finite width will cause the wave system to pass around the two ends of the absorber. If sufficient space is available the waves will rejoin at the rear of the absorber. If the waves rejoin "in phase" wave heights may superimpose to produce waves of greater height than the original incident wave. It should be noted that the attenuation observations in these two-dimensional tests were made in the lee of the wave blanket and do not delineate these end refraction effects which might prove to be locally dangerous in a three-dimensional prototype.

13. Blanket assemblies for large scale operations should achieve the necessary total thickness by being fabricated of multiple layers of standard blankets (i.e the 8 in.

thick blanket used in the tests) rather than by scaling up the geometry of the test blanket to a larger size. The small size unit construction is believed to offer a stiffer assembly with a more dispersed loading system. However, the total thickness of the assembled layers is the significant dimension involved in the determination of attenuation by interpolation of the data of Fig. 10.

14. A blanket constructed with an impermeable lower sheet will apparently achieve about the same wave height attenuation as one with a permeable type of lower sheet. The tests did not establish whether similar attenuation could be achieved by replacing the relatively stiff Trilok sheet with a limp impermeable sheeting.

15. Wave reflection from the front of the wave blanket accounts for only a very few per cent of the total energy dissipation produced by the blanket action.

16. A blanket fabrication consisting of a dense sponge gave essentially the same type of attenuation as a blanket of permeable Trilok. The conclusion is that internal flow resistance within the Trilok material can account for only a minor part of the total energy dissipation.

17. There was no evidence that wave energy was being converted to potential energy by the action of the wave blanket.

18. Attenuation appears to be dependent on the gravitational damping action of the water contained within the wave blanket. Although the wave is disturbed by this gravity action the ultimate dissipation of the wave energy associated with the disturbance must be of a viscous nature and must occur within the water of the wave.

19. Attenuation performance is not critically dependent on the structure of the blanket provided the structure interferes with orbiting of the contained water. The Trilok wave blanket provides such a structure in a tough flexible structural media.

20. The maximum mooring force required to stabilize the horizontal position of a blanket depends on the characteristics of both the blanket and the wave. The magnitude of the mooring force may be determined from the equation or graph of Fig. 21. The figure applies to any size of blanket of proportions similar to those of the test unit and provided suitable consideration is given to three-dimensional end effects. These tests do not serve to define the end effects. The data are applicable to sea water as well as fresh water.

21. Blankets with a length which is short relative to the wave length involve mooring forces which continually oscillate from zero to a maximum which is somewhat irregular for successive waves.

22. Blankets with a length which is long relative to the wave length involve mooring forces which continually oscillate from some nonzero value to a maximum. The pattern of force variation is quite uniform for successive waves.

23. The peak mooring forces given by Fig. 21 are derived from tests with a relatively inelastic mooring system. Mooring systems which involved greater elastic or damping action may be expected to reduce these peak mooring force requirements.

24. The data of Fig. 15 indicate that the attenuation of wave height remains substantially the same for mooring line slopes varying from 1:4 to 1:10.

25. The data of Fig. 21 indicate that the mooring force for a given blanket and wave condition does not change materially for variations in the mooring line slope from 1:4 to 1:10.

X. WAVE TRAP--TEST RESULTS

A. Attenuation Studies

1. Influence of Wave Length and Steepness

Unlike the wave blanket the wave trap was supplied for test in only one length and one relative thickness. As a result the test program for the wave trap consisted of exposing the one test unit to various wave lengths and wave steepnesses with a 1:10 mooring line slope and a 4.5-ft water depth. The resulting wave attenuation was measured with the facilities previously described. The first part of the program consisted of test numbers 167-176 as shown in Appendix B. These tests demonstrated that the buoyancy of the float sheet was inadequate to maintain this sheet near the surface with a resulting tendency for the assembly to move toward the bottom for the more severe waves. The tests also demonstrated that the widely spaced lashings between the 18-in. strips that constituted the valve sheet permitted considerable venting or bleeding around the valves during the up pull wave phase.

Following the initial tests the sponsor requested that additional flotation and weighting be applied to the wave trap to reduce the sinking tendency and that additional lashing be provided in the valve sheet jointings. These changes were made in accord with the description given in Section III and the tests were rerun as tests 191-201 and listed in Appendix B.

The foregoing comparative tests have been plotted in Fig. 22 using the same coordinate system that was employed with the previously plotted wave blanket data. As with the wave blanket it may be noted that the data of Fig. 22 show an excellent wave height attenuation for small values of the ratio of wave length to trap length. The attenuation then diminishes with increasing values of the ratio.

Unlike the wave blanket which showed an attenuation performance (see Figs. 7, 8, and 9) which improved as the wave steepness increased, the wave trap showed a slight decrease in performance with increased steepness.

Figure 22 further shows that the revised wave trap construction gave a definite improvement in attenuation performance relative to the original trap even though the front portion of the assembly continued to submerge with the longer and steeper waves.

For comparison of the attenuation data of the wave blanket and the wave trap, the wave trap data of tests 191-201 have been superimposed on the wave blanket data of Fig. 10 to give Fig. 23.

2. Influence of Frontal Wave Reflection

The height of the wave reflected from the wave trap was evaluated for each test run by the technique described in Section V.

The reflection values for the tests are listed in Appendix B. The data are very limited but give some support to the following:

a. The reflection values with the original wave trap were considerably higher than those with the revised construction.

b. There was some tendency for an increase in relative wave height reflection to be accompanied by a decrease in wave height attenuation.

c. There was some tendency for the relative wave height reflection to increase with increasing wave steepness.

As with the wave blanket it appears that reflection is not a major factor in the attenuation performance of a wave trap.

B. Structural Studies

The orbital character of water in deep and shallow water waves was briefly described in Section IV in which it was pointed out that the vertical motion of the water diminishes with depth below the surface. If a flexible, impermeable, horizontal sheet were lightly stretched through such orbiting water the resulting local vertical motion of the sheet would approximate the local vertical motion of the water. If the sheet were positioned at the water surface the total vertical motion of a point on the sheet should be essentially the wave amplitude. If the sheet were positioned near the bottom the vertical motion of the sheet should be essentially zero.

If two such sheets of neutral buoyancy were connected by numerous taut vertical tension ties the orbiting action should initially produce tensile forces in the ties with each passage of a wave crest. These tensile forces would raise the lower sheet and lower the upper sheet. Under prolonged action the two sheets would move toward each other and would eventually seek a neutral position in which the lines would remain slack and the wave energy system would be conserved. However, by providing buoyancy in the upper sheet and ballast plus check valves in the lower sheet of a wave trap as described in Section III and Fig. 3, a positive force system is provided to prevent the sheets from coming together in search of a slack-line neutral position. In addition to maintaining spacing of the sheets the gravitational and valve actions combine to give a downward force which increases with wave steepness and height. In the tests it was noted that this progressive pumping action of the valve system was sufficient to cause settling or submergence of the front portion of the assembly. With the greater test wave heights submergence progressed until the valve sheet lowered itself to the channel floor.

Since tests were conducted in a 54-in. water depth with only one sheet spacing involving lines of 40-in. length, no positive statement can be made about the diving characteristics of the wave trap in deep water. It is, however, conceivable that in deep water the trap as tested might continue to submerge until the diminishing dynamic forces become equal to the rather modest buoyant forces. The wave height attenuation characteristics of a deeply submerged mat would presumably be quite low. On this basis, in order to prevent diving, it would appear that the wave trap as constructed for these tests should be restricted to installations where the length of the tension lines can be adjusted to a value somewhat less than the water depth.

For the foregoing type of wave trap in which the float sheet is essentially at the surface and the valve sheet is at the bottom, the difference in the vertical orbit motion is approximately the wave amplitude. For this condition the lift action of a wave crest on the float sheet should be roughly a water pressure equivalent to the wave amplitude, H_I, and it must be reasoned that the structural loading on the components would vary directly with the wave height.

In the simple test program the wave trap was not fitted with stress instrumentation and thus no relation between internal force and wave height could be evolved. However, periodic examinations were made of the wave trap to determine whether structural failures occurred under the test conditions. These examinations disclosed that virtually no failures occurred for the tests with wave heights of less than 1 ft, but damage as follows was evident after the test with a 1.5-ft wave:

a. Numerous tension lines broke during the test. The breaks occurred at various positions in these lines.

b. A number of the loose type metal rods contained in the fabric pockets of the valve sheet worked out of the pockets and dropped to the channel floor. The alternate type of rod, which was anchored in the stiffening hoses of the valve sheet, in many cases showed some evidence of a small lateral movement but none were lost.

c. In a very few cases the coated fabric material, which served as the valve sheet, tore in the narrow 1/2-in. portion existing between the valve openings. The pressure loading of the valve flap apparently exceeded the strength of the narrow bridging of the valve sheet.

It was not clearly established whether the above damage occurred under the normal wave action of the test program or as a result of the initial surge wave that always accompanied the beginning of wave generator operation. While the evidence is inconclusive there is some reason to believe that the wave trap as tested would not safely sustain wave heights or orbiting action of the order of 1.5 ft or greater.

Since the wave trap tests were conducted in only a single size and without internal stress instrumentation the problems of scaling up the internal stress values for a prototype design are not clearly established. However, as will be shown in the later treatment of the external mooring forces and as was shown in the earlier treatment of model laws for the wave blanket, there is evidence that these wave absorbers are primarily controlled by gravity forces. For this condition the Froude model law applies and it may be established that force ratios between the model and prototype will vary thus:

$$(\text{prototype force}/\text{model force}) \approx (\text{prototype length}/\text{model length})^3$$

Similarly the unit pressure relations will vary thus:

$$(\text{prototype pressure}/\text{model pressure}) \approx (\text{prototype length}/\text{model length})$$

In view of the fact that the wave trap tests were conducted at a scale which was roughly 10 per cent of that of probable prototype applications the above Froude force relation would impose prototype values about 1000 times as large as those of the model. This is obviously a staggering increase in the specifications for the design of a prototype wave trap. Two broad approaches to the prototype design then appear:

a. Beef-up the strength of the existing form of assembly to sustain the added loads of the prototype.

b. Retain the same general structure as in the existing trap but modify the assembly to produce maximum loadings which are tolerable to this structure.

If it is assumed that the existing component design of the structure already constitutes the most practical fabrication of available materials and assembly techniques, then alternate (b) above appears the most practical approach to the prototype design. To design along these lines requires a reconsideration of the factors that produce the loads.

Although the test program involved only one ratio of sheet spacing to water depth (40 in. to 54 in.) it may be rationalized that a decrease in this ratio will lead to a decrease in resulting internal pressures or forces. This decrease should occur because of the inherent manner in which the vertical motion of orbiting of the water decreases with depth. Since the loading of the lines and sheet components is more dependent on the differences of vertical orbiting motion for the positions of the two sheets than on the absolute value of the motion, the loading could be reduced by reducing the line length. A redesign along these lines should also involve adjustments of the gravitational and valve effects to assure that the trap remained floating at the surface without diving.

It must be recognized that redesign of the wave trap to involve limited and rather moderate internal force values will also limit the intensity of the forces which attenuate the wave. This, however, need be no real deterrent to effective attenuation but does require expansion of the area over which the limited intensity is applied. This is confirmed by the data of Fig. 22 which shows that good attenuations can be achieved only when the wave trap length is considerably longer than the wave length. In other words it appears more practical to dissipate the energy of the wave by sustained application of a small force rather than with a brief application of a massive force which may prove damaging to the attenuating structure.

C. Mooring Forces

The mooring force studies of the wave trap were conducted with the facilities previously described and the resulting maximum load values are listed for tests 167-201 in Appendix B.

Because these test values were very limited in number and involved only one size scale the mooring force data offered relatively little for analysis. However, the range of mooring force values for the wave trap was quite similar to those for comparable test conditions with the wave blanket. From this it was rationalized that the dominant force system was probably quite similar to that of the wave blanket. With this in mind the wave trap data were subjected to an arbitrary plotting system similar to that selected for the wave blanket analysis. Manipulation of the data in this manner eventually leads to the functional plotting and equation shown in Fig. 24. Analysis of this equation shows a force system requiring the following relation:

$$\text{(prototype force/model force)} \approx \text{(prototype length/model length)}^3$$

A force relation of the above nature can only exist in fluid systems which are dominated by gravity forces. Since the model tests were conducted with a fairly large absolute size, it is unlikely that critical changes in the force mechanism will occur between the model size tested and the probable prototype size. There is then reasonable assurance that the summary plotting of Fig. 24 may also be used for the determination of mooring force values for prototype wave trap designs. It should be noted, however, that such mooring force extrapolations apply only to wave traps which are geometrically similar to the model. Modification of the wave trap design to other forms such as was recommended in Section X-B will require additional mooring force tests for determination of the appropriate force relations.

It should be noted in the data of Appendix B that with waves of low steepness (about 2 per cent steepness) the front mooring force fell to zero and the trap actually propelled itself forward toward the oncoming waves. The forward motion was observed to be as much as 3 ft per min. Since dynamometer facilities were not available for measuring forces from the stern, the trap was moored with light lines from the stern and the mooring force values were entered as -0 in Appendix B. The forward propelling force is believed to originate in the check valves which were all arranged with their hinges toward the front. Pressure closure of these valves involves the rearward acceleration of a small mass of water with a resulting forward reaction on the valve flap.

The forward propelling force should in the worst case be rather small and should be readily handled in the prototype by light stern mooring lines. Stern moorings would normally be used in any case to stabilize the trap position against various wind and current actions which might naturally occur. Alternating the direction of the valve hinging might also reduce the forward propelling action.

XI. WAVE TRAP--CONCLUSIONS AND RECOMMENDATIONS

1. The data of Fig. 22 indicate that a moored wave trap is capable of attenuating or diminishing the height of gravity waves to any desired degree. The attenuation characteristics of Fig. 22 are considered applicable to any prototype size of similar proportions provided suitable consideration is given to the three-dimensional end effects. These tests donot serve to define the end effects. The data should apply to sea water as well as fresh water.

2. The degree of attenuation achieved increases as the ratio of wave length to trap length decreases.

3. The trap length should preferably be considerably longer than the design wave length. A length multiple of as little as 1.5 might suffice for the revised form of trap, but the original form would require a length multiple of 3 or more. The multiple depends on the desired attenuation.

4. The front portions of the trap submerged as the wave height increased. The limit of submergence was established when the valve sheet reached the water bottom.

5. For a given wave the magnitude of the internal loads on a floating wave trap will vary roughly in proportion to the distance that the valve sheet is placed below the float sheet.

6. The given wave trap design in tests of limited duration appeared to be limited to wave heights (or differential vertical orbiting distances) of about 1 ft. Larger values produced evidence of structural damage due to the dynamic water forces. Tests of greater duration may limit the wave height even further.

7. A wave trap of similar proportions but of larger size than the test unit would be subjected to forces which would increase as the third power of the size ratio. Since the ocean-type installations will involve depths and wave

heights from 5 to 10 times those of the test, internal forces and stresses in a similar prototype unit will be from about 100 to 1000 times as great as those in the model.

8. It appears impractical to design a wave trap of the present form (valve sheet near the bottom) to sustain the prototype forces which will be involved. It appears more practical to retain the general form of the present component designs but restrict the sheet spacing to a distance which will provide for differential vertical orbiting distances equivalent to about 1 ft. Some modification of valves, flotation, and ballasting may be required to prevent submergence. Provision of buoyancy in the mooring system to absorb the downward component of the mooring line force may also prove helfpul.

9. The comments contained in Section IX, item 12, relative to end effects on a wave blanket of finite width apply equally well to a wave trap of finite width.

10. The mooring forces required to maintain the wave trap in position may be obtained from the graph of Fig. 24. This graph applies to installations of any size provided that all elements are similar in proportion to the unit tested. The graph is based on relatively few tests and should be used conservatively. The graph applies to tests made under two-dimensional conditions. Application to three-dimensional installations involving end effects will require correction.

11. A prototype wave trap of large extent may in nature require a fixed orientation of mooring and a consequent rather wide variation of wave approach direction. The tests described herein involved only one direction of wave presentation to the wave trap geometry but the test data are considered quite applicable to a wide variation in wave presentation. This conclusion stems from the essentially nondirectional nature of the trap construction.

12. In waves of low steepness the wave trap tended to propel itself forward into the oncoming wave. This weak secondary force requires either stern mooring lines or revision of the hinging position of the check valves to provide better balance of valve-induced horizontal forces.

LIST OF REFERENCES

[1] Schwartz, F. M. and Watts, M. J. A Study of Wave-Damping Properties of Several Geometric Configurations of Plastic Materials, Navy Department, David Taylor Model Basin Report No. 1313, March 1959.

[2] Killen, J. M. The Sonic Surface-Wave Transducer, University of Minnesota, St. Anthony Falls Hydraulic Laboratory Technical Paper No. 23-B, July 1959.

[3] Ripken, J. F. An Experimental Study of Flexible Floating Breakwaters, University of Minnesota, St. Anthony Falls Hydraulic Laboratory Technical Paper No. 31-B, October 1960.

FIGURES

(1 through 24)

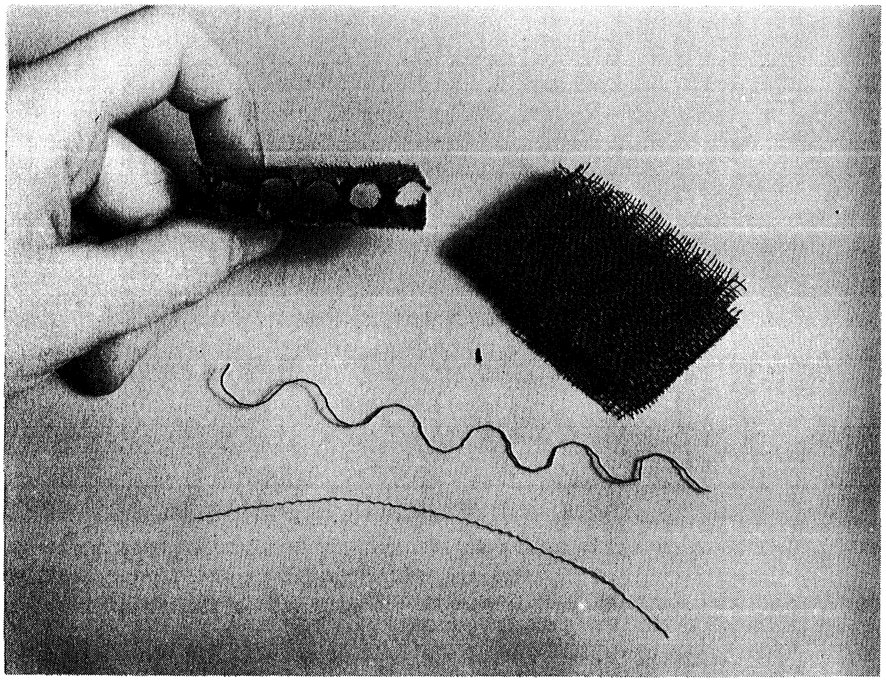


Fig. 1 - The 4-Ply Trilok Fabric

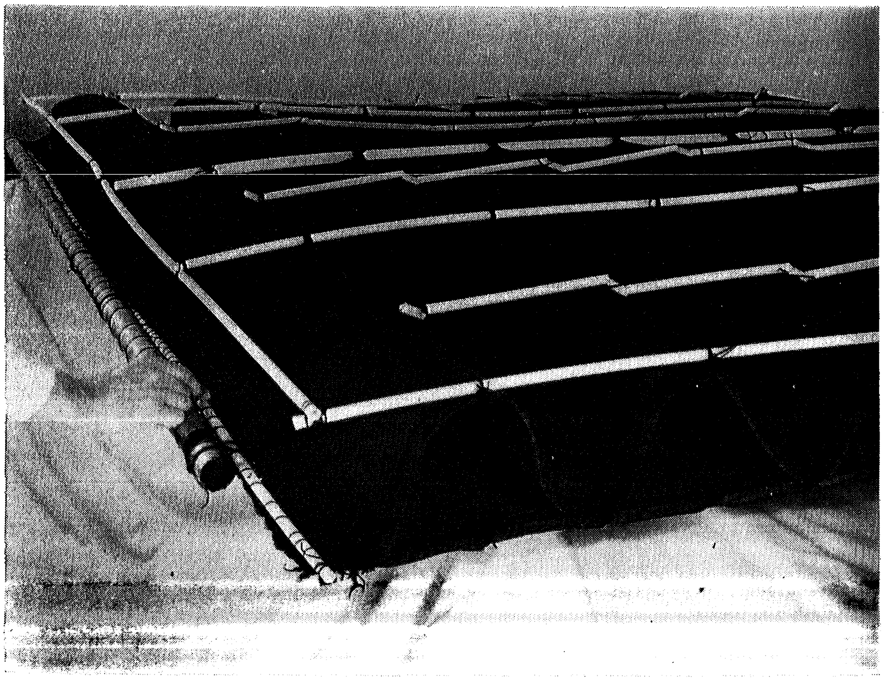
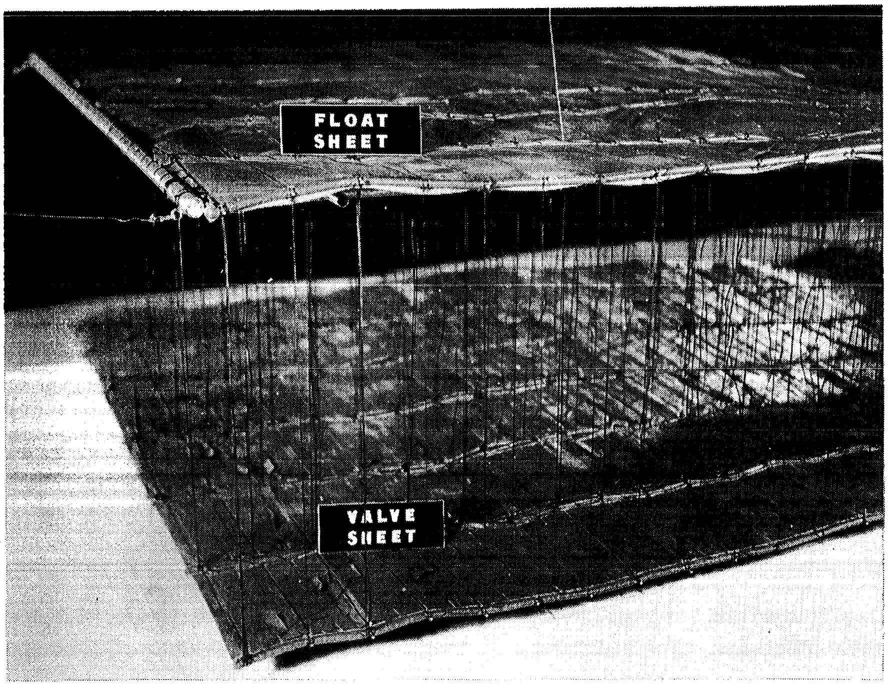
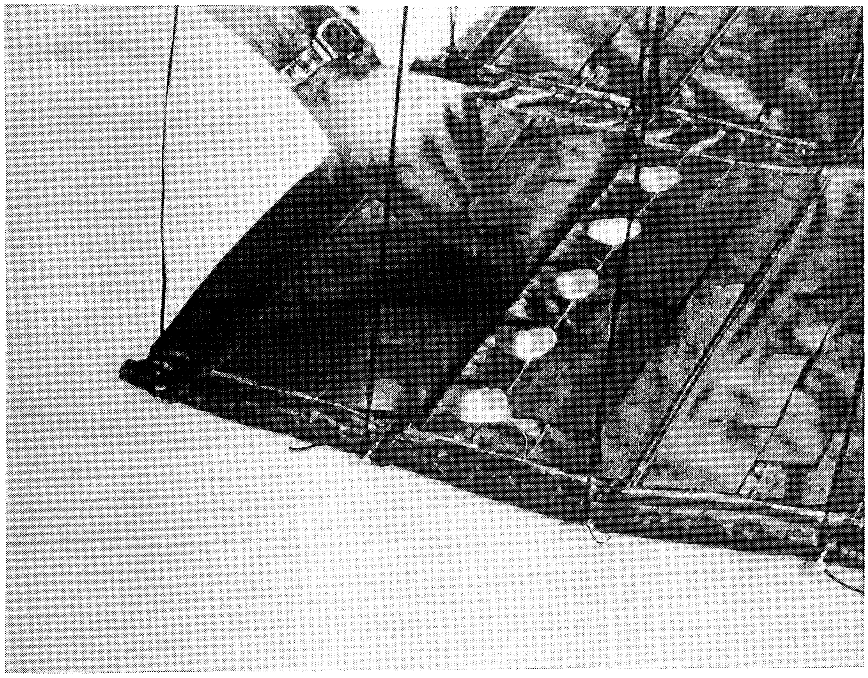


Fig. 2 - Assembly of the 8 in. Thick Wave Blanket

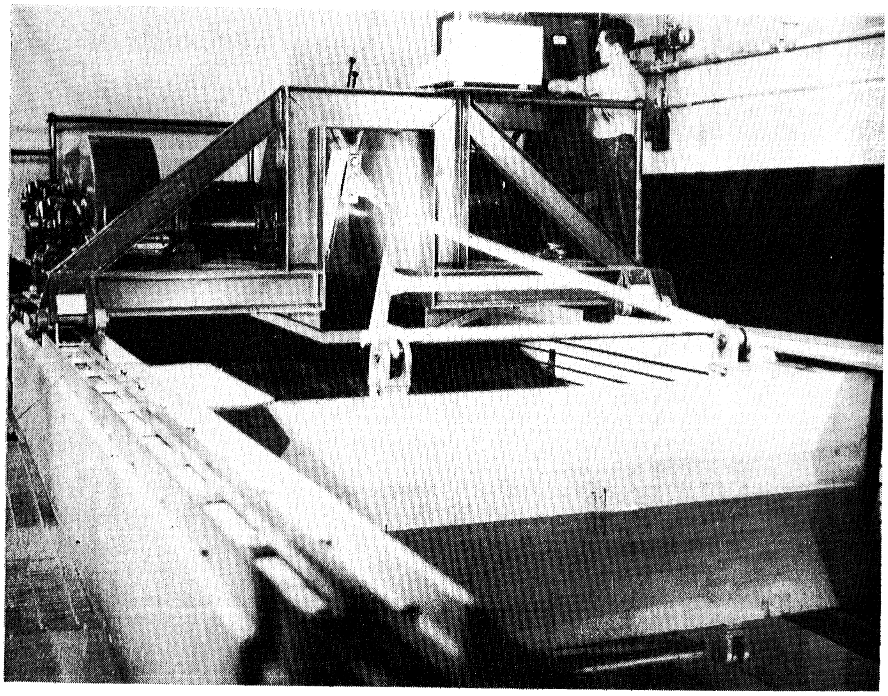


(a) The Wave Trap Assembly

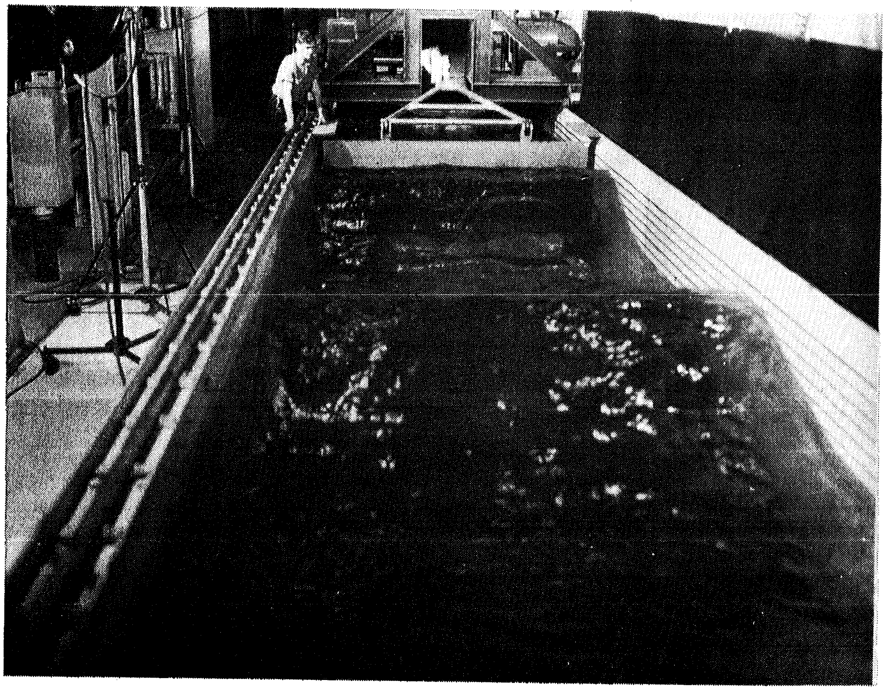


(b) The Valve Sheet

Fig. 3 – The Wave Trap



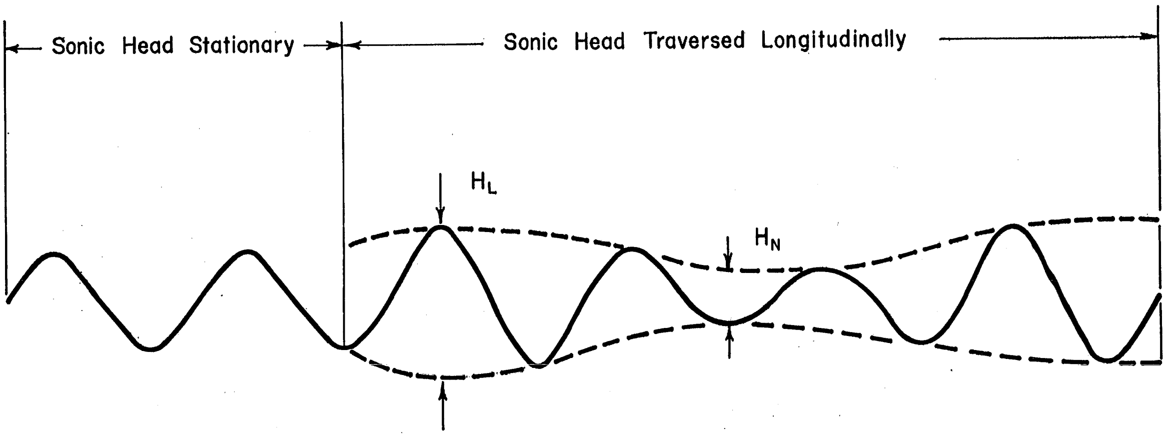
(a) The Wave Generator



(b) A Generated Wave of Length 15 ft and Height 1.5 ft

(The roughened surface condition is due to reflections from a test wave blanket in the channel)

Fig. 4 – The Wave Generator



Incident Wave Height $H_I = (H_L + H_N)/2$

Reflected Wave Height $H_R = (H_L - H_N)/2$

Fig. 5 - Method of Analyzing a Typical Wave Record from the Seaward Sonic Head

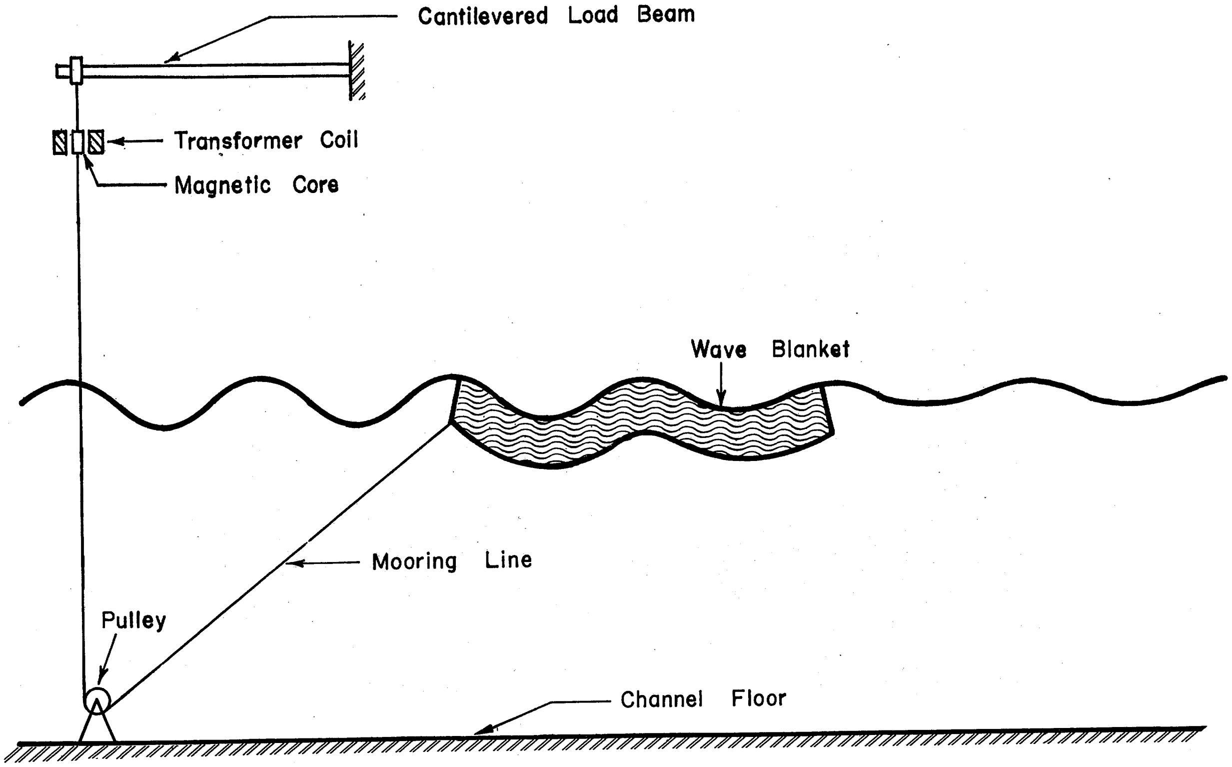


Fig. 6 - A Schematic Sketch of the Mooring Force Dynamometer

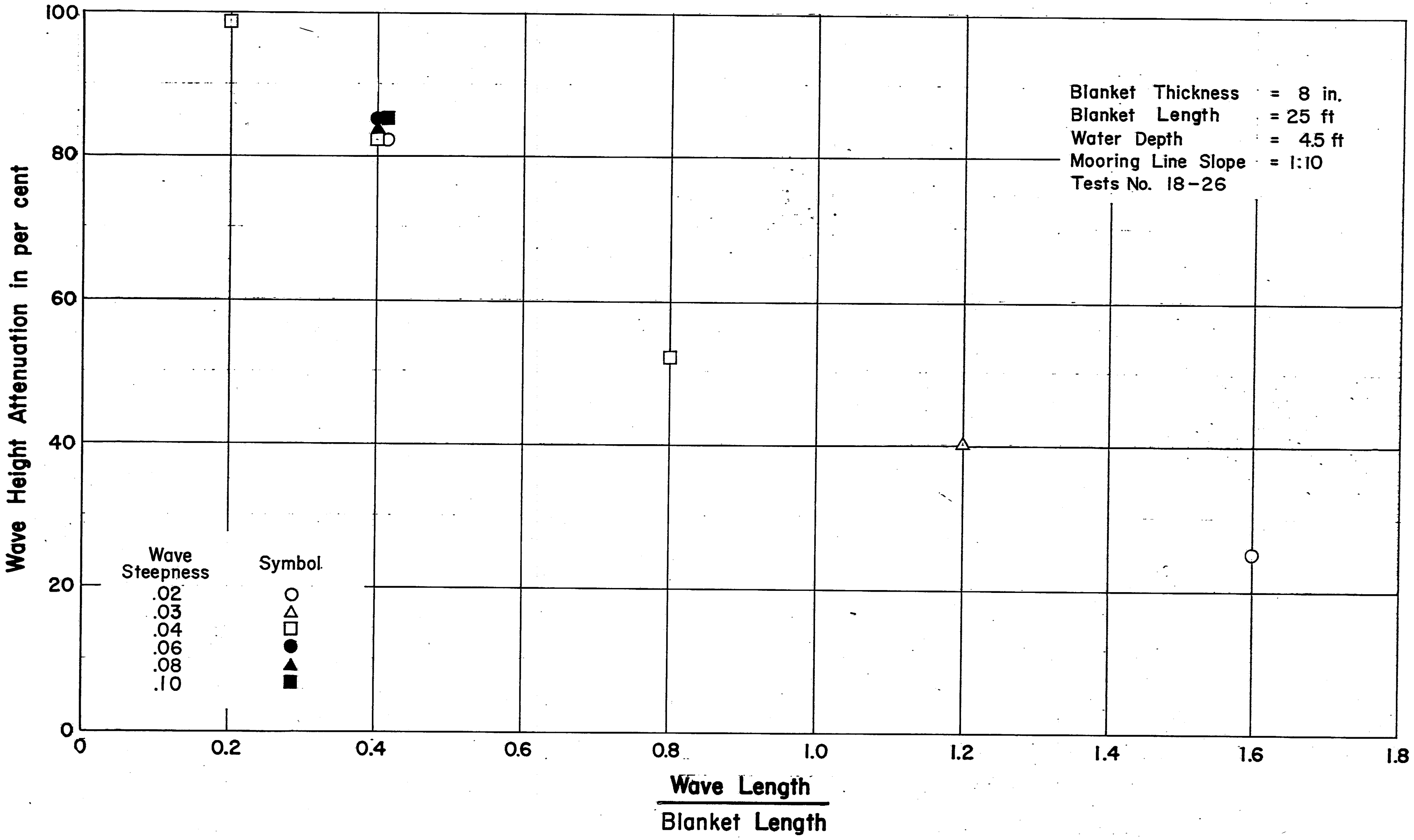


Fig. 7 – Wave Height Attenuation of a Single-Layer Blanket of Length--25.0 ft

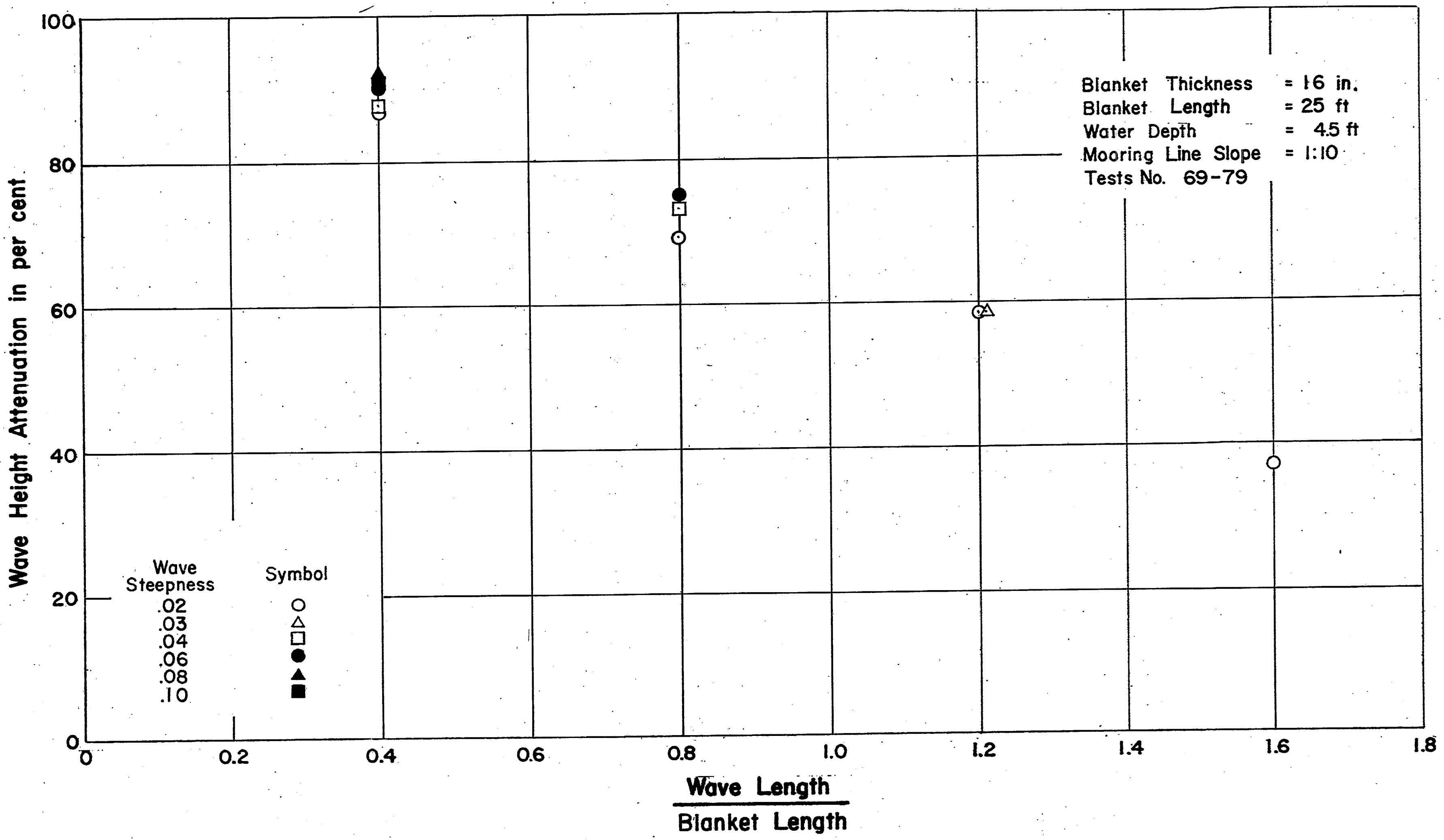


Fig. 8 – Wave Height Attenuation of a Double-Layer Blanket of Length--25.0 ft

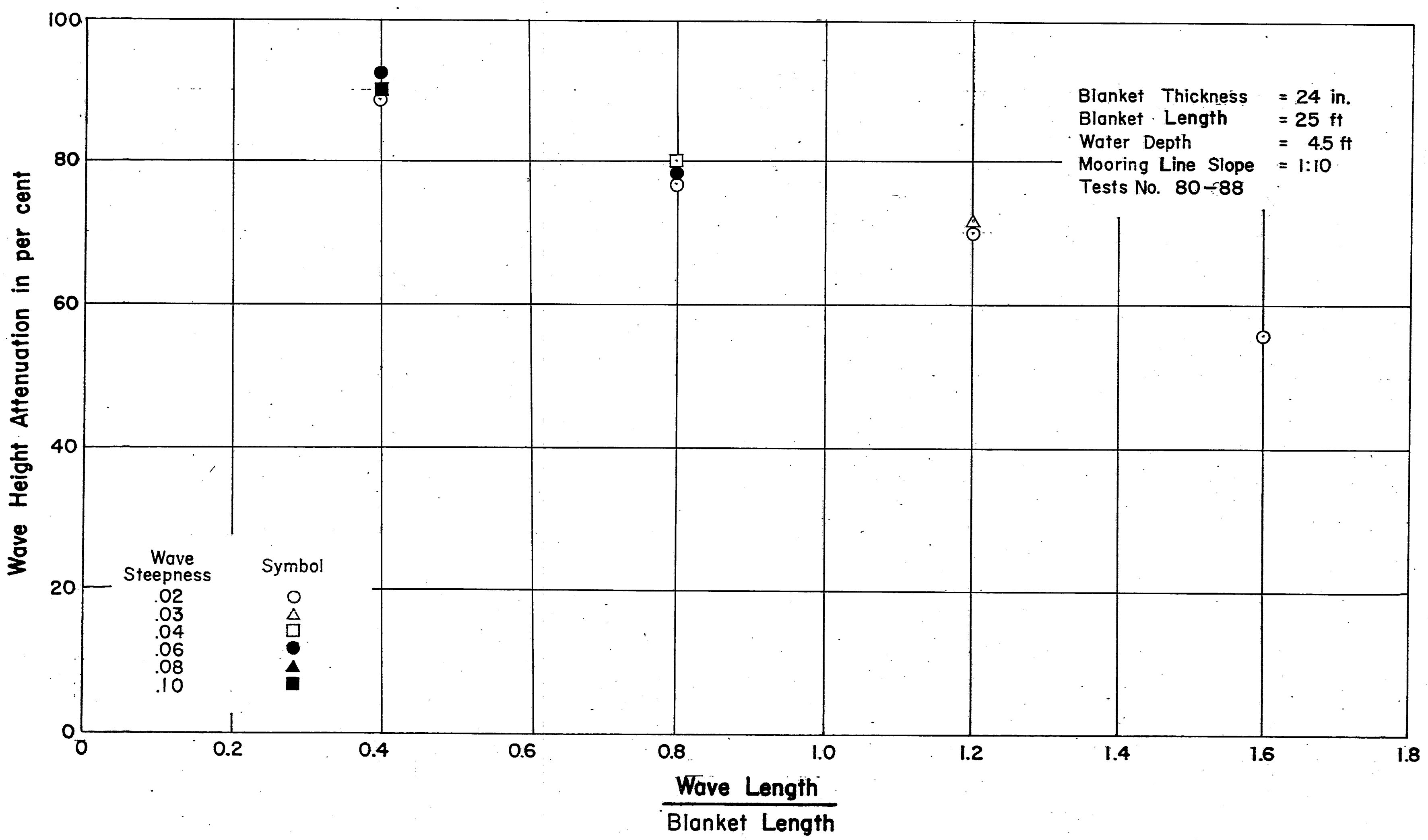


Fig. 9 – Wave Height Attenuation of a Three-Layer Blanket of Length--25.0 ft

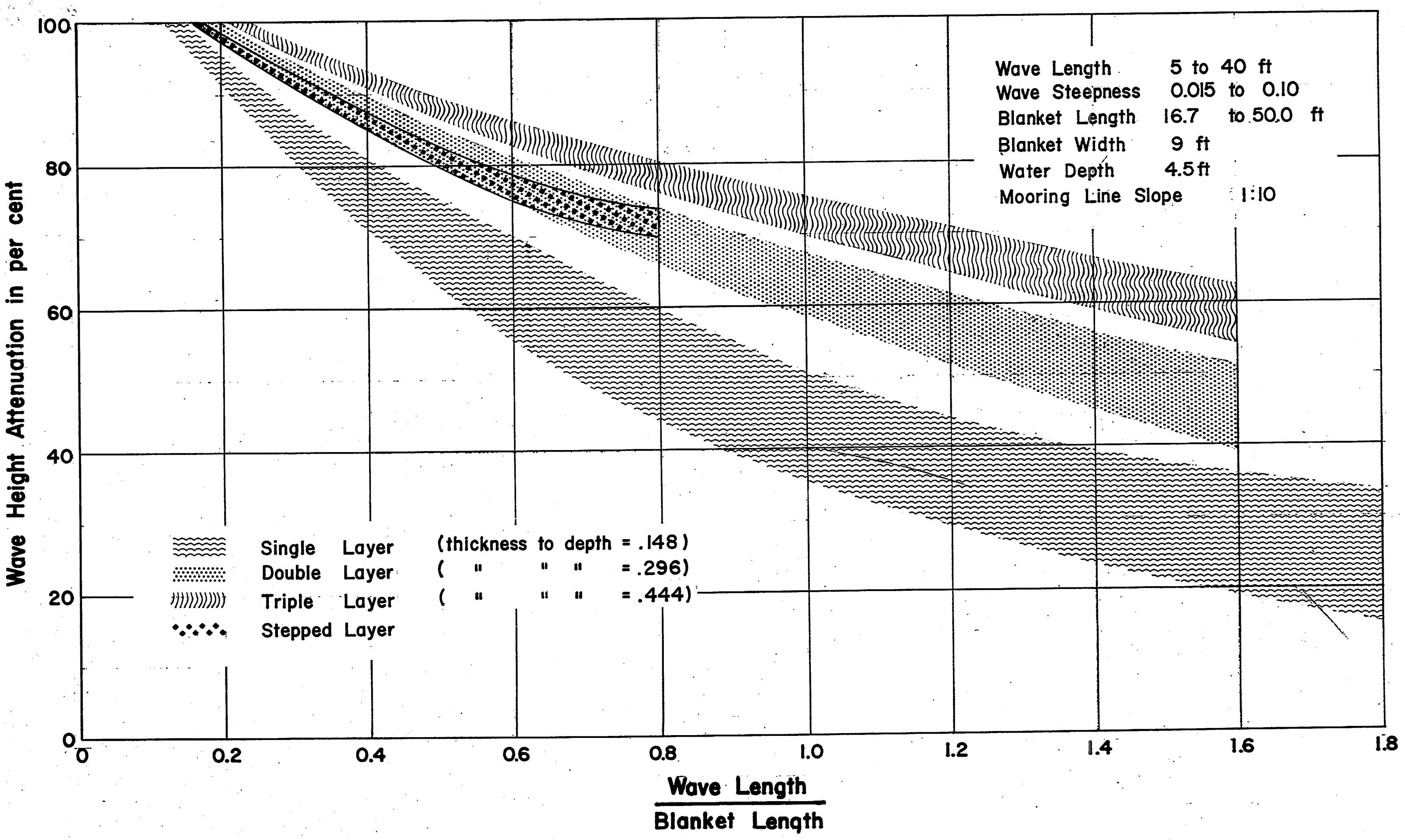


Fig. 10 – Summary Plotting of Wave Height Attenuation for the Wave Blanket with Water Depth of 4.5 ft

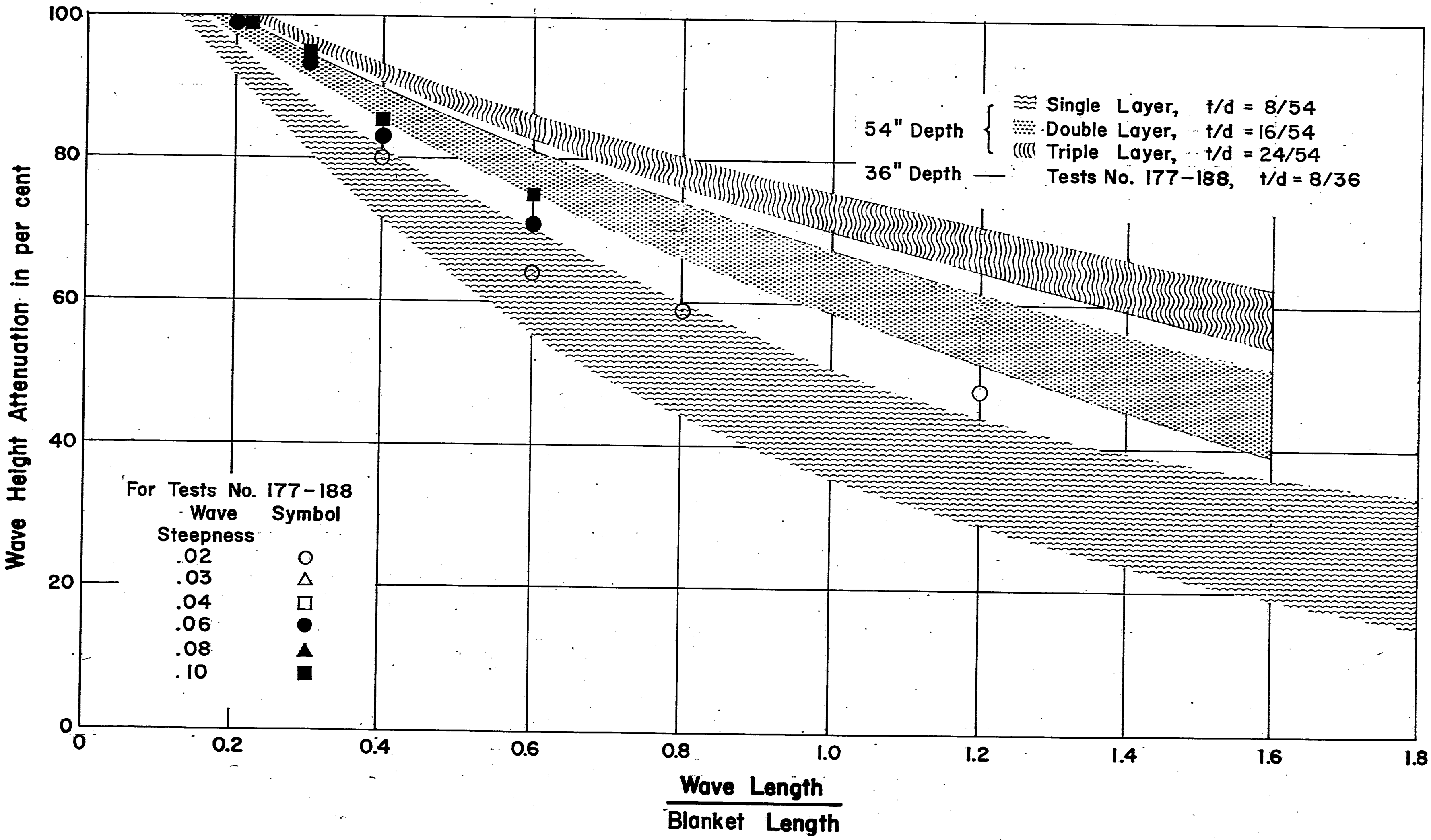


Fig. 11 – Comparative Wave Height Attenuation Effects for Wave Blankets with a Scale Ratio of 1 to 1.50

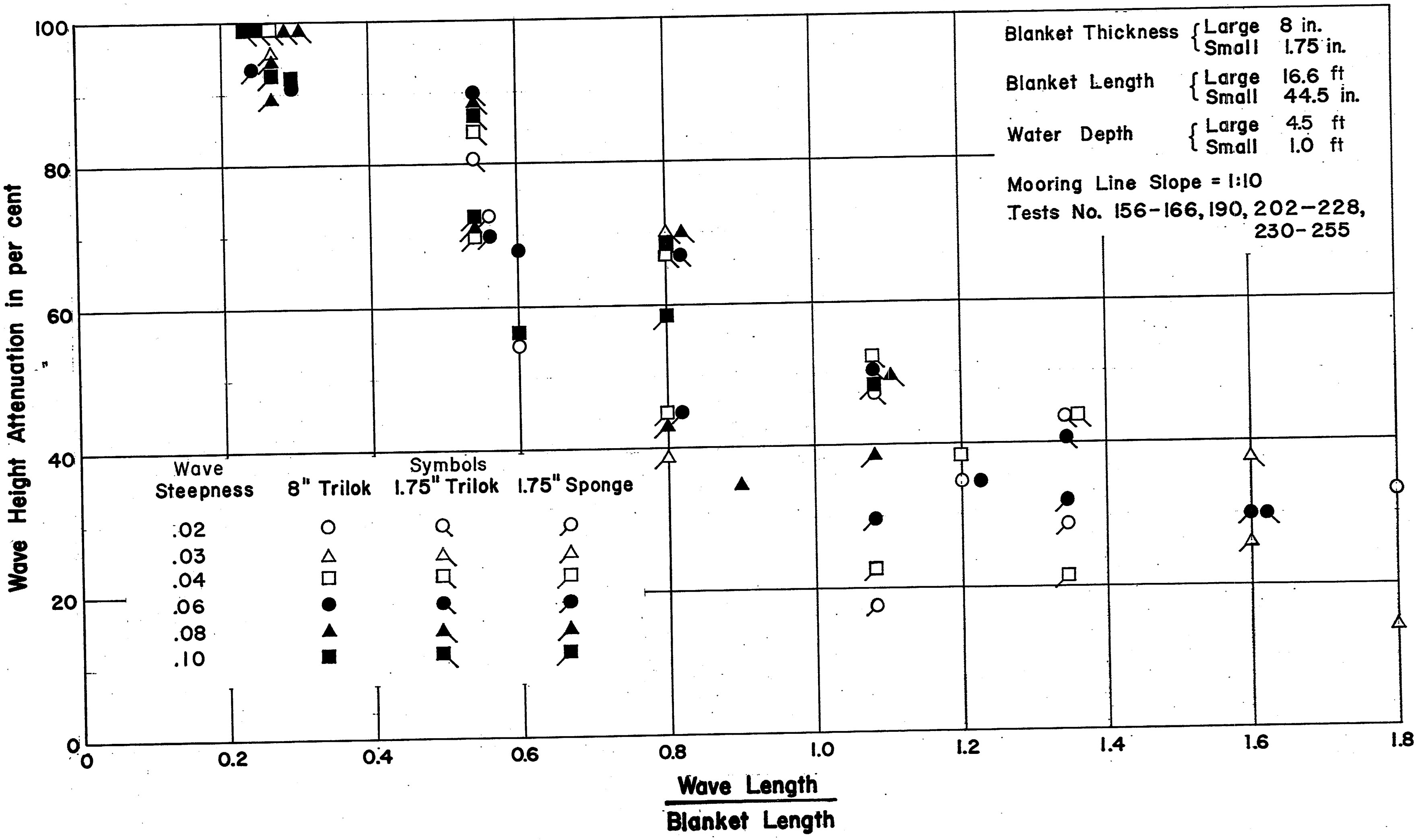


Fig. 12 – Comparative Wave Height Attenuation Effects for Wave Blankets with a Scale Range of 1 to 4.5

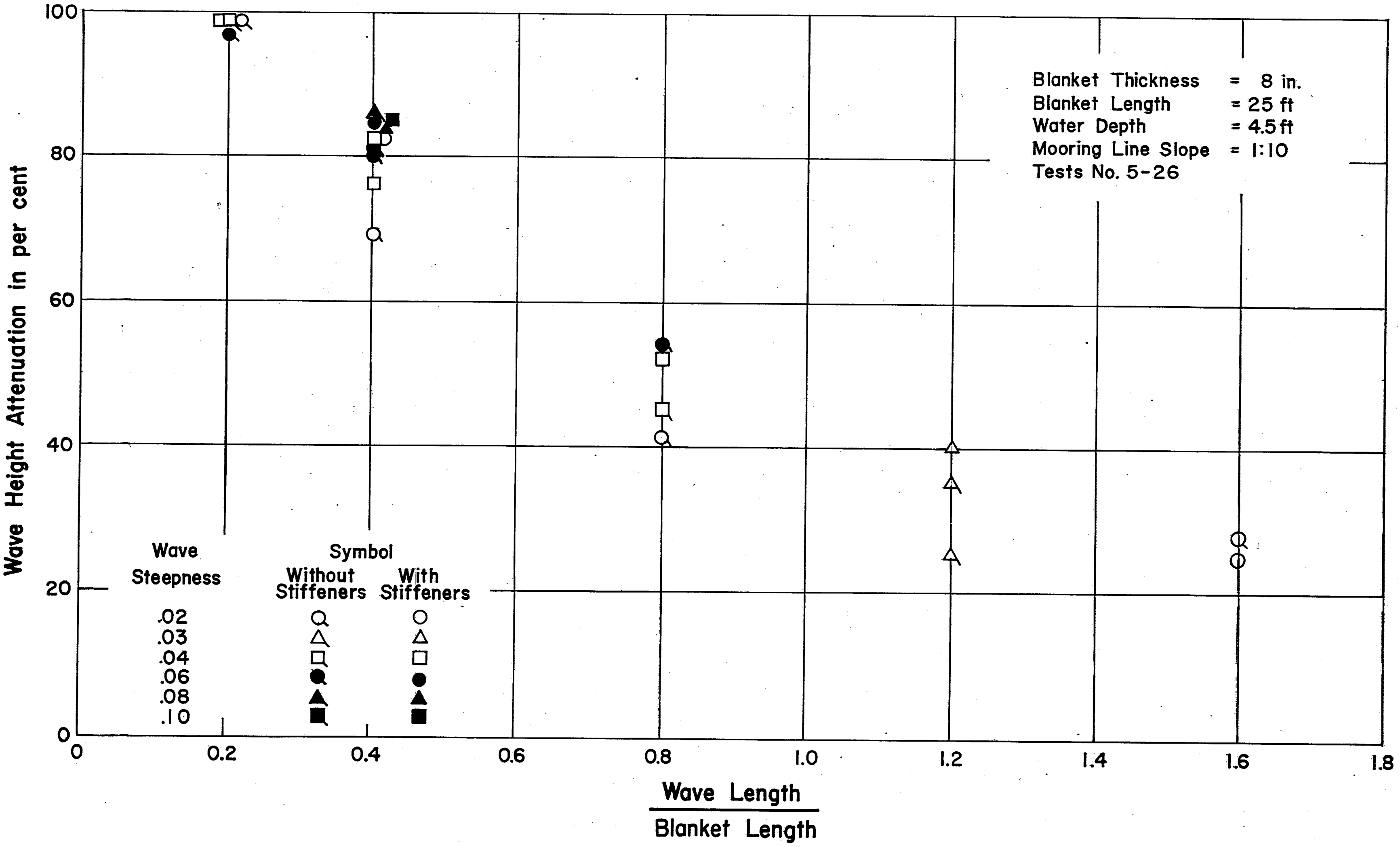


Fig. 13 – Comparative Wave Height Attenuation Effects Provided by Wave Blanket Stiffening Tubes

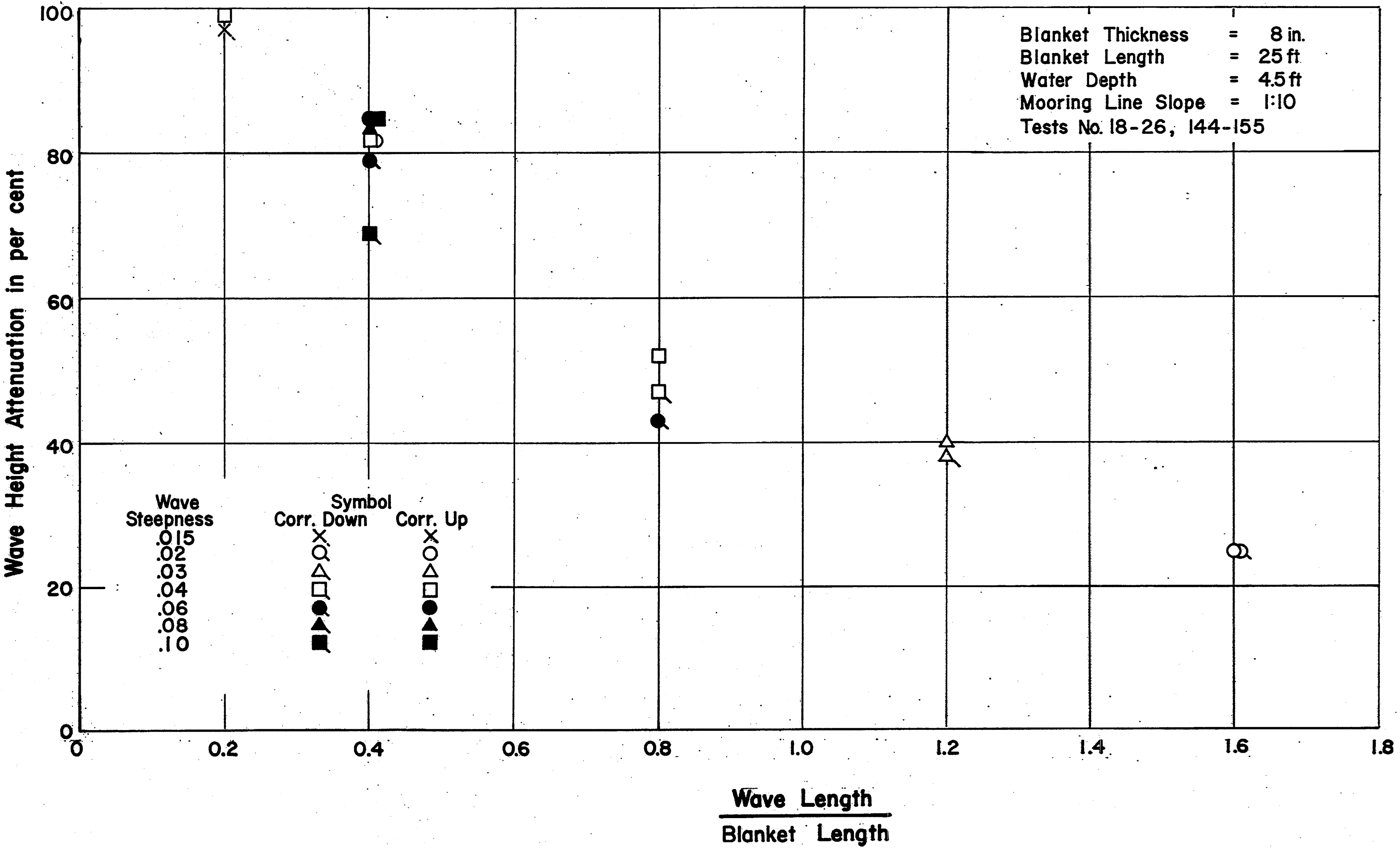


Fig. 14 – Comparative Wave Height Attenuation Effects with Wave Blanket Inversion

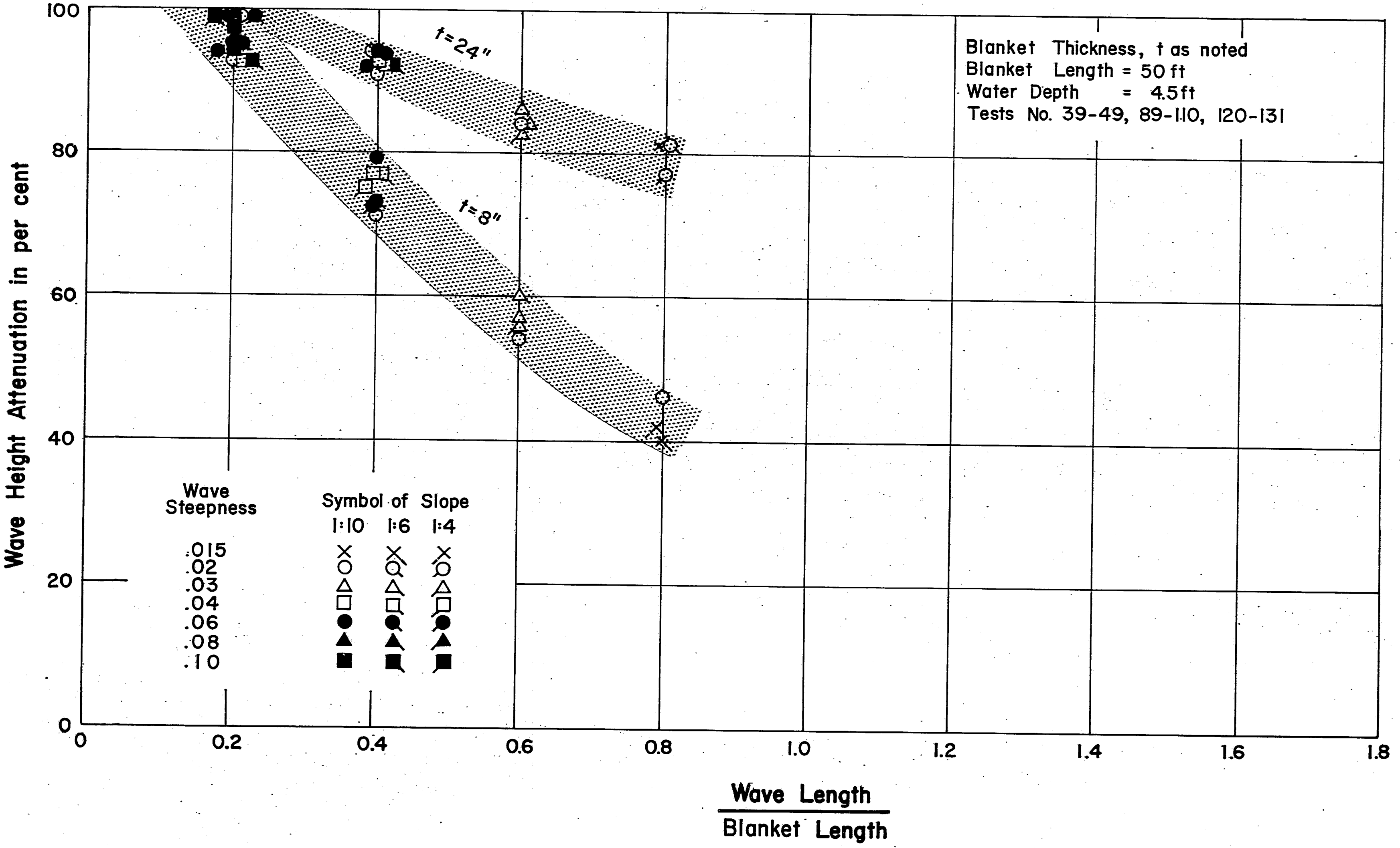


Fig. 15 – Comparative Wave Height Attenuation Effects with Variation of Mooring Line Slope

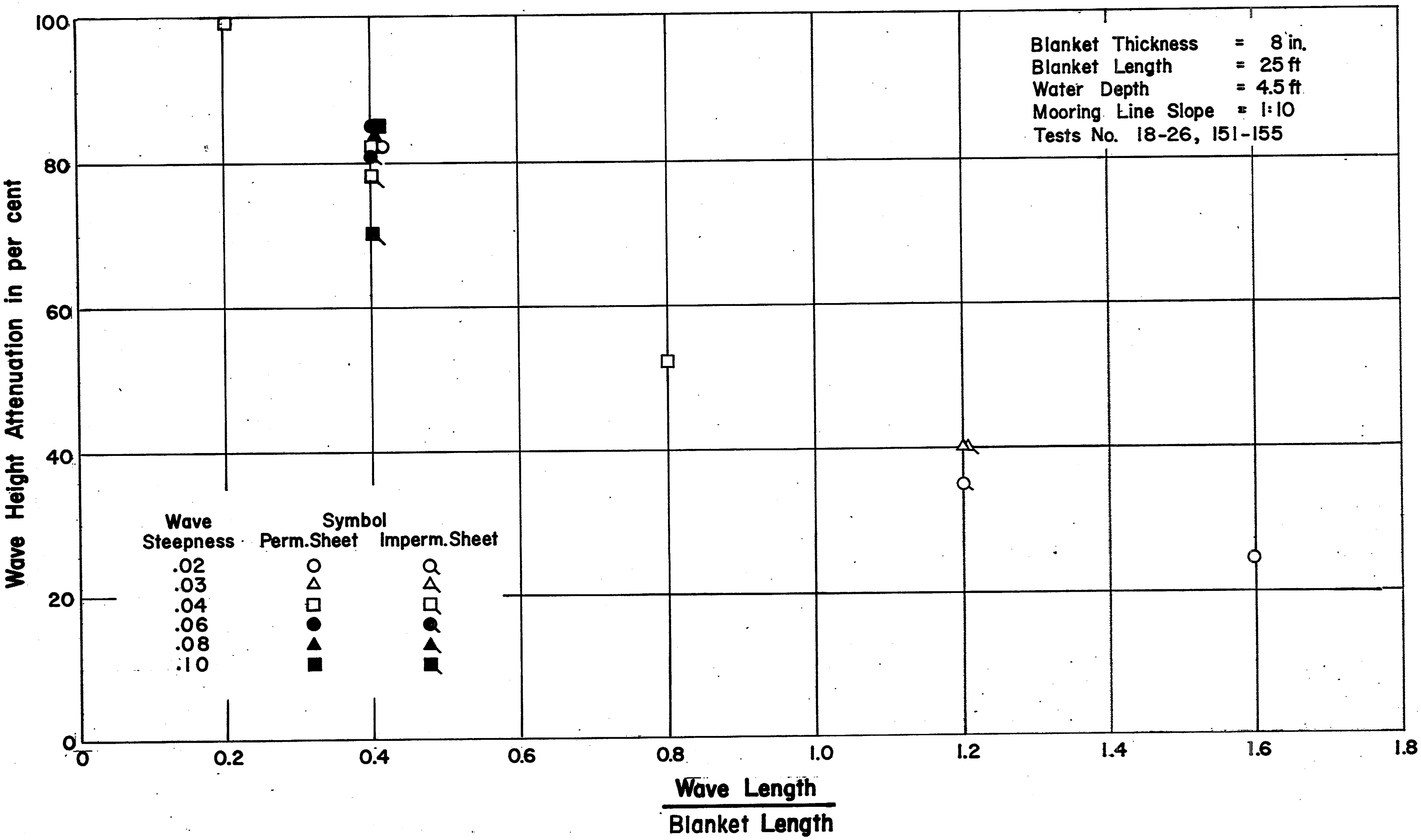


Fig. 16 – Comparative Wave Height Attenuation with a Permeable and an Impermeable Lower Blanket Sheet

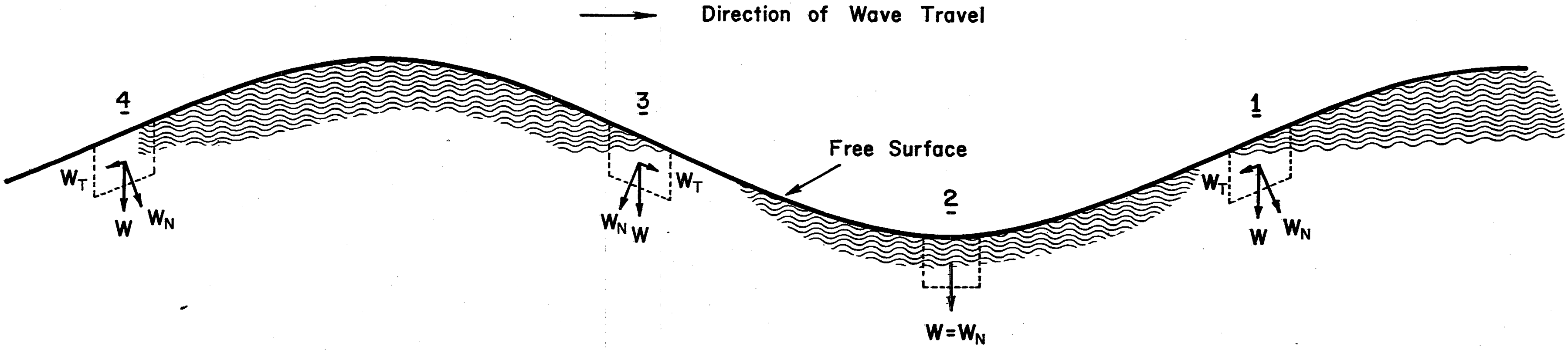
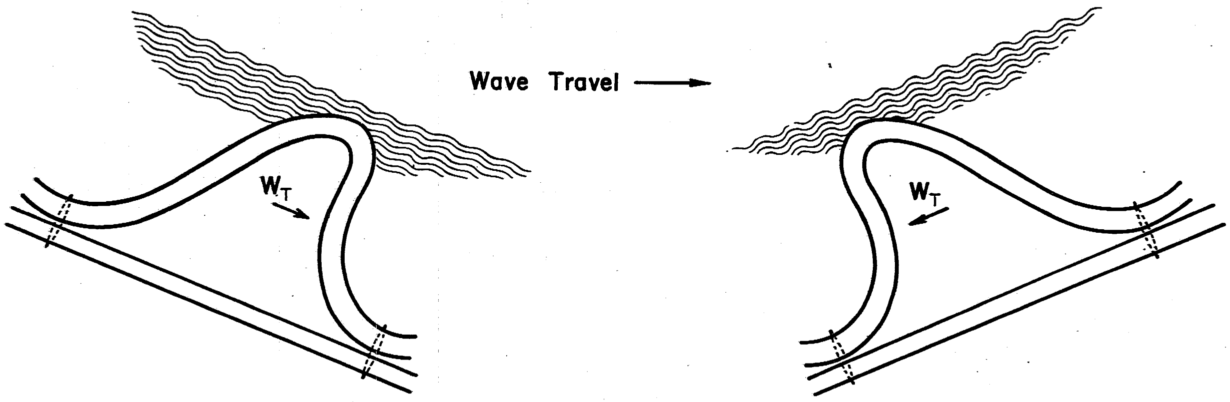


Fig. 17 – Directional Aspects of the Wave Gravitational Force



(a) Approaching Wave Slope

(b) Receding Wave Slope

Fig. 18 – Distortion of the Wave Blanket Corrugations under Gravity Action

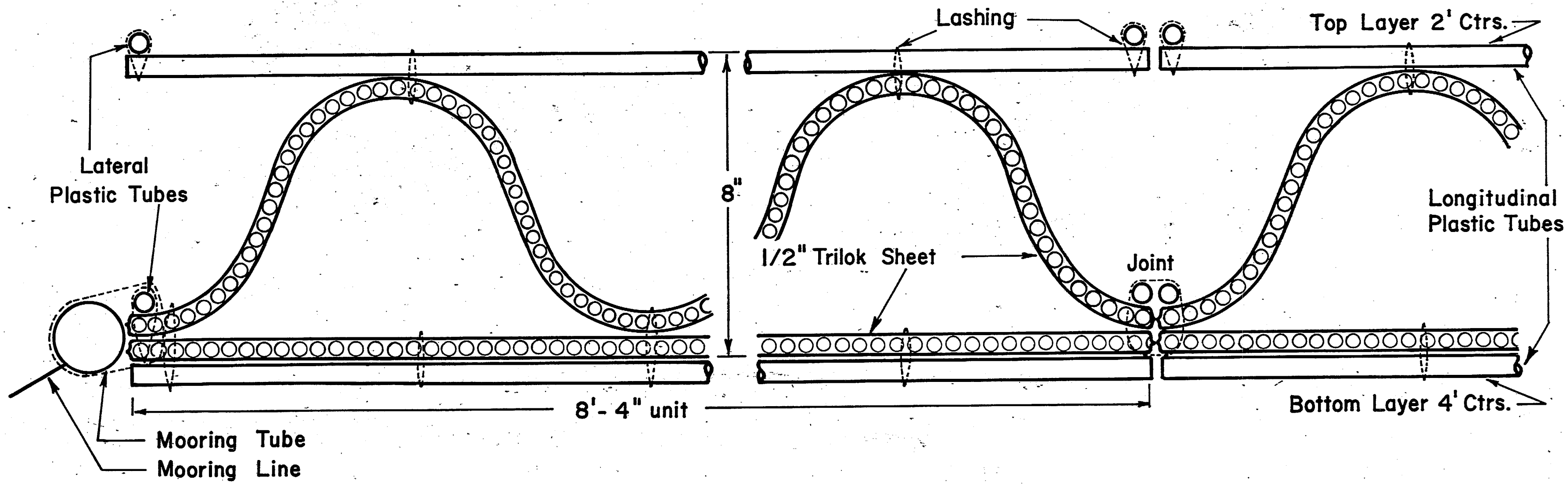
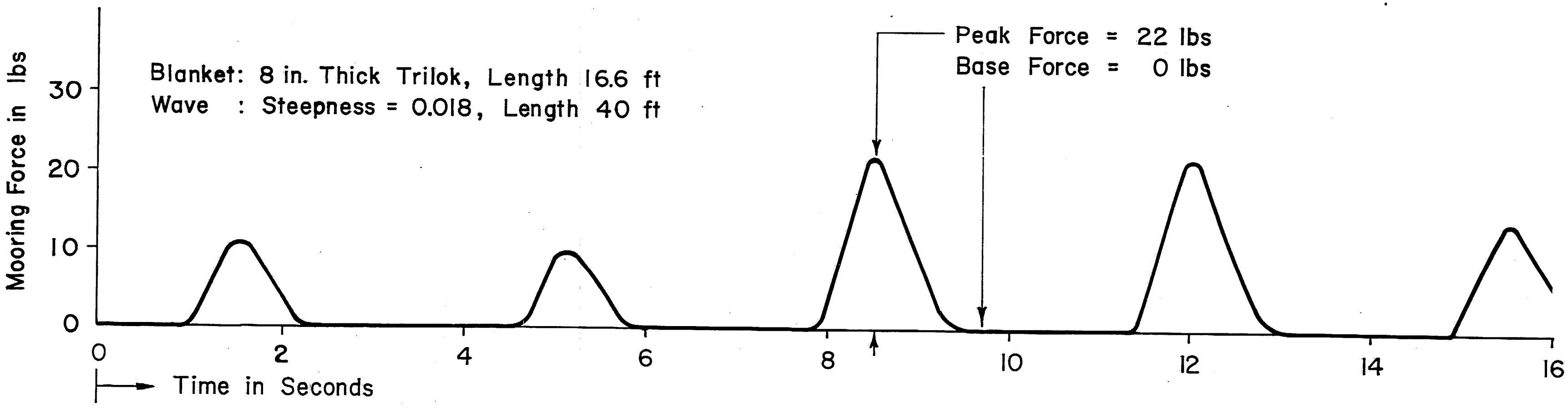
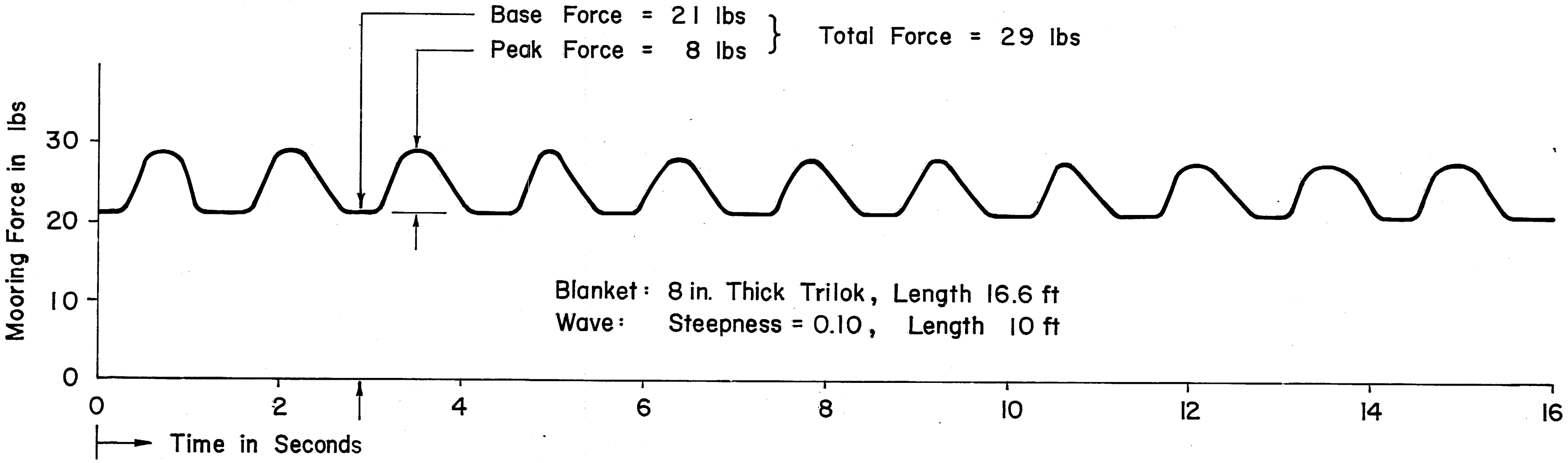


Fig. 19 – Structural System of the Single-Layer Wave Blanket



(a) Record from Test No. 166



(b) Record from Test No. 160

Fig. 20 – Typical Mooring Force Records for the Wave Blanket

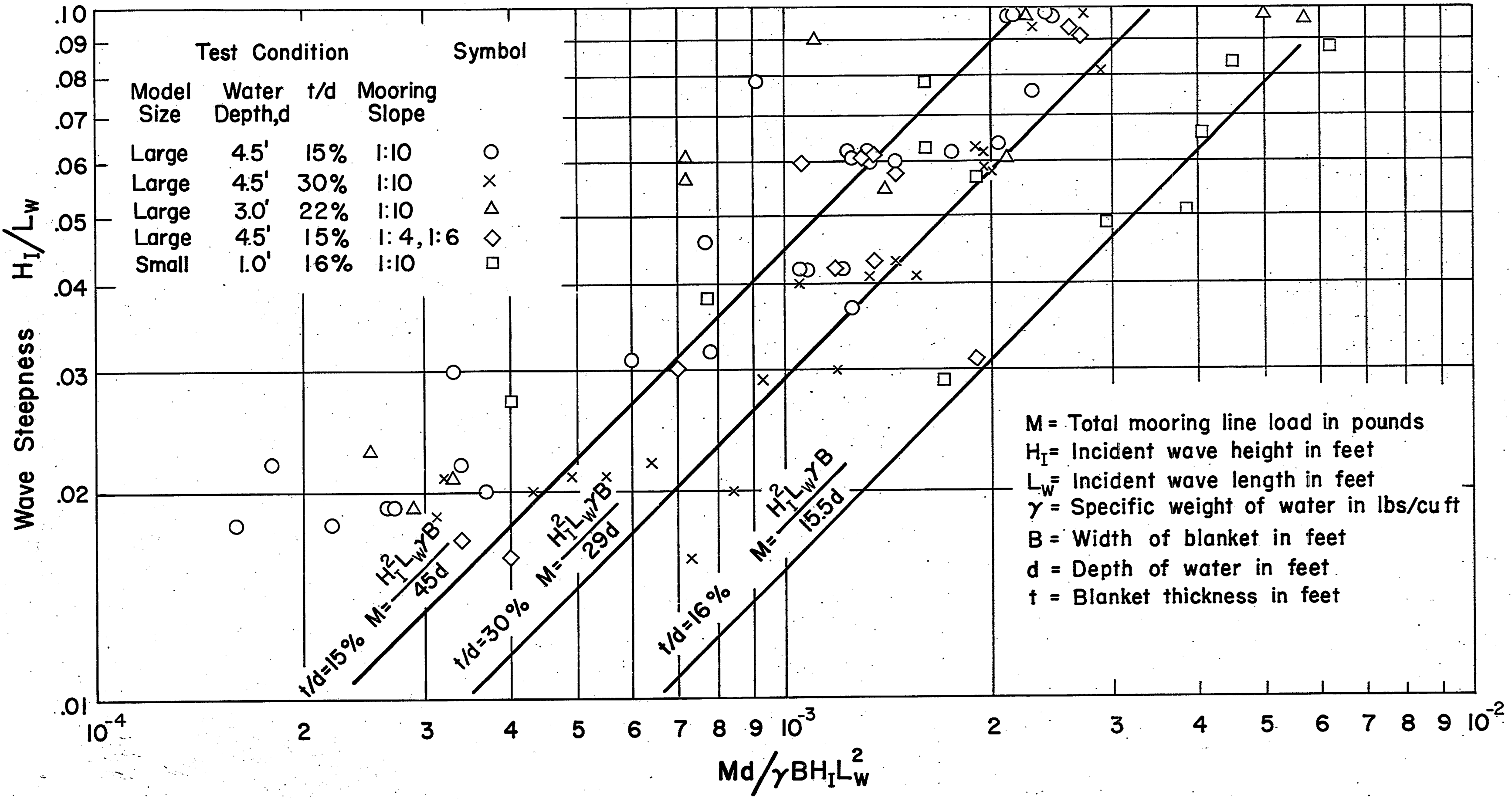


Fig. 21 - Summary Graph of Mooring Forces for the Wave Blanket

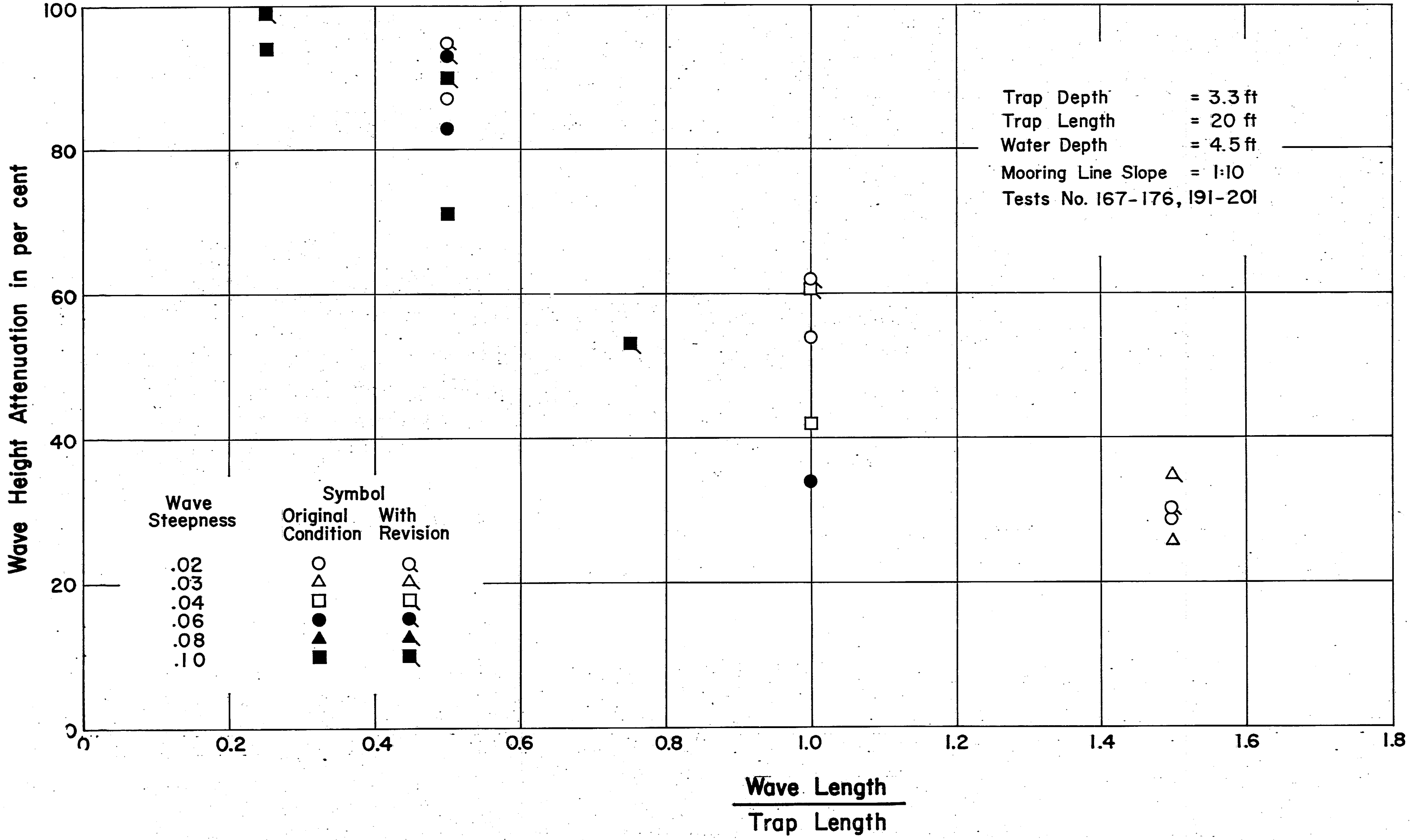


Fig. 22 - Wave Height Attenuation for a Wave Trap

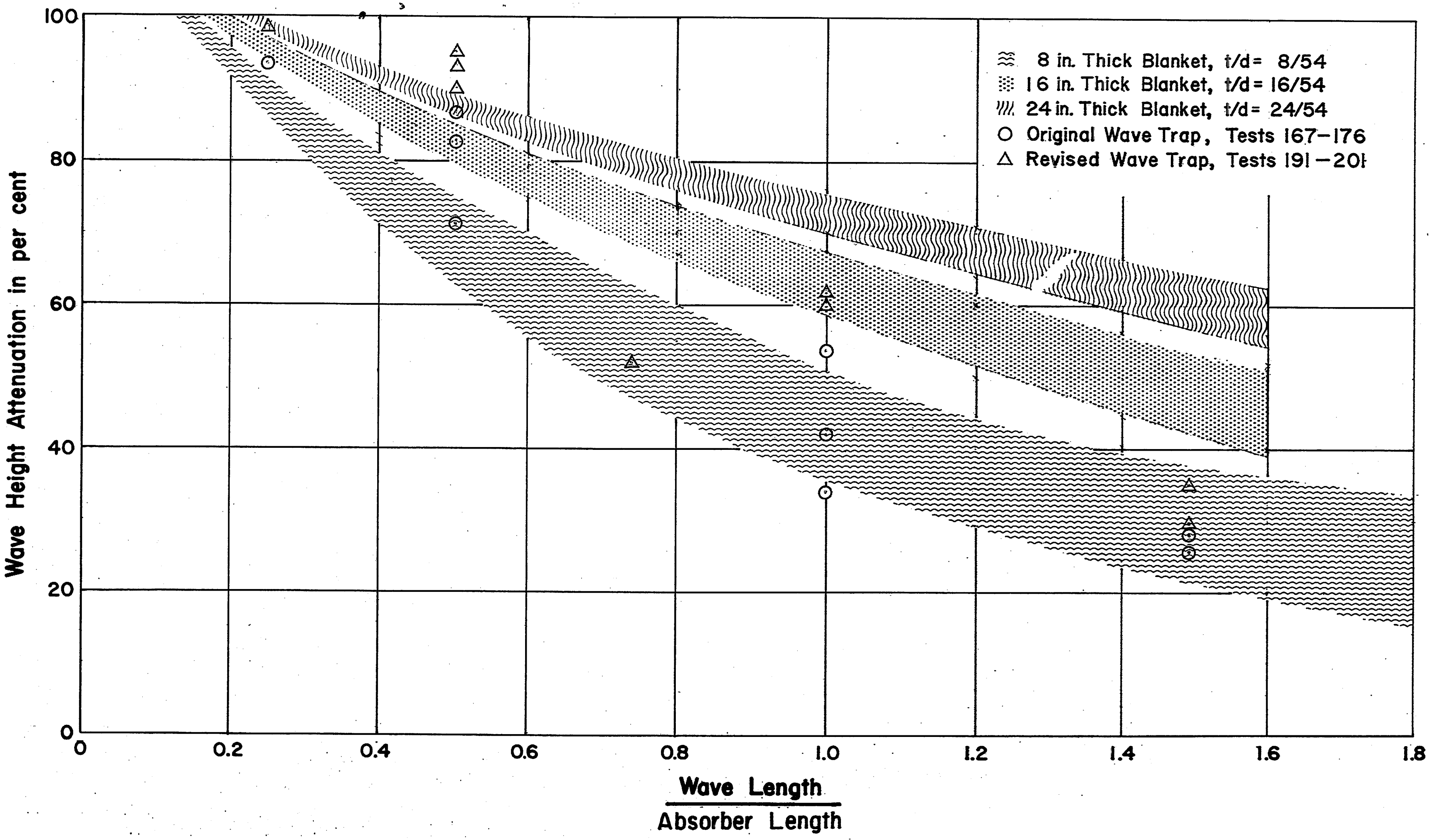


Fig. 23 – Comparative Wave Attenuation Effects for the Wave Blanket and the Wave Trap

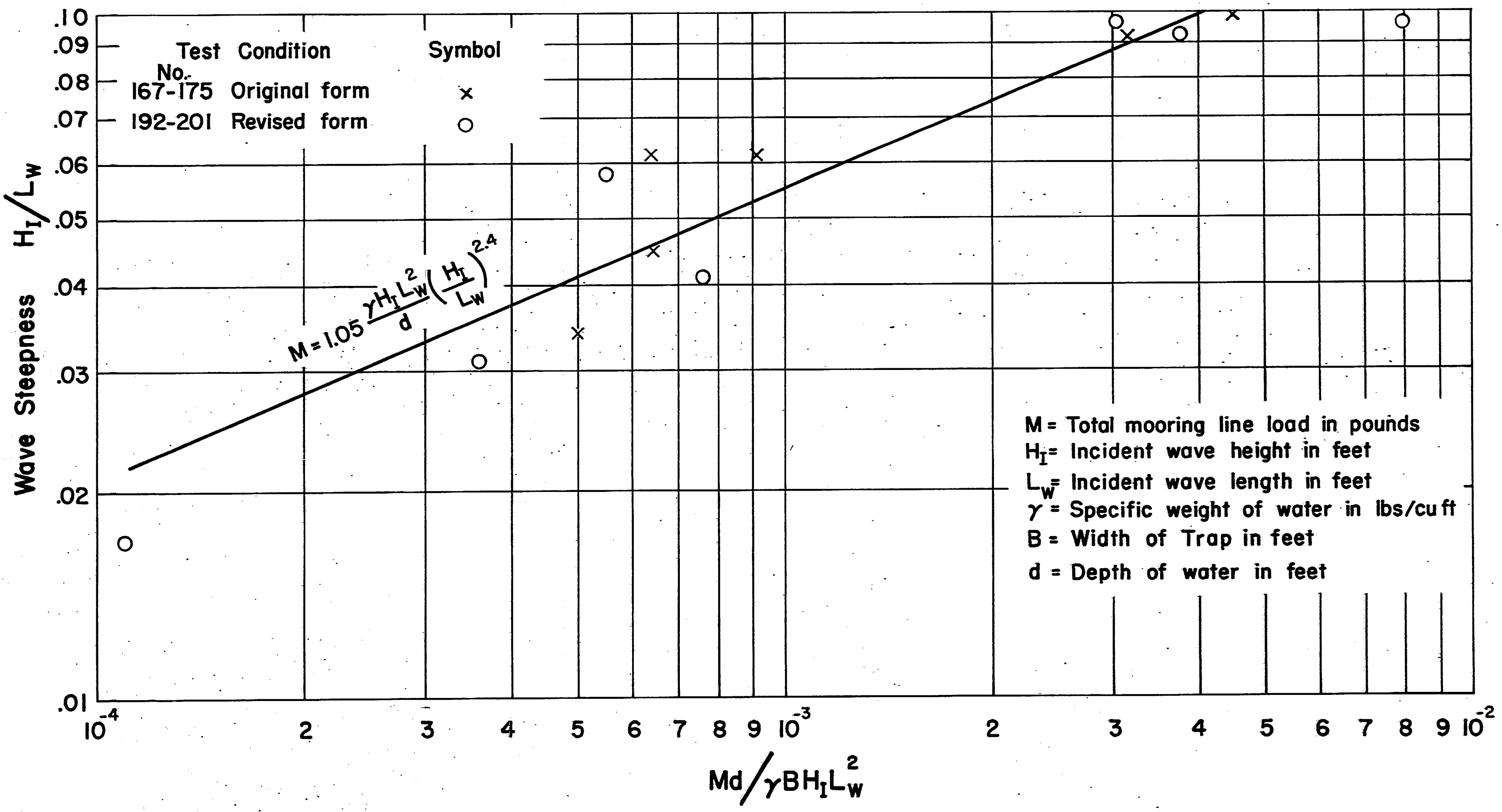


Fig. 24 - Summary Graph of Mooring Forces for the Wave Trap

APPENDIX A

TEST DATA FOR THE WAVE BLANKET

APPENDIX A

TEST DATA FOR THE WAVE BLANKET

Test No.	No. of Blanket Layers	Blanket Depth t ft	Blanket Length L_B ft	Wave Length L_w ft	L_w/L_B	Incident Wave Height H_I ft	Wave Steepness H_I/L_w	Trans. Wave Height H_T ft	Wave Height Atten. %	Reflected Wave %	Water Depth d ft	Mooring Line Slope	Mooring Force M Base lbs	Mooring Force M Peak lbs	Mooring Force M Total lbs	$\frac{Md}{H_I \gamma B L_w^2}$ x 10^{-5}	Buckling Evidence	Special Conditions
5	1	0.67	25	5	0.2	0.21	0.041	0.001	99	23	4.5	1:10	-	-	0	-	-	Tested without Stiffening Tubes at Joints
6	1	0.67	25	10	0.4	0.38	0.038	0.09	76	2	4.5	1:10	-	-	2	-	-	
7	1	0.67	25	20	0.8	0.81	0.040	0.44	45	4	4.5	1:10	-	-	63	-	B	
8	1	0.67	25	30	1.2	0.90	0.030	0.67	25	3	4.5	1:10	-	-	90	-	B+	
9	1	0.67	25	10	0.4	1.05	0.105	0.20	81	7	4.5	1:10	-	-	38	-	-	
10	1	0.67	25	10	0.4	0.84	0.084	0.17	86	7	4.5	1:10	-	-	20	-	-	
11	1	0.67	25	10	0.4	0.61	0.061	0.12	80	7	4.5	1:10	-	-	9	-	-	
12a	1	0.67	25	10	0.4	0.19	0.019	0.06	69	9	4.5	1:10	-	-	0	-	-	
12b	1	0.67	25	5	0.2	0.11	0.022	-	99	7	4.5	1:10	-	-	-	-	-	
13	1	0.67	25	5	0.2	0.31	0.062	0.01	97	7	4.5	1:10	-	-	-	-	-	
14	1	0.67	25	20	0.8	0.40	0.020	0.23	41	5	4.5	1:10	-	-	-	-	B+	
15	1	0.67	25	20	0.8	1.25	0.062	0.58	54	7	4.5	1:10	-	-	-	-	B+	
16	1	0.67	25	40	1.6	0.75	0.020	0.54	28	7	4.5	1:10	-	-	-	-	B+	
17	1	0.67	25	30	1.2	0.77	0.026	0.52	35	4	4.5	1:10	-	-	-	-	B+	
18	1	0.67	25	10	0.4	0.39	0.039	0.07	82	0	4.5	1:10	-	-	0	-	-	Stiffness Added in all Later Tests
19	1	0.67	25	10	0.4	0.20	0.020	0.03	82	2	4.5	1:10	-	-	0	-	-	
20	1	0.67	25	10	0.4	0.60	0.060	0.09	85	6	4.5	1:10	-	-	1	13.8	-	
21	1	0.67	25	10	0.4	0.79	0.079	0.12	84	8	4.5	1:10	6	3	9	91	-	
22	1	0.67	25	10	0.4	0.98	0.098	0.15	85	6	4.5	1:10	21	5	26	212	-	
23	1	0.67	25	5	0.2	0.21	0.042	-	99	2	4.5	1:10	-	-	0	-	-	
24	1	0.67	25	20	0.8	0.84	0.042	0.41	52	4	4.5	1:10	6	38	44	105	B	
25	1	0.67	25	30	1.2	0.92	0.031	0.55	40	7	4.5	1:10	6	55	61	60	B+	
26	1	0.67	25	40	1.6	0.75	0.019	0.56	25	5	4.5	1:10	4	20	24	26.5	B+	
27	1	0.67	33.4	5	0.15	0.23	0.046	0	100	5	4.5	1:10	-	-	-	-	-	
28	1	0.67	33.4	10	0.3	0.20	0.020	0.03	83	5	4.5	1:10	-	-	-	-	-	
29	1	0.67	33.4	10	0.3	0.39	0.039	0.06	85	4	4.5	1:10	-	-	-	-	-	
30	1	0.67	33.4	10	0.3	0.62	0.062	0.06	90	6	4.5	1:10	-	-	-	-	-	
31	1	0.67	33.4	10	0.3	0.82	0.082	0.07	90	5	4.5	1:10	-	-	-	-	-	
32	1	0.67	33.4	10	0.3	1.02	0.102	0.10	90	10	4.5	1:10	-	-	-	-	-	

Test No.	No. of Blanket Layers	Blanket Depth t ft	Blanket Length L_B ft	Wave Length L_w ft	L_w/L_B	Incident Wave Height H_I ft	Wave Steepness H_I/L_w	Trans. Wave Height H_T ft	Wave Height Atten. %	Reflected Wave %	Water Depth d ft	Mooring Line Slope	Mooring Force, M Base lbs	Peak lbs	Total lbs	$\frac{M_d}{H_I \gamma B L_w^2}$ x 10^{-5}	Buckling Evidence	Special Conditions
33	1	0.67	33.4	20	0.6	0.43	0.022	0.20	55	3	4.5	1:10	-	-	-	-	B	Stiffness Added
34	1	0.67	33.4	20	0.6	0.84	0.042	0.31	62	3	4.5	1:10	-	-	-	-	B	
35	1	0.67	33.4	20	0.6	0.95	0.042	0.35	63	4	4.5	1:10	-	-	-	-	B	
36	1	0.67	33.4	30	0.9	0.62	0.021	0.36	42	5	4.5	1:10	-	-	-	-	B+	
37	1	0.67	33.4	30	0.9	0.90	0.030	0.51	41	12	4.5	1:10	-	-	-	-	B+	
38	1	0.67	33.4	40	1.3	0.64	0.016	0.46	30	12	4.5	1:10	-	-	-	-	B+	
39	1	0.67	50	10	0.2	0.20	0.020	0.02	73	5	4.5	1:10	-	-	-	-	-	
40	1	0.67	50	10	0.2	0.37	0.037	0.02	93	8	4.5	1:10	-	-	6	125	-	
41	1	0.67	50	10	0.2	0.61	0.061	0.03	95	5	4.5	1:10	8	2	10	125	-	
42	1	0.67	50	10	0.2	0.76	0.076	0.03	96	10	4.5	1:10	20	2	22	230	-	
43	1	0.67	50	10	0.2	0.98	0.098	0.03	97	6	4.5	1:10	27	3	30	246	-	
44	1	0.67	50	20	0.4	0.41	0.022	0.12	71	7	4.5	1:10	4	3	7	34.4	B	
45	1	0.67	50	20	0.4	0.84	0.042	0.19	77	1	4.5	1:10	7	44	51	122	B	
46	1	0.67	50	20	0.4	1.19	0.060	0.25	79	3	4.5	1:10	-	-	80	132	B	
47	1	0.67	50	30	0.6	0.56	0.018	0.26	54	5	4.5	1:10	-	-	-	-	B	
48	1	0.67	50	30	0.6	0.90	0.030	0.39	57	5	4.5	1:10	-	-	-	-	B+	
49	1	0.67	50	40	0.8	0.65	0.016	0.38	40	10	4.5	1:10	-	-	-	-	B+	
50	2	1.33	50	10	0.2	0.94	0.094	0.02	97	5	4.5	1:10	18	9	27	230	-	
51	2	1.33	50	10	0.2	0.39	0.039	0.01	97	0	4.5	1:10	-	-	0	-	-	
52	2	1.33	50	20	0.4	0.39	0.020	0.07	82	0	4.5	1:10	6	10	16	84	-	
53	2	1.33	50	20	0.4	0.82	0.041	0.09	89	3	4.5	1:10	17	46	63	155	-	
54	2	1.33	50	20	0.4	1.16	0.058	0.12	90	3	4.5	1:10	28	88	116	200	B	
55	2	1.33	50	30	0.6	0.62	0.021	0.15	76	2	4.5	1:10	2	37	39	55	-	
56	2	1.33	50	30	0.6	0.90	0.030	0.21	76	3	4.5	1:10	17	106	123	118	B+	
57	2	1.33	50	40	0.8	0.66	0.016	0.24	64	7	4.5	1:10	1	96	97	73.5	B	
58	2	1.33	33.4	10	0.3	0.19	0.019	0.01	93	6	4.5	1:10	-	-	0	-	-	
59	2	1.33	33.4	10	0.3	0.39	0.039	0.02	94	4	4.5	1:10	-	-	0	-	-	
60	2	1.33	33.4	10	0.3	0.58	0.058	0.03	95	4	4.5	1:10	12	2	14	192	-	
61	2	1.33	33.4	10	0.3	0.80	0.080	0.03	96	6	4.5	1:10	23	2	25	248	-	
62	2	1.33	33.4	10	0.3	1.04	0.104	0.04	96	8	4.5	1:10	35	5	40	306	-	
63	2	1.33	33.4	20	0.6	0.41	0.020	0.10	76	4	4.5	1:10	4	5	9	43	-	
64	2	1.33	33.4	20	0.6	0.82	0.041	0.15	81	4	4.5	1:10	16	39	55	132	B	

Test No.	No. of Blanket Layers	Blanket Depth t ft	Blanket Length L_B ft	Wave Length L_w ft	L_w/L_B	Incident Wave Height H_I ft	Wave Steepness H_I/L_w	Trans. Wave Height H_T ft	Wave Height Atten. %	Reflected Wave %	Water Depth d ft	Mooring Line Slope	Mooring Force M			$\frac{Md}{H_I \gamma B L_w^2}$ x 10^{-5}	Buckling Evidence	Special Conditions
													Base lbs	Peak lbs	Total lbs			
65	2	1.33	33.4	20	0.6	1.18	0.059	0.23	80	6	4.5	1:10	23	95	118	197	B	Stiffness Added
66	2	1.33	33.4	30	0.9	0.60	0.020	0.19	68	6	4.5	1:10	2	41	43	64	B	
67	2	1.33	33.4	30	0.9	0.90	0.030	0.27	70	7	4.5	1:10	0	98	98	98	B+	
68	2	1.33	33.4	40	1.2	0.83	0.021	0.29	65	12	4.5	1:10	0	54	54	32.5	B+	
69	2	1.33	25	10	0.4	0.19	0.019	0.03	87	5	4.5	1:10	-	-	0	0	-	
70	2	1.33	25	10	0.4	0.40	0.040	0.05	88	8	4.5	1:10	1	4	5	105	-	
71	2	1.33	25	10	0.4	0.62	0.062	0.06	90	6	4.5	1:10	12	3	15	194	-	
72	2	1.33	25	10	0.4	0.81	0.081	0.07	92	4	4.5	1:10	27	2	29	288	-	
73	2	1.33	25	10	0.4	1.00	0.100	0.08	91	9	4.5	1:10	33	1	34	272	-	
74	2	1.33	25	20	0.8	0.44	0.022	0.14	69	5	4.5	1:10	3	11	14	64	-	
75	2	1.33	25	20	0.8	0.86	0.043	0.23	73	4	4.5	1:10	18	45	63	145	B	
76	2	1.33	25	20	0.8	1.26	0.063	0.31	75	3	4.5	1:10	18	100	118	188	-	
77	2	1.33	25	30	1.2	0.63	0.021	0.26	58	13	4.5	1:10	10	25	35	49.5	B	
78	2	1.33	25	30	1.2	0.86	0.029	0.36	58	10	4.5	1:10	5	85	90	93	B+	
79	2	1.33	25	40	1.6	0.72	0.018	0.45	37	13	4.5	1:10	5	40	45	31	B+	
80	3	2	25	10	0.4	0.93	0.093	0.09	90	9	4.5	1:10	25	5	30	-	B	
81	3	2	25	10	0.4	0.59	0.059	0.05	92	8	4.5	1:10	10	0	10	-	-	
82	3	2	25	10	0.4	0.21	0.021	0.02	89	2	4.5	1:10	-	-	0	-	-	
83	3	2	25	20	0.8	0.45	0.022	0.10	77	4	4.5	1:10	5	5	10	-	-	
84	3	2	25	20	0.8	0.89	0.045	0.18	80	6	4.5	1:10	20	32	52	-	B	
85	3	2	25	20	0.8	1.22	0.061	0.25	79	13	4.5	1:10	15	100	115	-	-	
86	3	2	25	30	1.2	0.59	0.020	0.18	70	11	4.5	1:10	10	20	30	-	B	
87	3	2	25	30	1.2	0.94	0.031	0.27	71	12	4.5	1:10	15	65	80	-	B	
88	3	2	25	40	1.6	0.70	0.018	0.31	56	14	4.5	1:10	1	50	51	-	B+	
89	3	2	50	10	0.2	0.91	0.091	0.01	99	9	4.5	1:10	22	9	31	-	B	
90	3	2	50	10	0.2	0.58	0.058	0.01	99	8	4.5	1:10	9	2	11	-	-	
91	3	2	50	10	0.2	0.21	0.021	0	100	0	4.5	1:10	-	-	0	-	-	
92	3	2	50	20	0.4	0.43	0.021	0.04	91	3	4.5	1:10	4	9	13	-	-	
93	3	2	50	20	0.4	0.92	0.046	0.06	93	6	4.5	1:10	22	40	62	-	-	
94	3	2	50	20	0.4	1.26	0.063	0.07	94	8	4.5	1:10	29	100	129	-	-	
95	3	2	50	30	0,6	0.56	0.019	0.09	84	6	4.5	1:10	4	27	31	-	B	
96	3	2	50	30	0.6	0.91	0.030	0.14	84	4	4.5	1:10	2	85	87	-	B	

Test No.	No. of Blanket Layers	Blanket Depth t ft	Blanket Length L_B ft	Wave Length L_w ft	L_w/L_B	Incident Wave Height H_I ft	Wave Steepness H_I/L_w	Trans. Wave Height H_T ft	Wave Height Atten. %	Reflected Wave %	Water Depth d ft	Mooring Line Slope	Mooring Force M Base lbs	Mooring Force M Peak lbs	Mooring Force M Total lbs	$\frac{M_d}{H_I \gamma B L_w^2}$ x 10^{-5}	Buckling Evidence	Special Conditions
97	3	2	50	40	0.8	0.68	0.017	0.13	81	8	4.5	1:10	0	58	58	-	B	Stiffness Added
98	3	2	50	20	0.4	0.92	0.046	0.07	92	7	4.5	1:10	21	40	61	-	-	
99	3	2	50	10	0.2	0.62	0.062	0.01	99	0	4.5	1:6	9	4	13	-	-	
100	3	2	50	10	0.2	1.00	0.100	0.01	99	7	4.5	1:6	28	4	32	-	-	
101	3	2	50	20	0.4	0.89	0.045	0.07	92	6	4.5	1:6	14	37	51	-	B	
102	3	2	50	20	0.4	1.21	0.061	0.09	93	6	4.5	1:6	14	94	108	-	B	
103	3	2	50	40	0.8	0.74	0.018	0.14	81	10	4.5	1:6	0	78	78	-	B	
104	3	2	50	30	0.6	1.00	0.033	0.13	86	8	4.5	1:6	0	120	120	-	B	
105	3	2	50	30	0.6	0.93	0.031	0.16	83	10	4.5	1:4	0	106	106	-	B	
106	3	2	50	40	0.8	0.68	0.017	0.15	77	9	4.5	1:4	0	69	69	-	B	
107	3	2	50	20	0.4	0.88	0.044	0.07	92	5	4.5	1:4	5	61	66	-	B	
108	3	2	50	20	0.4	1.23	0.061	0.09	92	5	4.5	1:4	17	93	110	-	-	
109	3	2	50	10	0.2	0.64	0.064	0.01	99	5	4.5	1:4	0	9	9	-	-	
110	3	2	50	10	0.2	0.92	0.092	0.01	99	8	4.5	1:4	46	21	67	-	-	
111	step	1.33	50	10	0.2	0.21	0.021	0.01	97	4	4.5	1:10	-	-	0	-	-	
112	step	1.33	50	10	0.2	0.58	0.058	0.01	98	3	4.5	1:10	7	3	10	-	-	
113	step	1.33	50	10	0.2	0.96	0.096	0.03	97	4	4.5	1:10	26	5	31	-	-	
114	step	1.33	50	20	0.4	0.42	0.021	0.07	83	1	4.5	1:10	3	8	11	-	-	
115	step	1.33	50	20	0.4	0.86	0.043	0.10	88	3	4.5	1:10	19	45	64	-	-	
116	step	1.33	50	20	0.4	1.21	0.060	0.16	87	5	4.5	1:10	19	68	87	-	B	
117	step	1.33	50	30	0.6	0.56	0.019	0.14	74	6	4.5	1:10	0	28	28	-	B	
118	step	1.33	50	30	0.6	0.86	0.029	0.19	77	6	4.5	1:10	0	71	71	-	B	
119	step	1.33	50	40	0.8	0.69	0.017	0.19	75	4	4.5	1:10	0	66	66	-	B	
120	1	0.67	50	20	0.4	1.20	0.060	0.32	73	6	4.5	1:6	7	58	65	106	-	
121	1	0.67	50	20	0.4	0.86	0.043	0.20	77	4	4.5	1:6	7	50	57	134	-	
122	1	0.67	50	10	0.2	0.94	0.094	0.06	93	6	4.5	1:6	27	3	30	260	-	
123	1	0.67	50	10	0.2	0.61	0.061	0.03	95	3	4.5	1:6	15	2	17	225	-	
124	1	0.67	50	30	0.6	0.92	0.031	0.37	60	5	4.5	1:6	2	65	67	188	B	
125	1	0.67	50	40	0.8	0.69	0.017	0.37	46	9	4.5	1:6	0	46	46	34	B+	
126	1	0.67	50	40	0.8	0.64	0.016	0.38	41	2	4.5	1:4	0	50	50	40	B	
127	1	0.67	50	30	0.6	0.91	0.030	0.40	56	5	4.5	1:4	2	68	70	70	B	
128	1	0.67	50	20	0.4	1.16	0.058	0.32	72	5	4.5	1:4	22	62	84	145	-	

Test No.	No. of Blanket Layers	Blanket Depth t ft	Blanket Length L_B ft	Wave Length L_w ft	L_w/L_B	Incident Wave Height H_I ft	Wave Steepness H_I/L_w	Trans. Wave Height H_T ft	Wave Height Atten. %	Reflected Wave %	Water Depth d ft	Mooring Line Slope	Mooring Force M			$\frac{Md}{H_I \gamma B L_w^2}$ x 10^{-5}	Buckling Evidence	Special Conditions
													Base lbs	Peak lbs	Total lbs			
129	1	0.67	50	20	0.4	0.85	0.042	0.22	74	5	4.5	1:4	5	45	50	119	-	Stiffness Added
130	1	0.67	50	10	0.2	0.91	0.091	0.05	94	6	4.5	1:4	27	3	30	270	-	
131	1	0.67	50	10	0.2	0.61	0.061	0.03	94	3	4.5	1:4	10	0	10	135	-	
132	1	0.67	50	10	0.2	0.60	0.060	0.04	93	1	4.5	1:10	11	0	11	146	-	
133	1	0.67	50	10	0.2	0.98	0.098	0.04	95	6	4.7	1:10	2	24	26	215	-	
134	1	0.67	50	20	0.4	0.85	0.042	0.14	84	2	4.5	1:10	10	35	45	106	-	
135	1	0.67	50	20	0.4	1.25	0.062	0.40	68	5	4.5	1:10	31	54	85	136	B	
136	1	0.67	50	30	0.6	0.95	0.032	0.37	61	12	4.5	1:10	5	58	63	78	B	
137	1	0.67	50	40	0.8	0.72	0.018	0.37	49	4	4.5	1:10	0	40	40	21.6	B	
138	1	0.67	50	40	0.8	0.70	0.017	0.38	45	8	4.5	1:10	0	56	56	-	-	Blanket Inverted with Corrugations Down
139	1	0.67	50	30	0.6	0.94	0.031	0.39	58	6	4.5	1:10	13	50	63	-	-	
140	1	0.67	50	20	0.4	0.88	0.044	0.22	74	9	4.5	1:10	20	27	47	-	-	
141	1	0.67	50	20	0.4	1.23	0.062	0.35	71	6	4.5	1:10	29	42	71	-	-	
142	1	0.67	50	10	0.2	0.61	0.061	0.02	96	0	4.5	1:10	12	0	12	-	-	
143	1	0.67	50	10	0.2	0.98	0.098	0.04	96	3	4.5	1:10	28	10	38	-	-	
144	1	0.67	25	10	0.4	0.97	0.097	0.29	69	3	4.5	1:10	27	4	31	-	-	
145	1	0.67	25	10	0.4	0.61	0.061	0.12	79	3	4.5	1:10	11	2	13	-	-	
146	1	0.67	25	5	0.2	0.52	0.010	0.02	97	4	4.5	1:10	9	1	10	-	-	
147	1	0.67	25	20	0.8	0.89	0.044	0.47	47	8	4.5	1:10	13	28	41	-	-	
148	1	0.67	25	20	0.8	1.25	0.062	0.70	43	7	4.5	1:10	7	45	52	-	-	
149	1	0.67	25	30	1.2	0.91	0.030	0.56	38	12	4.5	1:10	6	49	55	-	B	
150	1	0.67	25	40	1.6	0.73	0.018	0.55	25	5	4.5	1:10	4	29	33	-	B	Plastic Sheet Below Blanket
151	1	0.67	25	10	0.4	0.41	0.041	0.09	78	1	4.5	1:10	5	2	7	-	-	
152	1	0.67	25	10	0.4	0.60	0.060	0.11	81	2	4.5	1:10	12	3	15	-	-	
153	1	0.67	25	30	1.2	0.62	0.021	0.40	35	10	4.5	1:10	8	9	17	-	B	
154	1	0.67	25	30	1.2	0.93	0.031	0.56	40	13	4.5	1:10	2	55	57	-	B	
155	1	0.67	25	10	0.4	0.99	0.099	0.30	70	11	4.5	1:10	21	12	33	-	-	
156	1	0.67	16.6	5	0.3	0.51	0.102	0.03	93	7	4.5	1:10	5	2	7	450	-	
157	1	0.67	16.6	5	0.3	0.32	0.064	0.03	91	2	4.5	1:10	-	-	2	202	-	
158	1	0.67	16.6	10	0.6	0.20	0.020	0.09	55	2	4.5	1:10	-	-	1	37	-	
159	1	0.67	16.6	10	0.6	0.62	0.062	0.19	69	3	4.5	1:10	9	5	14	176	-	
160	1	0.67	16.6	10	0.6	1.00	0.100	0.44	56	9	4.5	1:10	21	8	29	240	-	

Test No.	No. of Blanket Layers	Blanket Depth t ft	Blanket Length L_B ft	Wave Length L_w ft	L_w/L_B	Incident Wave Height H_I ft	Wave Steepness H_I/L_w	Trans. Wave Height H_T ft	Wave Height Atten. %	Reflected Wave %	Water Depth d ft	Mooring Line Slope	Mooring Force M			$\frac{Md}{H_I \gamma B L_w^2}$ x 10^{-5}	Buckling Evidence	Special Conditions
													Base lbs	Peak lbs	Total lbs			
161	1	0.67	16.6	20	1.2	0.44	0.022	0.28	35	8	4.5	1:10	-	-	4	18.5	-	Stiffness Added
162	1	0.67	16.6	20	1.2	0.92	0.046	0.56	39	9	4.5	1:10	9	26	35	77	-	
163	1	0.67	16.6	20	1.2	1.25	0.062	0.81	35	8	4.5	1:10	2	74	76	123	-	
164	1	0.67	16.6	30	1.8	0.57	0.019	0.48	33	9	4.5	1:10	0	17	17	27	B	
165	1	0.67	16.6	30	1.8	0.90	0.030	0.73	19	13	4.5	1:10	1	32	33	33	B+	
166	1	0.67	16.6	40	2.4	0.71	0.018	0.60	15	5	4.5	1:10	0	22	22	15.7	B	
177	1	0.67	16.6	5	0.3	0.49	0.097	0.03	95	3	3.0	1:10	9	4	13	570	-	
178	1	0.67	16.6	5	0.3	0.30	0.061	0.02	93	9	3.0	1:10	-	-	2	72.5	-	
179	1	0.67	16.6	10	0.6	1.01	0.101	0.25	75	12	3.0	1:10	25	17	42	226	-	
180	1	0.67	16.6	10	0.6	0.55	0.055	0.16	71	8	3.0	1:10	8	6	14	139	-	
181	1	0.67	16.6	10	0.6	0.19	0.019	0.07	64	3	3.0	1:10	-	-	0	0	-	
182	1	0.67	16.6	20	1.2	0.43	0.021	0.22	48	6	3.0	1:10	6	4	10	31.5	-	
183	1	0.67	25	20	0.8	0.46	0.023	0.19	59	4	3.0	1:10	5	14	19	25	B	
184	1	0.67	25	10	0.4	0.91	0.091	0.14	85	10	3.0	1:10	30	11	41	108	-	
185	1	0.67	25	10	0.4	0.57	0.057	0.10	83	8	3.0	1:10	9	8	17	72.5	-	
186	1	0.67	25	10	0.4	0.19	0.019	0.04	80	5	3.0	1:10	-	-	1	28	-	
187	1	0.67	25	5	0.2	0.30	0.061	0	99	9	3.0	1:10	-	-	3	212	-	Sponge Blanket
188	1	0.67	25	5	0.2	0.52	0.105	0.01	99	7	3.0	1:10	7	5	12	490	-	
189	1	0.67	25	15	0.6	1.41	0.094	0.65	54	8	4.5	1:10	48	65	113	202	-	
190	1	0.67	16.6	15	0.9	1.33	0.089	0.87	35	3	4.5	1:10	19	85	104	208	-	
202	1	0.146	3.72	1	0.27	0.029	0.030	0.004	96	45	1.0	1:10	-	-	0	-	-	
203	1	0.146	3.72	1	0.27	0.061	0.060	0.004	94	30	1.0	1:10	-	-	0	-	-	
204	1	0.146	3.72	1	0.27	0.075	0.075	0.004	95	53	1.0	1:10	-	-	0	-	-	
205	1	0.146	3.72	1	0.27	0.082	0.082	0.008	90	48	1.0	1:10	-	-	0	-	-	
206	1	0.146	3.72	1	0.27	0.110	0.110	0.008	93	35	1.0	1:10	-	-	0	-	-	
207	1	0.146	3.72	2	0.54	0.045	0.022	0.012	74	20	1.0	1:10	-	-	0	-	-	
208	1	0.146	3.72	2	0.54	0.096	0.048	0.028	71	19	1.0	1:10	-	-	0	-	-	
209	1	0.146	3.72	2	0.54	0.129	0.064	0.038	71	16	1.0	1:10	-	-	0.25	-	-	
210	1	0.146	3.72	2	0.54	0.175	0.088	0.050	72	14	1.0	1:10	-	-	0.50	-	-	
211	1	0.146	3.72	2	0.54	0.232	0.116	0.063	73	8	1.0	1:10	-	-	1.5	-	-	
212	1	0.146	3.72	3	0.80	0.082	0.027	0.050	39	10	1.0	1:10	-	-	0	-	-	
213	1	0.146	3.72	3	0.80	0.150	0.050	0.082	45	8	1.0	1:10	-	-	1.5	-	-	

Test No.	No. of Blanket Layers	Blanket Depth t ft	Blanket Length L_B ft	Wave Length L_w ft	L_w/L_B	Incident Wave Height H_I ft	Wave Steepness H_I/L_w	Trans. Wave Height H_T ft	Wave Height Atten. %	Reflected Wave %	Water Depth d ft	Mooring Line Slope	Mooring Force M			$\frac{Md}{H_I \gamma B L_w^2}$ x 10^{-5}	Buckling Evidence	Special Conditions
													Base lbs	Peak lbs	Total lbs			
214	1	0.146	3.72	3	0.80	0.192	0.064	0.117	45	13	1	1:10	-	-	1.5	-	-	Sponge Blanket
215	1	0.146	3.72	3	0.80	0.238	0.079	0.134	44	12	1	1:10	-	-	2.75	-	-	
216	1	0.146	3.72	3	0.80	0.350	0.117	0.142	59	12	1	1:10	-	-	3.3	-	-	
217	1	0.146	3.72	4	1.07	0.082	0.020	0.067	18	6	1	1:10	-	-	0	-	-	
218	1	0.146	3.72	4	1.07	0.150	0.038	0.116	23	3	1	1:10	-	-	1.5	-	-	
219	1	0.146	3.72	4	1.07	0.250	0.062	0.175	30	7	1	1:10	-	-	2.0	-	-	
220	1	0.146	3.72	4	1.07	0.316	0.079	0.192	39	5	1	1:10	-	-	2.5	-	-	
221	1	0.146	3.72	4	1.07	0.360	0.090	0.184	49	7	1	1:10	-	-	2.5	-	-	
222	1	0.146	3.72	5	1.34	0.116	0.023	0.082	29	14	1	1:10	-	-	0	-	-	
223	1	0.146	3.72	5	1.34	0.216	0.043	0.167	23	15	1	1:10	-	-	1.0	-	-	
224	1	0.146	3.72	5	1.34	0.316	0.063	0.214	32	19	1	1:10	-	-	3.25	-	-	
225	1	0.146	3.72	6	1.60	0.192	0.032	0.142	26	13	1	1:10	-	-	1.5	-	-	
226	1	0.146	3.72	6	1.60	0.310	0.052	0.216	30	13	1	1:10	-	-	7.0	-	-	
227	1	0.146	3.72	7	1.88	0.200	0.028	0.183	8	8	1	1:10	-	-	5.0	-	-	
228	1	0.146	3.72	7	1.88	0.375	0.055	0.292	21	11	1	1:10	-	-	5.5	-	-	
229	1	0.146	3.72	8	2.15	0.175	0.022	0.168	4	14	1	1:10	-	-	4.0	-	-	
230	1	0.167	3.7	1	0.27	0.041	0.041	0	100	14	1	1:10	-	0	0	0	-	Modelled Trilok Blanket t = 1.75 in.
231	1	0.167	3.7	1	0.27	0.075	0.075	0	100	33	1	1:10	-	0	0	0	-	
232	1	0.167	3.7	1	0.27	0.092	0.092	0	100	35	1	1:10	-	0	0	0	-	
233	1	0.167	3.7	1	0.27	0.087	0.087	0	100	54	1	1:10	-	0	0	0	-	
234	1	0.167	3.7	1	0.27	0.094	0.094	0	100	46	1	1:10	-	0	0	0	-	
235	1	0.167	3.7	2	0.54	0.043	0.022	0.008	82	8	1	1:10	-	0	0	0	-	
236	1	0.167	3.7	2	0.54	0.087	0.044	0.013	85	8	1	1:10	-	0	0	0	-	
237	1	0.167	3.7	2	0.54	0.132	0.066	0.013	90	4	1	1:10	-	0	0	0	-	
238	1	0.167	3.7	2	0.54	0.175	0.088	0.017	88	5	1	1:10	-	0.60	0.60	620	-	
239	1	0.167	3.7	2	0.54	0.230	0.115	0.033	86	9	1	1:10	-	1.0	1.0	800	-	
240	1	0.167	3.7	3	0.81	0.077	0.028	0.023	70	9	1	1:10	-	0	0	0	-	
241	1	0.167	3.7	3	0.81	0.137	0.046	0.042	69	3	1	1:10	-	0	0	0	-	
242	1	0.167	3.7	3	0.81	0.200	0.066	0.067	67	8	1	1:10	-	1.0	1.0	405	-	
243	1	0.167	3.7	3	0.81	0.252	0.084	0.075	70	6	1	1:10	-	1.4	1.4	450	-	
244	1	0.167	3.7	3	0.81	0.324	0.108	0.104	68	8	1	1:10	-	2.2	2.2	550	-	
245	1	0.167	3.7	4	1.08	0.096	0.024	0.050	48	5	1	1:10	-	0	0	0	-	

Test No.	No. of Blanket Layers	Blanket Depth t ft	Blanket Length L_B ft	Wave Length L_w ft	L_w/L_B	Incident Wave Height H_I ft	Wave Steepness H_I/L_w	Trans. Wave Height H_T ft	Wave Height Atten. %	Reflected Wave %	Water Depth d ft	Mooring Line Slope	Mooring Force M			$\frac{Md}{H_I \gamma B L_w^2}$ x 10^{-5}	Buckling Evidence	Special Conditions
													Base lbs	Peak lbs	Total lbs			
246	1	0.167	3.7	4	1.08	0.159	0.039	0.075	53	5	1	1:10	-	0	0	0	-	Modelled Trilok Blanket t = 1.75 in.
247	1	0.167	3.7	4	1.08	0.254	0.063	0.125	51	10	1	1:10	-	0.90	0.90	162	-	
248	1	0.167	3.7	4	1.08	0.317	0.079	0.158	50	5	1	1:10	-	1.10	1.10	162	-	
249	1	0.167	3.7	5	1.35	0.106	0.021	0.059	44	6	1	1:10	-	0	0	0	-	
250	1	0.167	3.7	5	1.35	0.192	0.038	0.108	44	9	1	1:10	-	0.5	0.5	77	-	
251	1	0.167	3.7	5	1.35	0.288	0.058	0.171	41	10	1	1:10	-	1.8	1.8	187	-	
252	1	0.167	3.7	6	1.63	0.179	0.029	0.112	38	7	1	1:10	-	1.5	1.5	171	-	
253	1	0.167	3.7	6	1.63	0.309	0.051	0.216	30	13	1	1:10	-	5.8	5.8	385	-	
254	1	0.167	3.7	7	1.90	0.188	0.027	0.136	28	7	1	1:10	-	0.5	0.5	40	-	
256	1	0.167	3.7	7	1.90	0.342	0.049	0.234	32	7	1	1:10	-	6.5 ± 0.7		294	-	
257	1	0.167	3.7	8	2.17	0.175	0.022	0.141	19	5	1	1:10	-	5.6	5.6	360	-	

APPENDIX B

TEST DATA FOR THE WAVE TRAP

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TEST DATA FOR THE WAVE TRAP

Test No.	Trap Length L_T ft	Wave Length L_w ft	L_w/L_B	Incident Wave Height H_I ft	Wave Steepness H_I/L_w	Trans. Wave Height H_T ft	Wave Height Atten. %	Reflected Wave %	Water Depth d ft	Mooring Line Slope	Total Mooring Force M lbs	$\frac{Md}{H_I \gamma B L_w^2}$ $\times 10^{-5}$	Special Conditions
167	20	10	0.5	0.62	0.062	0.10	83	5	4.5	1:10	+5	64.4	Tested in Original Condition
168	20	10	0.5	0.21	0.021	0.03	87	8	4.5	1:10	-0	-	
169	20	10	0.5	0.92	0.092	0.27	71	7	4.5	1:10	+27	315.2	
170	20	5	0.25	0.50	0.101	0.03	94	17	4.5	1:10	+7	450	
171	20	20	1.0	0.43	0.021	0.20	54	8	4.5	1:10	-0	-	
172	20	20	1.0	0.90	0.045	0.52	42	20	4.5	1:10	29	64.4	
173	20	20	1.0	1.25	0.062	0.82	34	25	4.5	1:10	57	91	
174	20	30	1.5	0.60	0.020	0.42	29	13	4.5	1:10	-0	-	
175	20	30	1.5	1.02	0.034	0.75	26	11	4.5	1:10	57	50	
176	20	40	2.0	0.74	0.018	0.69	7	16	4.5	1:10	-0	-	
191	20	10	0.5	0.22	0.022	0.01	95	2	4.5	1:10	-0	-	Tested with Added Flotation and Weight
192	20	10	0.5	0.58	0.058	0.04	93	7	4.5	1:10	4	55.2	
193	20	10	0.5	0.93	0.093	0.09	90	10	4.5	1:10	43	368	
194	20	5	0.25	0.48	0.096	0	99	7	4.5	1:10	6	800	
195	20	20	1.0	0.40	0.020	0.15	62	5	4.5	1:10	-0	-	
196	20	20	1.0	0.82	0.041	0.32	61	12	4.5	1:10	31	76.4	
197	20	20	1.0	-	-	-	-	-	4.5	1:10	-	-	
198	20	30	1.5	0.55	0.018	0.38	30	5	4.5	1:10	2	3.2	
199	20	30	1.5	0.93	0.031	0.60	35	8	4.5	1:10	37	36	
200	20	40	2.0	0.69	0.017	0.45	35	7	4.5	1:10	15	10.9	
201	20	15	0.75	1.45	0.097	0.69	53	9	4.5	1:10	122	304	