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THE DAVID W. TAYLOR MODEL BASIN

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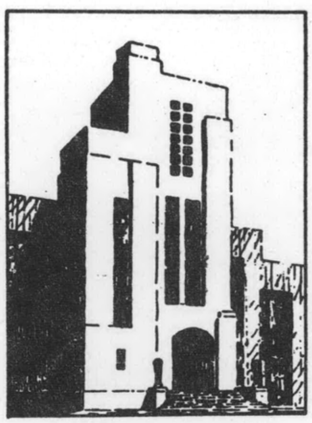
ON THE STATUS OF
COMPLEX WAVE GENERATION
IN MODEL TANKS

by

Wilbur Marks

Prepared for The Eleventh American Towing Tank Conference held at the David Taylor Model Basin, September 1956.



July 1956

Report 1069

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ABSTRACT

A survey is made of all those tank facilities that are known to experiment with the generation of model complex seas or that are planning to experiment in this field.

The wave generating systems are divided into two classes: a) those intended to produce long-crested irregular waves, and b) those intended to produce short-crested irregular waves. The tank installations are briefly described. Emphasis is given to the different techniques used to generate irregular waves in the laboratory. These methods range from the manual application of a paddle to stir up the water, to the precise reproduction of the sea surface, at any point in the tank.

It is found that most towing tanks which deal in irregular waves are restricted to the long-crested variety owing to the existing long channel test facilities. Some basins are building new facilities for work in oblique-regular and short-crested seas; others are revamping present installations.

INTRODUCTION

Models are most familiar to the naval architect as the small scale ships which are tested in towing tanks. To the physicist and mathematician this definition is alien; models mean something quite different. Often it is desirable, when asking a question of an event in nature, to be able to define the system analytically, then mathematical tools may be used to manipulate the original formulation until the solution is found. The model, in this case, is the explicit definition of an initial state, in mathematical terms, that will render it amenable to treatment. Since phenomena in nature may be extraordinarily complex, mathematical models boast a wide range of descriptive accuracy.

Such has been the case with the seaway. The sine wave, though unrealistic, is a well-behaved forcing function. In addition, it can be physically realized in the towing tank with little difficulty. Also sinusoidal conditions are easy to repeat and ship performance tests are relatively simple to analyze. Most important, many ship-behavior predictions based on sine wave theory and experimentation are substantiated by observation. Because in many cases it is a good first approximation, the sine wave has enjoyed a long and unchallenged reign in the realm of naval architecture.

Recently, the oceanographer has been successful in demonstrating mathematically what has long been suspected, that the seaway is composed of a multiplicity of independent sinusoidal components combined in random phase.[15, 16] This characterization of the seaway is far removed from a sinusoid; in fact, the integration of the infinitesimal components is not even carried out in the Riemann sense.[15] However, with certain linearizing assumptions, the equations of motion have yielded to solution for at least three degrees of freedom, with this new representation as the forcing function.[3]

References are listed on page 12.

In the light of these developments, it has become apparent that present ship testing methods are in danger of stagnation if sine waves continue to be the sole exciting force. It is generally agreed that investigations should be made in irregular seas. At least one experiment with ship behavior in complex seas has confirmed this belief. At the Stevens Institute of Technology, model performance in regular waves showed regular fluctuations of bending moment of moderate magnitude. Repetition of the tests in irregular waves yielded much higher values which it is believed greatly increased the significance of the results.[4]

What constitutes an adequate irregular sea for the naval architect is subject to controversy. Some investigators have suggested that as long as ships are made to roll in head and following seas enough simulated realism is injected into the problem. At the other extreme the suggestion is made that an exact replica of a genuine sea condition is an indisputably, sufficient condition for a model of the seaway and in addition it affords the unique opportunity to recreate, and perhaps solve, a special problem which has occurred at sea. This, of course, only holds for those ships equipped with a ship-borne wave recorder.[5]

The present interest in irregular wave generation indicates a need for a summary of progress in this endeavor at the various laboratories. It is hoped that this survey will acquaint tank operators with the goings-on and future plans at installations which are known to be interested in the complex seaway. The following sections briefly outline the nature of the facilities and methods of wave generation. The summary section contains a tabular outline, in condensed form, of the information reported here.

PART I

IRREGULAR LONG-CRESTED WAVES

Section 1 -- Experimental Towing Tank, Stevens Institute of Technology, I

The first logical step in the transition from the simple sine (or trochoidal) wave to the reproduction of the actual seaway in model tanks is the generation of irregular long-crested waves. Although, in this case, the properties of ships that have eluded experimentation in the past (roll, yaw, sway) will still remain virtually unexplored, there is still a great need and desire to examine the three remaining degrees of freedom under more realistic conditions. Basic concepts of wave research [1] and ship motions prediction [3] may be verified to a great extent, while refined techniques for seaway reproduction are studied.

Most towing facilities are of the long narrow type and can easily effect a change-over to the type of programming that will yield desired complexities in the structure of surface waves, albeit long-crested. This has been the case at the Stevens Institute of Technology where the 100 foot tank (9 feet wide, 4.5 feet deep) has experienced the first attempt of the naval architect to inject a planned realism into ship model testing. The basic assumption that the seaway never repeats itself is the key to the work at Stevens. In order to reproduce a state of sea then, it is only required to recreate its statistical properties in an intelligent manner. Since it is believed that the sea surface is made up of an infinite number of sinusoidal components randomly combined, the desired effect may be achieved by propagation of a finite sum of these components sufficient to yield a suitable approximation.

The first step is to choose the spectrum of the sea state to be investigated and to reduce to scale the period range in which most of the energy is found. Next, the desired number of discrete periods are chosen within this range and a rectangular distribution is set up with period as abscissa and frequency of occurrence as ordinate. The mechanics of the system require a sample space of 100 points (this will be explained), therefore the product of the number of periods and the number of times each period is used must equal 100. The numbers are mixed up and chosen, one at a time, randomly until the last one is exhausted. This is the program which is fed to the plunger wavemaker. The different speeds of the waves allow for the proper combination of sinusoidal components at some distance down the tank.

The mechanics of the programming device [6] are straightforward. A 100 contact rotary switch is arranged to advance one position each time the plunger reaches the top of a stroke (hence the 100 point program). Each of the 100 contacts is in turn connected at random to one of 25 different motor speed control points which covers a wide range of plunger periods wherein is included the period range of the desired spectrum. This, in effect, is the frequency control. Roughly, two minutes of wave making, without repetition of the program, is possible. In addition, the rotary switch has seven banks of such contacts which can be wired to operate separately or successively. The amplitude input is constant but a 3 foot wide plank immediately in front of the wavemaker reduces the height of waves less than three feet long. This is necessary, otherwise the short waves would break due to instability, and this may seriously complicate the analysis.

To some, this method may be an oversimplification or even too crude an approximation, but results [6] indicate that this may prove to be a powerful tool in ship testing. Figure 1 shows that an irregular wave pattern set up in the Stevens Tank can be repeated almost identically by feeding the same program into the wavemaker. The importance of this in ship performance comparison is well known. Figure 2 shows the energy spectrum analysis of a wave record made in the Stevens Tank. The computed spectrum is seen to be equivalent to a theoretical spectrum appropriate to a wind speed of 40 knots but limited in growth by a duration of 24 hours. [2]

At the present time irregular long-crested waves are providing the forcing function for a series of tests to determine the motions and the midship bending moment properties of a destroyer. [7]

Section 2 -- Neyrpic Hydraulic Laboratory, Grenoble, France, I

The tanks of the Neyrpic Laboratory are designed primarily for the study of wave effects on coastal structures and beaches. It will be useful however to review the thoughts on wave generation expressed at this laboratory. At least one other installation has adopted a particular wavemaker designed at Neyrpic (Part I, Section 4).

The simplest instrument for wave production here is the single flap type for use in long narrow channels as a generator of long-crested waves, or in broad basins as an approximate point source of radial waves. The mechanics of the wavemaker are believed suitable for the generation of irregular waves, if necessary, by frequency modulation. [8]

A variation on this theme is the adaptation of the multi-flap machine in another tank at Neyrpic (Part I, Section 3). The "snake-type" wave machine (Part II, Section 2) is their latest innovation.

Section 3 -- Neyrpic Hydraulic Laboratory, Grenoble France, II

The multi-flap machine is no more than a row of single flap machines, each of which can be rotated about a vertical axis to emit waves at any angle. Normally, all the flaps are parallel to each other, like a venetian blind. The result is a train of sinusoidal long-crested waves, if the phases are properly arranged. If, however, the orientation of the flaps and the phasing are not harmoniously combined, confused seas result. It is admitted that the mechanics of the system greatly restrict the production of prescribed irregularity. [8] One major difficulty is the large inertia inherent in the wavemakers which hampers desired amplitude variation through frequency modulation. This seems analogous to the problem at Stevens Institute of Technology (Part I, Section 1), where the difficulty was eliminated by use of a 3 foot wide "filtering plant" immediately in front of the wavemaker.

The multi-flap machine can generate oblique long-crested waves with the possibility of introducing irregularity. Also short-crested waves of an unpredictable (at this time) nature are capable of generation.

Section 4 -- Netherlands Ship Model Basin, Wageningen, Holland

The principle feature of the new Seakeeping Laboratory of the NSMB [9] is the "snake-type" wavemaker (Figure 3). Since this machine was developed at Neyrpic, it will receive closer attention in Part II, Section 2. The new tank is unique in itself. The 328 foot basin (80.4 feet wide and 8.2 feet deep) is bounded on two sides by wave generators, and on the other two sides by absorbing beaches which are claimed to be near 100 percent effective. The proof of this lies in the fact that the waves essentially retain their shape, even after hours of generation.

The rows of pillars in the center of the tank might tend to alarm the casual observer but the surrounding wire mesh guards reduce reflection and diffraction to a minimum. Their presence in the tank is simply explained; they hold the roof up. The existence of high frequency wavelets on the main wave system does not disturb the naval architects at the NSMB. Their effect is considered negligible. The generation of oblique long-crested waves is a simple operation with this system (Figure 4).

The program for irregular wave generation is similar to that employed in the Stevens Tank (Part I, Section 1), but here models can be tested at any desired heading. The programming of short-crested waves by individual control of stroke and phase was considered, but the idea was abandoned on economic grounds.

Plans for the near future include the investigation of refined methods of irregular seaway production and the mathematical analysis of such situations. [10]

Section 5 -- Ship Model Towing Tank, Massachusetts Institute of Technology

The MIT Tank is 108 feet long, 8.5 feet wide and 4 feet deep. There is a paddle type wavemaker, hinged at the bottom of the tank at one end and a curved beach at the other end. Wave lengths up to 20 feet and heights up to one foot are the upper bounds of this wave machine. A detailed description of the towing tank is available in the literature. [11]

For production of irregular waves the system lends itself well to changes of wave height and length while the wavemaker is in operation. Plans are being made to construct a program whereby systematic variation of wave frequencies will yield confused seas with predetermined components. [12]

Section 6 -- Delft Technological University Towing Tank, Delft, Holland

At this writing, unfortunately, no direct information from Delft is available, consequently, the information reported here stems from an external source [10] and is of necessity limited.

The wave generating mechanism is a pneumatic type wavemaker which is patterned after the deep tank facility at DTMB.[13] The narrow basin limits generation to long-crested waves. It is believed that a programming system is now being installed that is basically the same as that employed in the Stevens Tank (Part I, Section 1). The exact nature of the irregular wave patterns that it is intended to produce is not known.

Section 7 -- Ship Model Towing Tank, University of California

Perhaps the most ambitious program for irregular wave generation comes from the University of California's towing tank, where current plans call for the recreation of a given sea surface time history (wave record) at any desired place in the tank. The theory has been worked out[14] and the mechanics of the programmer are in a state of near completion.

At one end of the 200 foot tank (8 feet wide, 6 feet deep) is a bulkhead generator and at the other a sloping beach. To produce waves, the bulkhead moves forward and backward on rollers; the wave period is equal to the time of one such complete oscillation. The amplitude of the emitted wave is regulated by varying the length of the stroke of the bulkhead. A full description of the tank is given by Paulling.[15]

As in most tanks, initial attempts to set up irregular wave patterns consisted of manually varying the period and amplitude controls in a random fashion. This has been abandoned for the present scheme which appears to show great promise.

Linear hydrodynamic theory has been employed to predict the height of the sea surface as a function of time at any distance from the origin (wavemaker). If this function is known (wave record) then the input at the wavemaker can be specified in terms of paddle position as a function of time. An electromechanical computer which uses 35 mm film records has been designed to translate wave records into the required paddle displacement -- time histories.

PART II

IRREGULAR SHORT CRESTED WAVES

Section 1 -- Experimental Towing Tank, Stevens Institute of Technology, II

Success in generation of long-crested waves in their 100 foot tank (Part I, Section 1) has prompted the authorities at the Experimental Towing Tank to adapt their 75 foot square (4.5 feet deep) tank to irregular wave generation. It is expected that once the facility is in operation much time will be devoted to the problem of short-crested seas.

In principle, it is identical to the system already described, except that installation of a rotatable carriage will make it possible to run a model at any relative heading to the waves. This admits investigation of the three elusive degrees of freedom; roll, sway and yaw. The transition from long-crested to short-crested waves is believed possible through the medium of removable blocks in front of the 75 foot wavemaker. Experiments in a small model of the basin indicate that diffraction effects achieved in this manner provide a reasonable representation of a short-crested sea. [16]

The first research planned for this facility is the determination of the coupled "response amplitude operators" for a Series 60 model (0.60 block coefficient) and for a similar model with extreme V-sections forward, at all headings.

Section 2 -- Neyrpic Hydraulic Laboratory, Grenoble, France, III

At Neyrpic the "snake-type" wavemaker is considered to be the most perfect tool for the generation of complex seas.[8] It is composed of many elements each of which is a small generator, in a part of the vertical boundary, which confines the fluid (Figure 3). If the minimum size requirement for each element is observed, [17] there is, in principle, no limitation on the shape of the wave which can be generated. There is, of course, no restriction on the shape of the wavemaker. Figure 5, for example, shows a convex snake-type generator producing either convex waves (full lines) or plane waves (dotted lines). In a more conventional tank, short-crestedness is demonstrated (Figure 6) by crossing wave trains emitted from different portions of the generator.

If "perfection" is measured by ability to reproduce actual sea surface conditions, then the "snake-type" generator suggests that further investigation of its properties is required.

Section 3 -- Beach Erosion Board, Washington, D.C.

The Beach Erosion Board, Army Corps of Engineers, has perhaps the most unique tank facility in the world. In its outdoor man-made pond, which measures 300 feet by 150 feet by 3 feet, are located 10 wavemakers of the bulkhead type, each one 50 feet long. The wavemakers are portable and can be arranged in any desired fashion or even removed, if necessary. The test pond is surrounded by a sloping beach made of rip-rap, and by dumping more rocks at the right places, to form additional beaches, the pond can be divided into many indpendent test areas.

Irregular waves are a prime feature of the work here but there is no desire for the "ordered irregularity" sought by the ship model tester. The wavemakers may be uniformly arranged as shown in Figure 7 where four wavemakers are arranged in pairs, at an angle. To produce irregularity, phasing may differ, or the frequencies may be constantly varied. The desired end result is short-crested confusion as typified in Figure 8 where the waves are incicent on a four section breakwater. Wave probes measure the disturbance, and correlation of sea state with force on the jetty is obtained through the significant height or maximum height of the recorded waves.

Section 4 -- Maneuvering Basin David Taylor Model Basin

The David Taylor Model Basin is in the process of building a tank facility for the express purpose of ship model investigation in irregular seas and in particular short-crested seaways. This maneuvering basin will be 350 feet long by 200 feet wide by 20 feet deep. There will be 8 pneumatic wavemakers, each 25 feet across, along the short side and 13 pneumatic wavemakers along the other side. Absorbing beaches will complete the boundaries of the basin. A detailed description of the maneuvering basin is given by Brownell.[18] Figure 9 shows a one-tenth scale model of the proposed maneuvering basin.

The eight wavemakers may be operated jointly to produce regular or irregular long-crested waves, or they may be given individual instruction for the creation of short-crested seas. The bank of 13 wavemakers can only be operated jointly, on a main-line drive system.

Programming for the wavemakers will be completely automatic. This facility will not be available for at least two years and this is perhaps fortunate. The field of irregular wave generation is in a state of flux, both theoretical and experimental, and two years should provide enough time for something concrete to materialize from the flurry of activity that has recently been initiated. The wave generating system, as designed, is believed to have enough flexibility to at least duplicate the wave making techniques in use today.

Since short-crested seas in the towing tank are a new problem, it may be profitable to summarize some of the problems connected with this new medium and to review the work planned at the Taylor Model Basin.

The statistical representation of the seaway seems to hold the most promise for experimenters at the moment, therefore, the technique of reproduction of two-dimensional energy spectra of the sea surface[3] is being investigated. This method has an additional advantage in that it can be used to determine certain properties of the maneuvering basin which must be known such as a definition of the maximum possible working area and a check on the two-dimensional spectrum once the seaway is created. This will be discussed.

The basic principle of short-crested wave generation in the maneuvering basin is individual automatic programming of the eight wavemakers, each of which will receive 60 instructions per minute for wave frequency and amplitude. Whether sinusoidal components will be fed into the generators, to be combined down tank, as at Stevens (Part I, Section 1), or wave records reproduced directly, is open to question, but a basic problem still exists in determining how far down the tank the surface becomes statistically stationary. Figure 10 illustrates this point. In the one-tenth scale model of the maneuvering basin short-crested waves were produced by changing the frequencies of the wavemakers. It can be seen that after the waves have travelled a short distance from the bank of generators an appearance of homogeneity defines the dimensions of the tank wherein tests can be made and this area can be found by energy spectrum analysis of wave records. The assumption that a stationary seaway has the same energy spectrum at all points is the key to the solution of this problem.

Of equal importance is the analysis of the short-crested sea surface. This will provide a quantitative definition of the seaway that will make model tests meaningful. There are several methods available for this task, but the one that seems most adaptable to tank work consists of making a 12-sided figure at a constant speed while recording waves all the time.[19] The principle of the Doppler shift is utilized to determine the directions and frequencies of the component wave trains. This method was designed for ships equipped with wave recorders[5] but may well be suited for the tank, where the towing carriage can be utilized as a carrier for the wave probe.

The proof of the validity of the directional spectrum lies in the time histories made at a fixed point in the tank. The one-dimensional energy spectrum is the integral with respect to direction of wave travel of the two-dimensional spectrum. This is a good check on the analysis of the short-crested seaway. The computation involved in the reduction of this type of data is prohibitive but the oceanographer, having worked on this problem for some years, is equipped to process the data in electronic wave analyzers (essentially Fourier analyzers). There are a number of these machines in circulation and they will be investigated.

The success of short-crested wave generation in the maneuvering basin lies in the diffraction effects which exist at the edges of the individual wavemaker. An example of wave diffraction is seen in Figure 11 where only a single wavemaker is active. How well the directional aspect of the seaway is defined by combinations of these apparently spherical waves is of prime importance and is receiving maximum attention in experimentation in the one-tenth scale model.

It is interesting to note that in Figure 10 some of the short-crestedness is due to the fact that two of the wavemakers are dormant. This situation is, in fact, analogous to the suggestion made for generating short-crested seas in the Stevens 75 foot square tank, by placing diffracting blocks in front of the wavemaker (Part II, Section 1).

SUMMARY

Irregular wave generation is in its infancy and is suffering from growing pains. This will continue while more installations devote time to research (both theoretical and experimental) on the problem. The first phase, that of production of a long-crested irregular seaway, is being explored very vigorously with notable successes at some of the installations listed. The second phase, short-crested irregularity, is of necessity lagging behind, since some of its basic problems are related to the first phase and are still unsolved.

It is hoped that continued activity will produce techniques that will make the results of ship model testing even more meaningful than they are now.

A brief summary of the installations herein discussed is contained in Table 1.

ACKNOWLEDGEMENT

Sincere thanks is extended to all the laboratories which contributed literature and personal information on the work reported here.

TABLE 1 — FACILITIES CAPABLE OF GENERATING IRREGULAR SEAS

LABORATORY	Tank Dimensions (feet) Length	Width	Depth	Wave Generator Type	Number	Type of Seaway	Model Heading (relative to waves)	Irregular Wave Generation Present	Future	Remarks
Experimental Towing Tank Stevens Institute of Technology	100	9.0	4.5	plunger	1	long-crested irregular	0°, 180°	*	*	Theoretical one-dimensional spectra reproduced in tank.
Neyrpic Hydraulic Laboratory Grenoble, France				flapper	1	long-crested irregular possible	0°, 180°			Ships not tested - primarily for coastal structures and beach evolution.
Neyrpic Hydraulic Laboratory Grenoble, France				"snake-type"	many	interference of several long-crested trains	0°, 360°			Cross-seas by interference of two or more long-crested regular wave trains from different directions.
Netherlands Ship Model Basin Wageningen, Holland	328	80.4	8.2	"snake-type"	many	long-crested irregular	0°, 360°		*	
Massachusetts Institute of Technology Ship Model Towing Tank	108	8.5	4.0	flapper	1	long-crested irregular	0°, 180°		*	
Delft Technological University Towing Tank, Delft, Holland	300	14	9	pneumatic	1	long-crested irregular	0°, 180°		*	Wave generating program essentially the same as ETT.
University of California Ship Model Towing Tank	200	8.0	6.0	rolling bulkhead	1	long-crested irregular	0°, 180°	*	*	Can reproduce a given wave record at any point in the tank.
Experimental Towing Tank Stevens Institute of Technology	75	75	4.5	plunger	1	long-crested and short-crested irregular	0°, 360°		*	Short-crestedness achieved by placing diffracting blocks in front of wave-maker.
Neyrpic Hydraulic Laboratory Grenoble, France				flapper	many	short-crested possible	0°, 360°			Complex sea of specific nature difficult to obtain.
Beach Erosion Board, U.S. Army Corps of Engineers, Washington, D.C.	300	100	3	horizontally oscillating bulkhead	10	short-crested		*	*	Ships not tested - solely for coastal structures and beach evolution - wave-makers are portable.
David Taylor Model Basin Washington, D.C.	350	200	20	pneumatic	21	short-crested	0°, 360°	*	*	Planned reproduction to scale of two-dimensional wave spectrum. No testing in beam seas for short-crested conditions.

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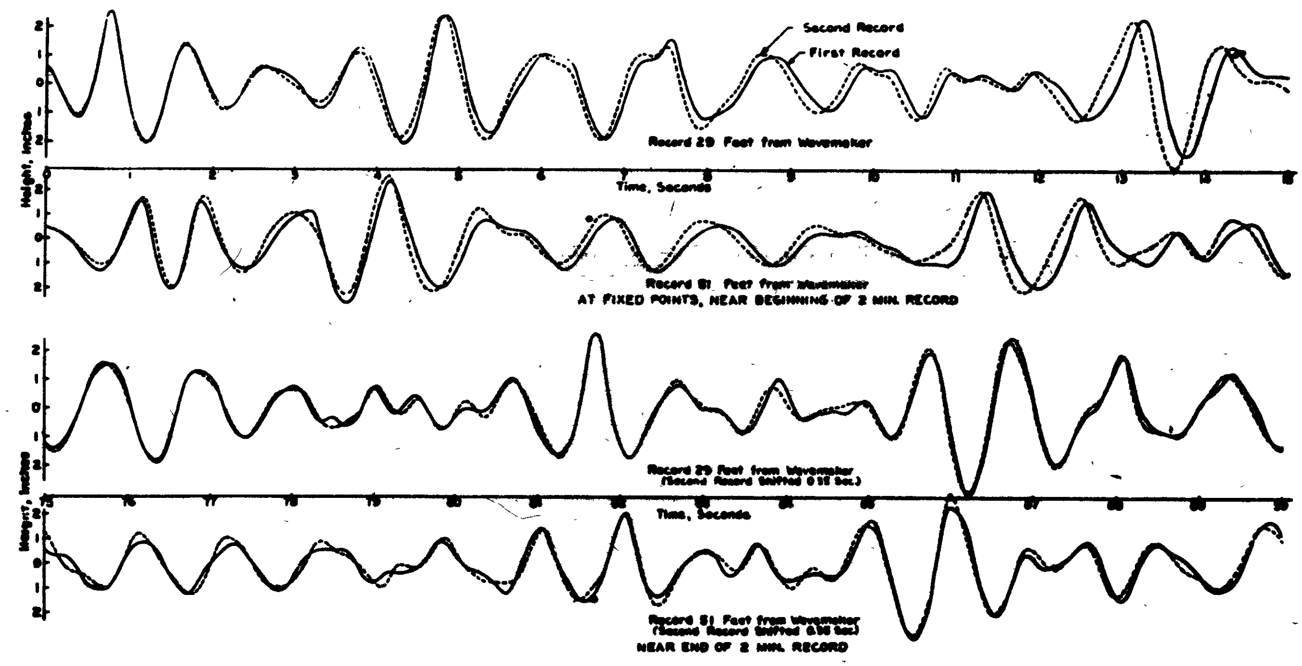

Figure 1 -- Comparison of two successive sample irregular wave records at fixed points, with automatic wavemaker control.

After E.V. Lewis

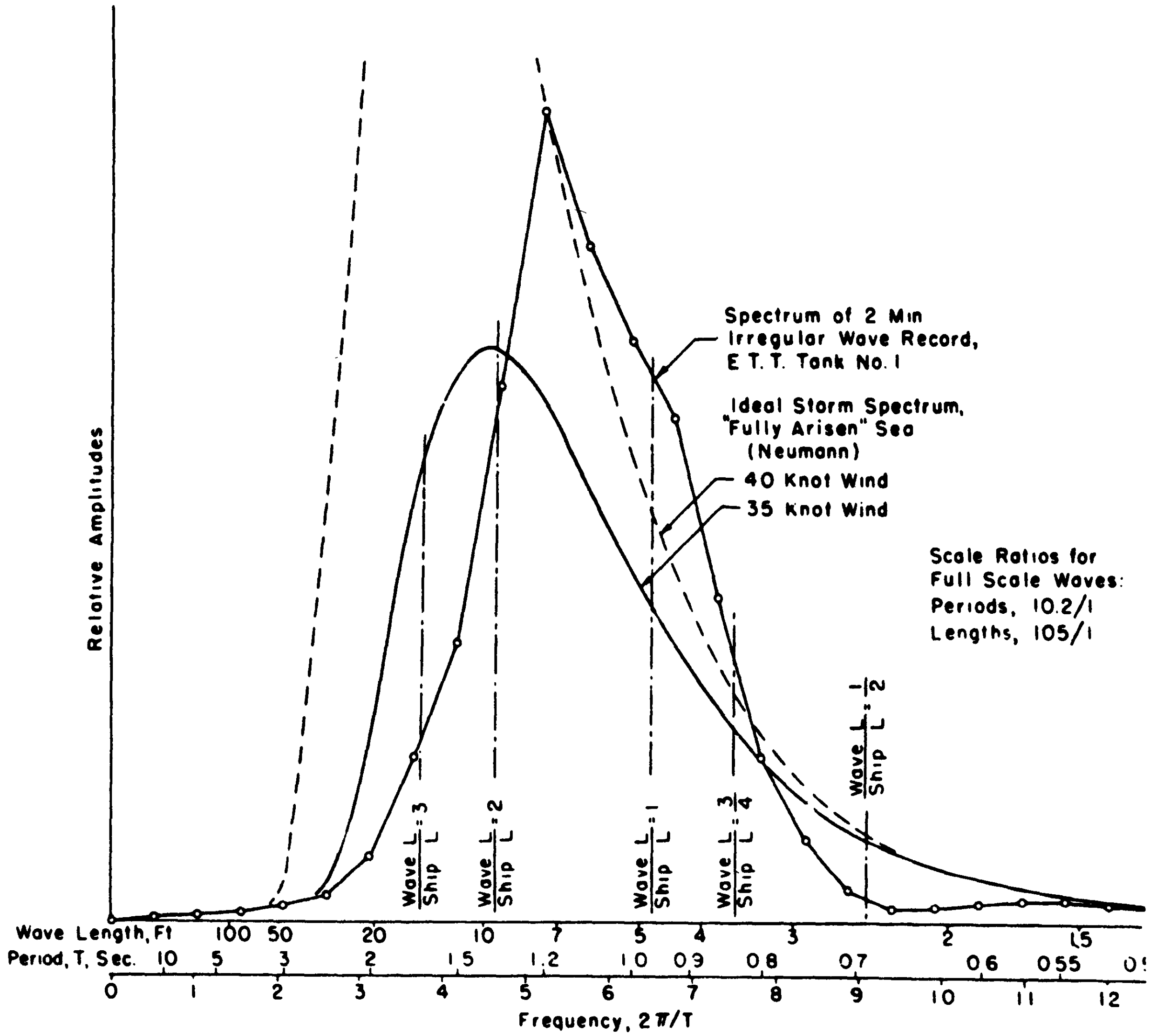

Figure 2 -- Analysis of irregular tank wave record: Energy spectrum showing relative amplitudes of component waves. (Recorded at stationary point during three model runs at 1.42 knots.)

After E.V. Lewis

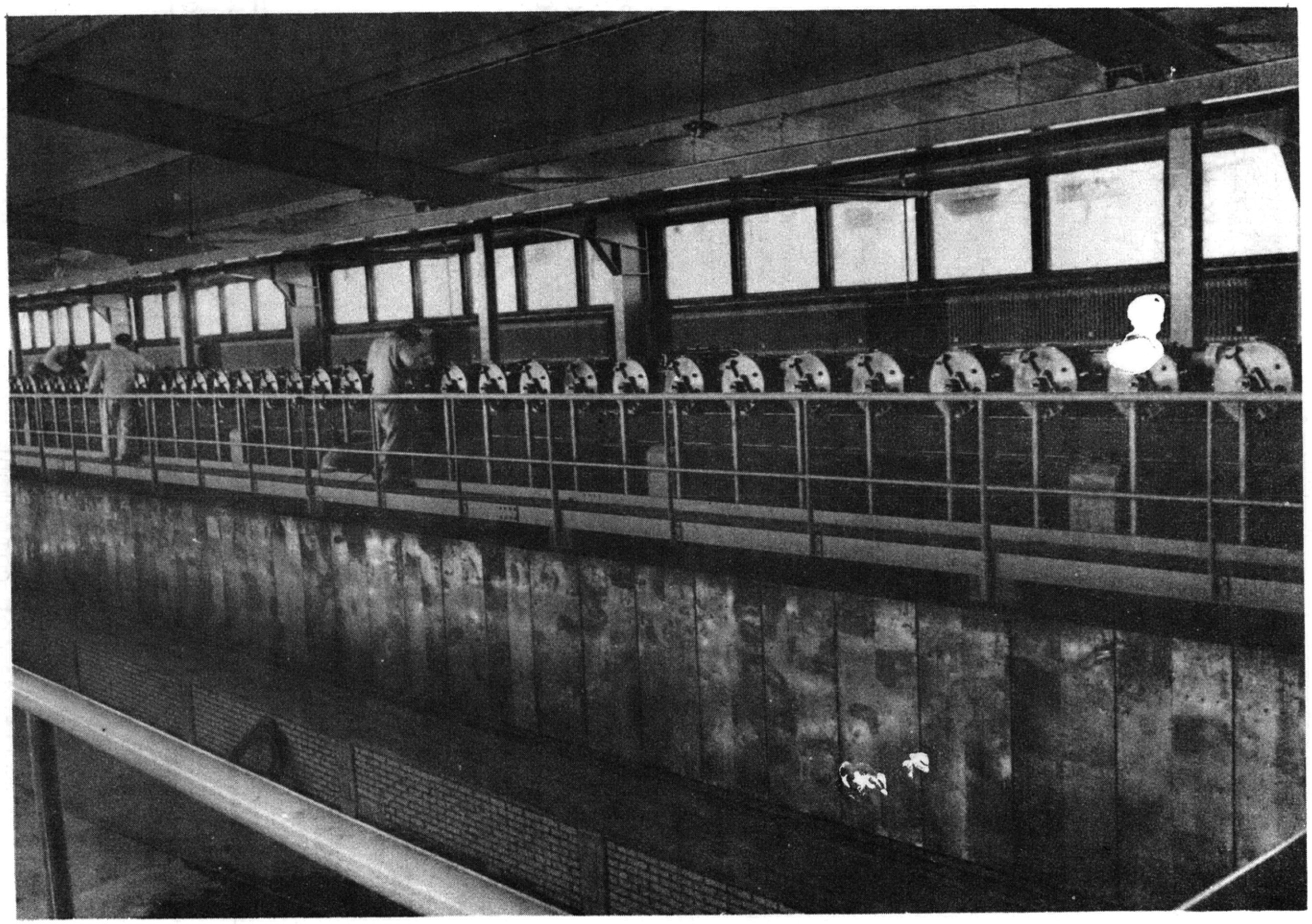

Figure 3 -- The "snake-type" wave generator at the Netherlands Ship Model Basin.

Courtesy Netherlands Ship Model Basin

Figure 4 -- Oblique regular waves produced by the "snake-type" wave generator, (after 40 minutes of operation).

Courtesy Netherlands Ship Model Basin

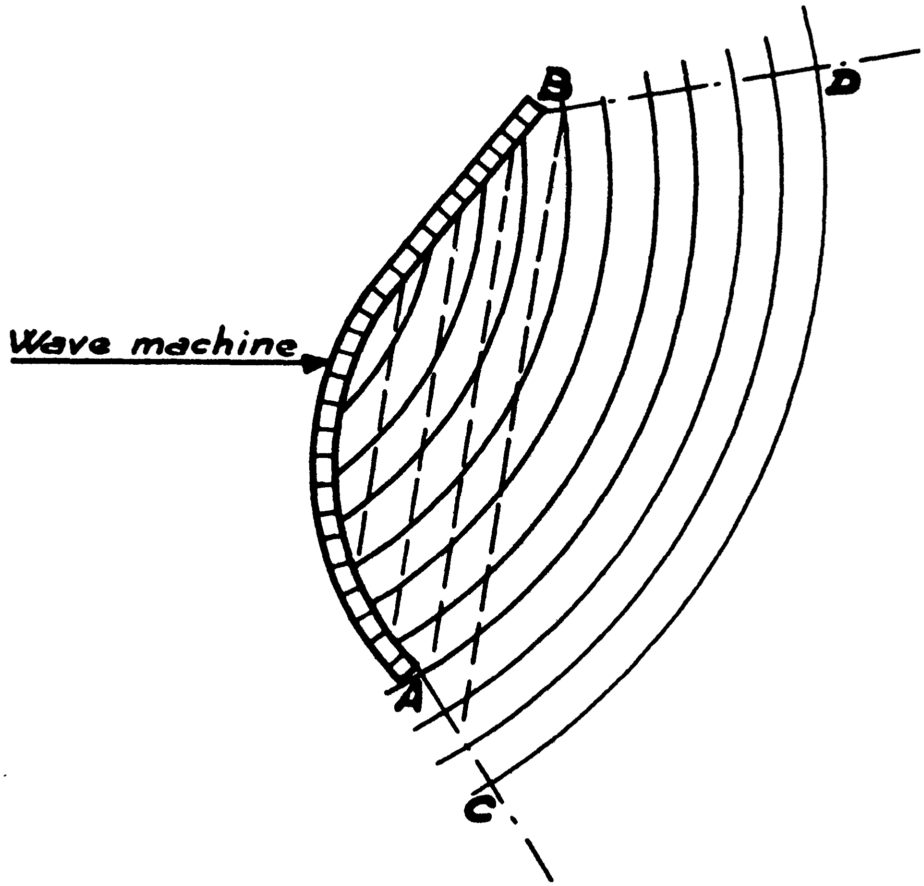

Figure 5 — Concave form of "snake-type" wave generator.

After Biesel

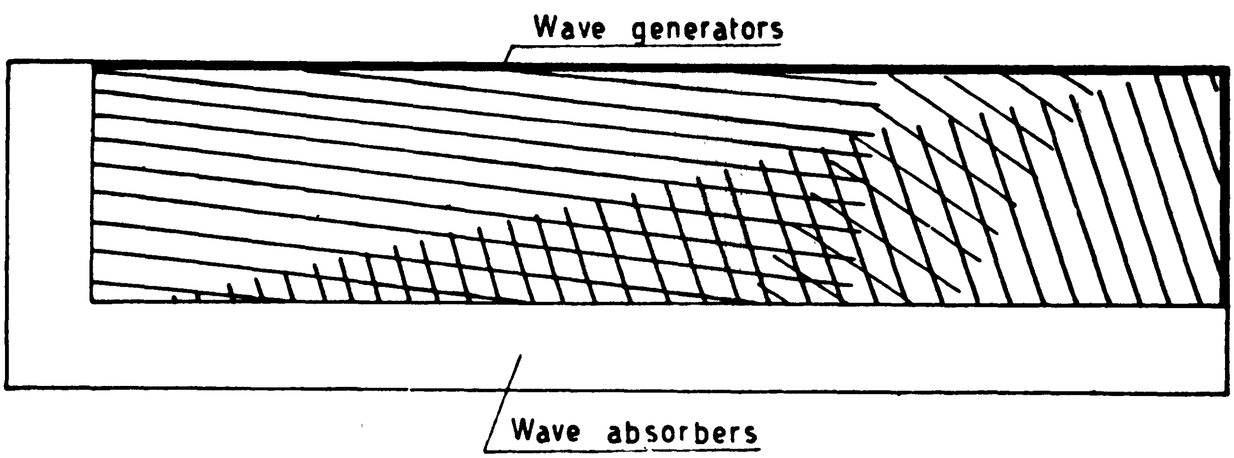

Figure 6 — Complex wave pattern made by a "snake-type" wave generator.

After van Lammeren and Vossers

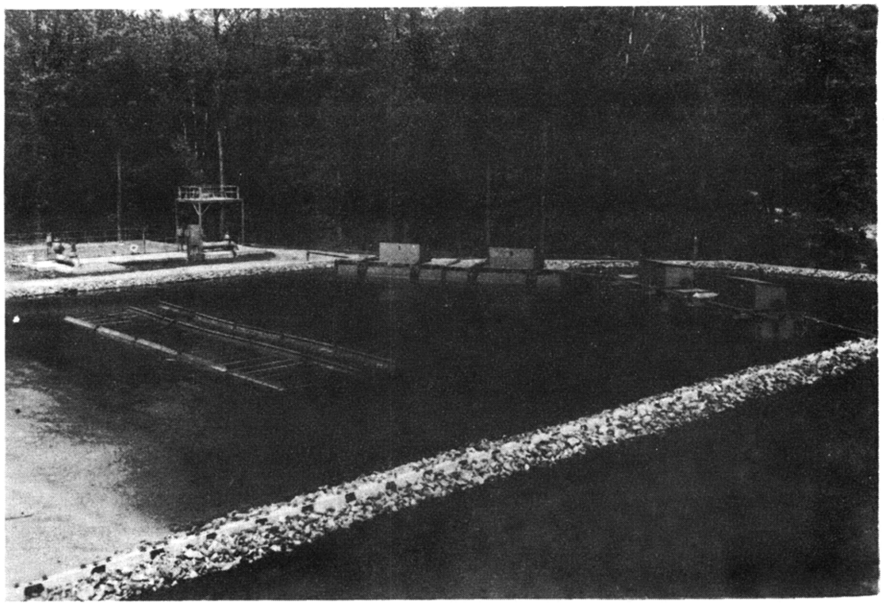

Figure 7 -- Four 50 foot wavemakers, arranged in pairs, to test wave action on a jetty (foreground).

Courtesy Beach Erosion Board, U.S. Army Corps of Engineers

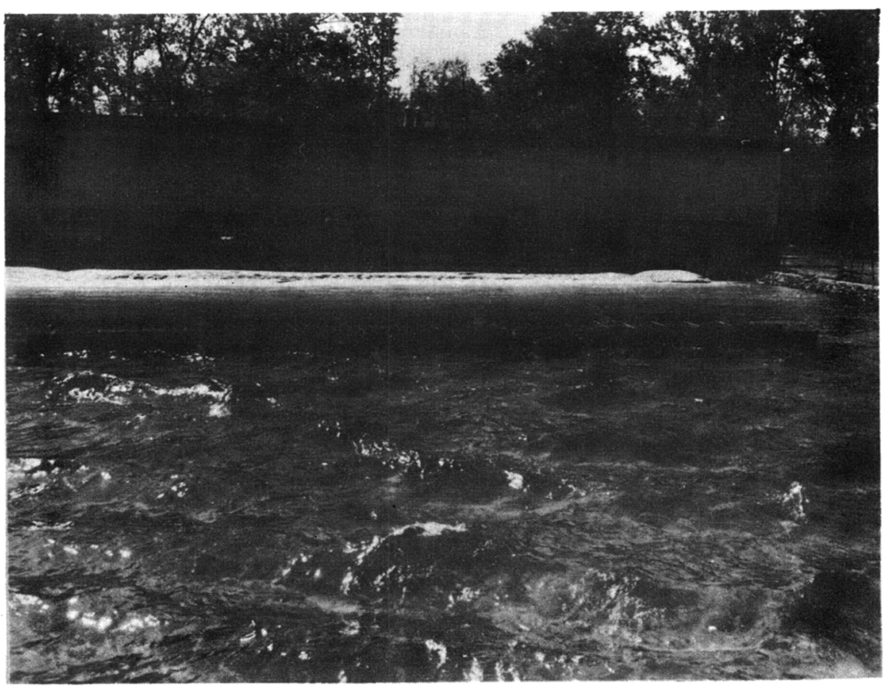

Figure 8 -- Short-crested seas produced by four wavemakers (not in photo), out of phase and with different periods, incident on a four-section jetty.

Courtesy Beach Erosion Board, U.S. Army Corps of Engineers

Figure 9 -- One-tenth scale model of the proposed maneuvering basin.

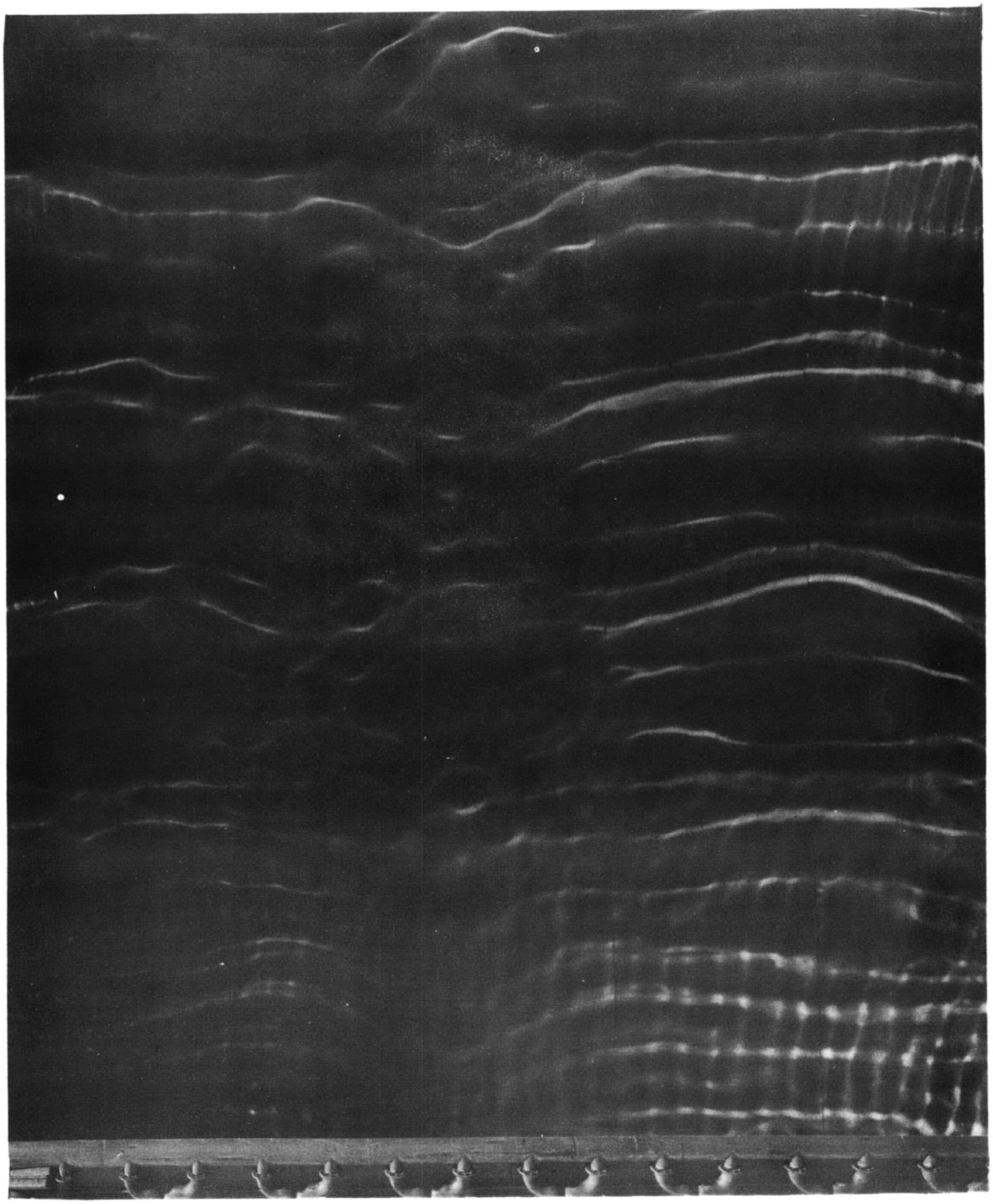

Figure 10 -- "Confused sea" obtained by programming a different frequency into each wavemaker.

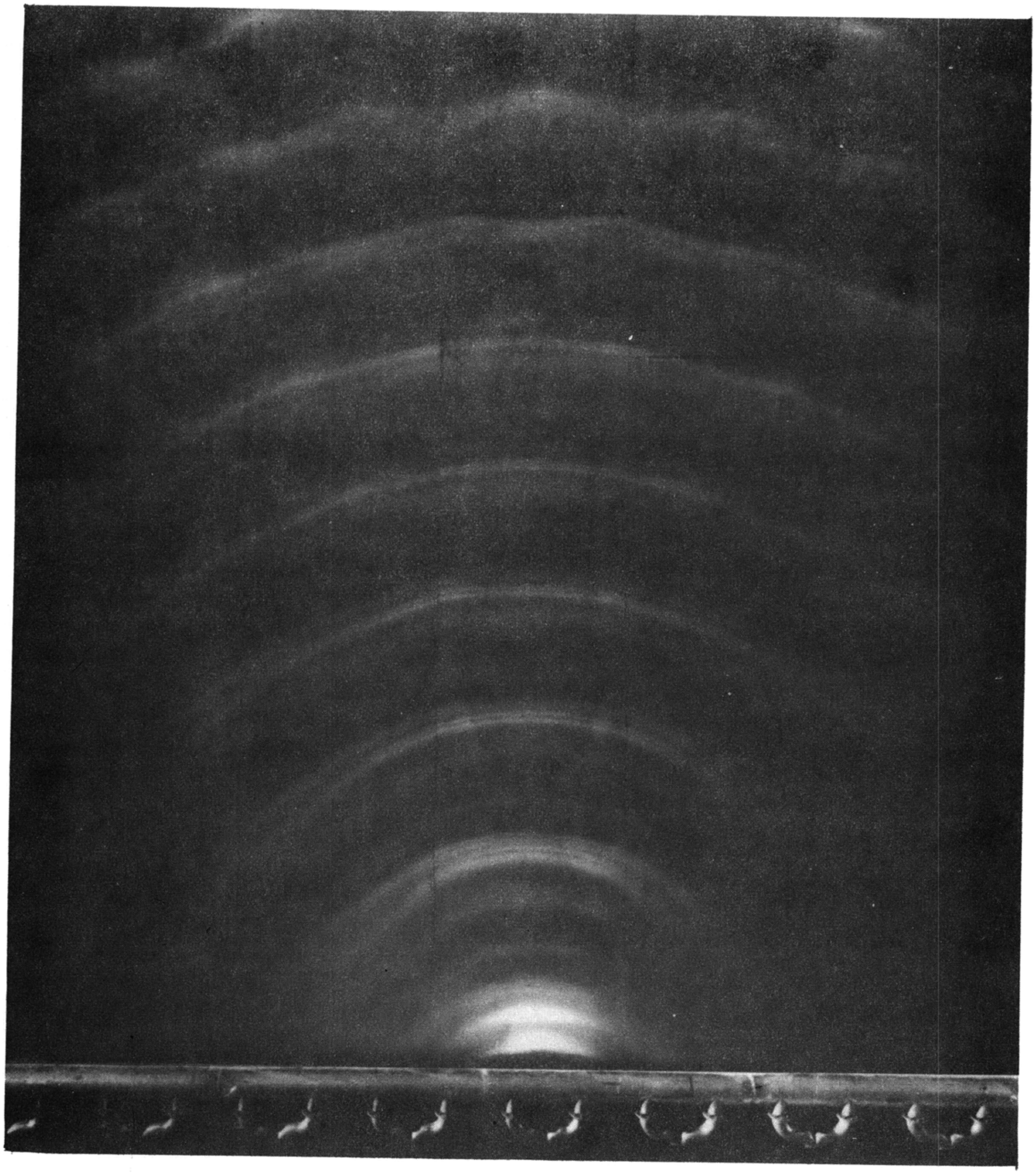

Figure 11 -- A single wavemaker generating a 2.5 foot wave.