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EQUIPMENT FOR TESTING MODEL SHIP AND SEAPLANE HULLS IN OBLIQUE SEAS

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This paper describes the details of the construction of a wave basin used for investigating the behavior of model ship and seaplane hulls when traveling at different angles to the predominate wave front. The various components consist of the towing basin, towing motor, wave generator, wave absorbers, wave guides, wave filter, towing carriage, and instrumentation for measuring the model motions and wave profile. At the present time projects are being sponsored in this basin by the Bureau of Aeronautics, Navy Department and by David Taylor Model Basin, Navy Department.

TOWING BASIN

The towing basin was built in an outdoor tank 85 ft in diameter and $6\frac{1}{2}$ ft deep. The sides slope inward and the bottom diameter is 72 ft. The sides and bottom are made from concrete. This tank was originally used for water storage and for evaporation studies.

The testing basin itself is 40 ft wide and 65 ft long as shown in Fig 1. At one end is the wave generator, and at the other is a gravel-beach wave absorber. Wave guides made from plywood panels provide the sides of the testing area.

In using this outdoor tank the limitations resulting from a relatively long and narrow wave basin are avoided. This low length-to-width ratio also provides an ideal basin in which models can be towed at different angles to the wave front. Fig 1 is a schematic diagram showing the basin in plan view.

TOWING MOTOR

The models are towed across the seaway by an endless belt. The towing motor, and the idler pulley which is located on the opposite side of the basin are both portable and can be moved easily to any point on the periphery of the pond. In this way the models can be towed at any direction to the seaway.

The power for the towing mechanism is supplied by a $1\frac{1}{2}$-Hp, 3-phase, 440-volt induction motor. The motor speed is reduced to the proper speed by a worm-gear reduction unit, a V-belt speed changer, and a series of step-cone pulleys. The towing line is made of nylon and is driven by an $8\frac{1}{4}$-in. diameter lucite pulley. About 50 lbs. tension is applied to the towing line through a counterweight located at the idler pulley.

Towing speeds up to 18 fps have been attained while towing a 9-lb model. The maximum speeds are reduced somewhat when a carriage or instrument leads are towed along with the model. The model speed is obtained by measuring the speed of the towing line.

WAVE GENERATOR

The waves are created by oscillating a cylinder in the vertical plane. The cylinder is made from standard 10-gage steel pipe 14 in. in diameter and 42 ft long. The pipe is supported at the quarter points by support links. A roller-cage bearing on a $2\frac{1}{2}$-in. vertical pipe at each end of the cylinder restricts the wave generator motion to the vertical only. A steel plate 12 in. wide has been welded along the lower edge of the plunger to act as a stiffener and pressure cutoff.

The power required to oscillate the wave plunger is supplied by a 10-Hp, 3-phase, 440-volt induction motor. Speed reduction is accomplished by a worm-gear drive and by a pair of roller-chain sprockets. The motor and speed reduction unit drive a 14-in. diameter crank plate. A connecting rod attaching the wave plunger to an adjustable pin on the crank plate transforms the rotation of the motor to oscillation of the wave plunger.

The wave length produced is changed by varying the speed of rotation of the crank plate. This is accomplished by changing sprockets in the final drive of the wave generator driving motor. Choice of wave length is therefore limited to the sprockets available. Wave lengths of 2.3 ft, 3.8 ft, 4.6 ft, 5.0 ft, 7.5 ft, 8.5 ft and 9.6 ft have been produced. Since the water is $5\frac{1}{2}$ ft deep, the longest wave length which should be made for deep-water wave studies is approximately 11 ft.

The wave height can be varied by changing the crank-pin eccentricity which changes the stroke length of the wave plunger. The eccentricity of the crank-pin is continuously adjustable so that the wave height can be precisely adjusted to produce any height-length ratio. Experience has shown that the wave height can also be changed for a particular pin eccentricity by varying the static water level in the pond. The pond is always maintained at a standard water level in order to produce the optimum wave profile. If the water level is too low, the bottom edge of the plunger is out of the water at top-dead-center and when the plunger re-enters the water, the impact causes undesirable surface disturbances. If the static water level is too high, the plunger is submerged beyond its diameter at bottom-dead-center and again a surface disturbance is created as the plunger emerges from the water. The plunger most effectively produces the waves when the depth of submergence is somewhat less than the diameter of the cylinder. Consideration is now being given to the addition of a wedge form to the bottom of the plunger.

Waves as steep as 1 to 12 have been produced in the basin; however, the wave steepness has been limited to 1 to 15 for model testing. When the waves are as steep as 1 to 12 the equation of the wave profile becomes complex and the assumptions regarding a sinusoidal or trochoidal profile are invalid. When the wave length is as great as 9.6 ft, the maximum wave steepness attainable by the wave generator is approximately 1 to 35.

WAVE ABSORBERS

The waves are absorbed at the end of the seaway by a gravel-beach wave absorber. The gravel consists of $1\frac{1}{2}$-in. crushed rock. The slope of the surface of the beach is approximately 1 on 2 or 26° from the horizontal. The gravel is supported on a shelf made from welded-wire fabric. Erosion of the gravel is prevented by covering the surface of the beach with $\frac{1}{4}$-in. galvanized wire mesh. The thickness of gravel beach is 17-inches. Approximately one half of the depth of the beach is submerged below the static water level. Fig 2 is a cross sectional diagram of the wave absorber. Data by the Beach Erosion Board (1949) and by Healy (1953) indicate that only about 50% to 60% of the energy of the waves are absorbed by a beach as steep as 26°. In order to avoid the difficulties involved with reflections, the testing is completed before the reflections arrive at the area where the model is being towed.

The shelf supporting the absorber is anchored to the edge of the basin and in plan view the wave absorber is a segment of a circle. Hence any reflection of waves from the absorber is directed along a curved front. These reflections are focused at a point midway between the wave guides and about 20 ft from the wave absorber.

WAVE GUIDES

The diffraction of the wave front is prevented by the use of plywood wave guides. These wave guides form the side boundaries of the testing basin. They were constructed from 4-ft x 8-ft sheets of oiled plywood $\frac{1}{2}$ in. thick. Pipe standards made from $1\frac{1}{4}$-in. pipe and anchored to the floor of the tank support the wave guides. The plywood panels are mounted with approximately 1 ft freeboard and 3 ft submergence.

There is some deflection of the wave guides as the wave front passes down the seaway. However, reflections from the wave guides have not been a serious problem. Plans are now being made to replace the plywood panels with a more rigid structure.

Provisions have been made to slide down the plywood panels which are on the course of the model when testing at an angle to the wave front. These panels can be submerged to a point about 0.7 ft below the water surface to form a slot in the wave guides through which the model can be towed. This adds additional distance to the length of run which can be utilized to accelerate or decelerate the model or to tow the model near the edge of the pond for servicing.

When a wave guide is in the lowered position, diffraction of the wave front occurs as the wave passes the slot which results in a reduced wave height. Although this modification of the wave front is apparent for a distance of nearly one wave length along the crest of the wave, the effect is of minor importance to the general wave pattern.

WAVE FILTER

A floating filter is employed between the wave generator and the model testing area. This reduces the relatively high-frequency interference caused by reflections from the wave generator, by structural vibrations within the wave generator, or by the higher frequency harmonics of the primary wave itself.

The filter consists of two 2-in. x 6-in. x 39-ft wooden planks moored about 3 ft and 8 ft from the wave generator. These filters have very effectively filtered out all of the small-amplitude high-frequency disturbances. Experience has shown that the width of the plank should be less than 25% of the wave length being produced. Using a plank which is too wide seriously reduces the wave height appearing in the testing basin. The wave filters lose their effectiveness when they become waterlogged. Evidently about 1-in. of freeboard is required to prevent the small waves from being carried across the top of the plank.

MEASURING MODEL MOTIONS

Several methods of towing the models have been explored. The model seaplanes have been towed by a simple bridle arrangement. The model ship has been towed using a carriage. The model is attached to the carriage by means of a gimbal ring and vertical stem.

Of the six degrees of freedom, the motions of heave, pitch and roll have been chosen for measurements because the restoring forces for these three motions are mobilized by changes in the distribution of the buoyancy of the vessel. The importance of heave, pitch and roll has been pointed out previously by St. Denis and Pierson (1953). The most serious accelerations experienced by a vessel are a result of heave and pitch or roll.

Measurements of heave, pitch and roll have been taken from 16-mm motion-picture films. Two sets of movies are taken simultaneously from the front and the side at 24 frames per second. These front and side view movies make a valuable history of the tests; however, taking measurements from movies is time consuming and of limited accuracy. Therefore, other methods of making and recording these measurements have been explored.

MEASURING ANGLES OF PITCH AND ROLL

In considering other methods of measuring these six motions, the model motions can be divided into the angular measurements and the linear measurements. Pitch and roll are angular measurements and therefore may be subject to a slightly different consideration than the linear type measurements such as heave.

Generally speaking, the technique used in making any measurement should be such that the motion is not influenced in any way by the presence of the measuring device. To this was added two additional requirements - first, it would be desirable to avoid the use of any complicated electronic circuits and second, to avoid unnecessary structural parts.

To avoid complicated electronic circuits, the choice of possible electrical methods is limited to the basic Wheatstone bridge circuit. The use of electrical methods is desirable because they lend themselves to easy recording by an oscillograph, they can be made reasonably stable, they have a wide range of sensitivity, and they can be easily adapted for use on small models.

A simple light-weight tube has been developed recently which can be used to measure angles. It is called a Convectron Tube. The output is an electrical signal which is sinusoidal. All angles are measured relative to the direction of the gravity vector. The circuit is based upon the Wheatstone bridge circuit. The shortcomings of the Convectron Tubes lie in the fact that their reference datum is the earth's gravity field; therefore, they are sensitive to accelerations. Their advantages are that they are light in weight, reasonably small in size, and require only five small wires to the recording instrument.

During the past year the Convectron Tubes have been used in a series of tests on model ship and seaplane hulls. In addition the tests have been photographed from front and side as explained previously. Thus two independent sets of data are available which can be compared to determine if a "dynamic" calibration of the tubes can be obtained. At the present time it is not possible to draw any conclusions regarding the dynamic calibration.

MEASURING HEAVE

Before satisfactory measurements of heave can be made, a suitable reference point must be established. For the measurements made from the photographs, the reference point has been a $\frac{1}{4}$-in. wire cable. The cable has been tightly stretched across the basin and serves at a horizontal reference line. The sag of the cable is relatively small and is ignored for the center part of its span. This cable appears in the side view movies taken of all the tests.

An aluminum carriage traveling on three high-strength steel wires has been used during the tests of the model ship hull as a reference point for the heave measurements. The three wires have been carefully stretched to a stress of 100,000 psi. The sag is known when the carriage is at any particular point along the span. The carriage is also used to restrain the model motions of yaw, sway, and surge. A steel tube 1-in. square is fastened through a yoke and gimbal ring to the model at the center of gravity of the vessel. The square tube engages a ball-bearing roller-cage on the carriage and is free to move up and down but resists yaw. The stability of the carriage, the tension in the suspension wires, and the tension of the towing line were to restrain the swaying and surging.

The steel wire suspension bridge for the carriage is not entirely satisfactory and is to be replaced by a completely rigid truss-type bridge. The dynamics of the problem make the quantitative heave measurements using the carriage as a reference unreliable. The yawing tendency of the model was somewhat restrained; however, the model seemed to sway quite freely.

The heaving of the model relative to the carriage is measured by a micropotentiometer attached to the carriage. This micropotentiometer is actuated through a bowstring and sheave by vertical movement of the square tube attached to the model. The micropotentiometer is one element in a Wheatstone bridge circuit. When the bridle was used in towing the model seaplanes, all heave measurements were made from the movie film.

MEASURING WAVE PROFILE

PRIMARY PROBE

A Lucite frame supporting the probe wires was suspended over the basin by means of an adjustable boom. This mounting greatly facilitated the daily calibration of the probe and also aided in maintaining the probe in the proper position relative to the static water level. An auxiliary step-type probe was also attached to the boom and was used to adjust the resistance probe and for calibration purposes.

The wave profile is measured using a resistance-wire probe. Two chrome-nickel wires 0.016 in. in diameter having 0.23 ohms resistance per inch are used as the probe. The two wires are stretched $\frac{1}{2}$ in. apart on a Lucite frame and form one element of a Wheatstone bridge circuit. Alternating current is used at the tips of the probe to avoid the effects of the hydrolysis phenomenon.

There are certain disadvantages inherent in the use of the resistance-type probe. The relationship between water surface position and the electrical output is non-linear. Furthermore, the calibration of the system is dependent upon the conductivity of the water between the two wires. These difficulties have been overcome satisfactorily by always adjusting the position of the probes to the static water level existing in the basin. Each day before testing began the wires were carefully cleaned and the system calibrated at 3 or 4 points

AUXILIARY STEP PROBE

The auxiliary probe consisted of a number of small pointed wires carefully positioned at known distances along a vertical line. Each wire was insulated from the others. When a pointed wire contacted the water surface, the circuit to ground was completed and the corresponding small neon glow lamp was lighted on the control board. The position of the water surface relative to the resistance probe could be determined by observing the lighted glow lamps on the control board.

SUMMARY OF TESTING EXPERIENCES

The testing experiences can be divided into two groups - first the performance of the overall basin, and second, the performance of the models. The basin has been in operation for only two summers and several improvements are yet to be made in operation technique.

WAVE BASIN PERFORMANCE

Tests were conducted to calibrate the wave generator. The wave height is shown plotted as a function of the net plunger displacement in terms of the wave height-to-length ratio in Fig 3. The net plunger displacement was varied in two ways for obtaining these data. First, the water surface was varied and secondly the plunger stroke length was changed. The values of the eccentricity of the crank plate are also shown in Fig 3. The small figures at each point are the value of the wave height-length ratio.

There is some evidence that the efficiency of the wave absorbers could be improved. No quantitative measurements have been made to determine the effectiveness of the wave absorbers. The movement of the wave guides results in the establishment of a transverse wave system. This wave system is not apparent until the wave generator has been in operation for a few minutes. By conducting the model runs as soon as possible the difficulties resulting from deterioration of the wave profile are avoided.

MODEL PERFORMANCE

One model ship hull and two model seaplane hulls have been tested in this facility. The model ship hull was a 5 ft model of a tanker and the model speeds were 0, 1.3, 2.5, and 3.2 fps. These corresponded to Froude numbers of 0, 0.1, 0.2, and 0.25. In testing the tanker there were in all cases more than 11 wave encounters before the vessel reached the end of the run. There were at least 6 stabilized encounters. The number of stabilized wave encounters experienced by the model depended upon the model heading, the model speed, and the wave celerity.

The two seaplane hulls were 4 and 5 ft long having a length-to-beam ratio of 8 and 12 respectively. The seaplane hulls were tested at various speeds and loadings. The models speeds varied from 0 to 13.5 fps which corresponds to speed coefficients from 0 to 3.65. The load coefficients for the seaplanes varied from 1.5 to 4.7.

The seaplane models were not dynamic models. The hulls were equipped simply with an aluminum spar which supported the wing-tip floats. Therefore, aerodynamic lift was not a variable.

When the model was running with the waves on the headings of 0° to 45° and at the high speeds ($C_v = 3.65$) the seaway was not long enough to establish stabilized conditions because there were only two or three wave encounters during the entire run. At the other headings, however, the basin was of sufficient size for the model to experience 2 or 3 stabilized wave encounters. Experience indicates that as the frequency of encounter increases the number of runs required to reach stabilization is reduced. This is logical since at the higher speeds the hydrodynamic forces predominate the buoyant forces and the model motions are stabilized without "hunting.".

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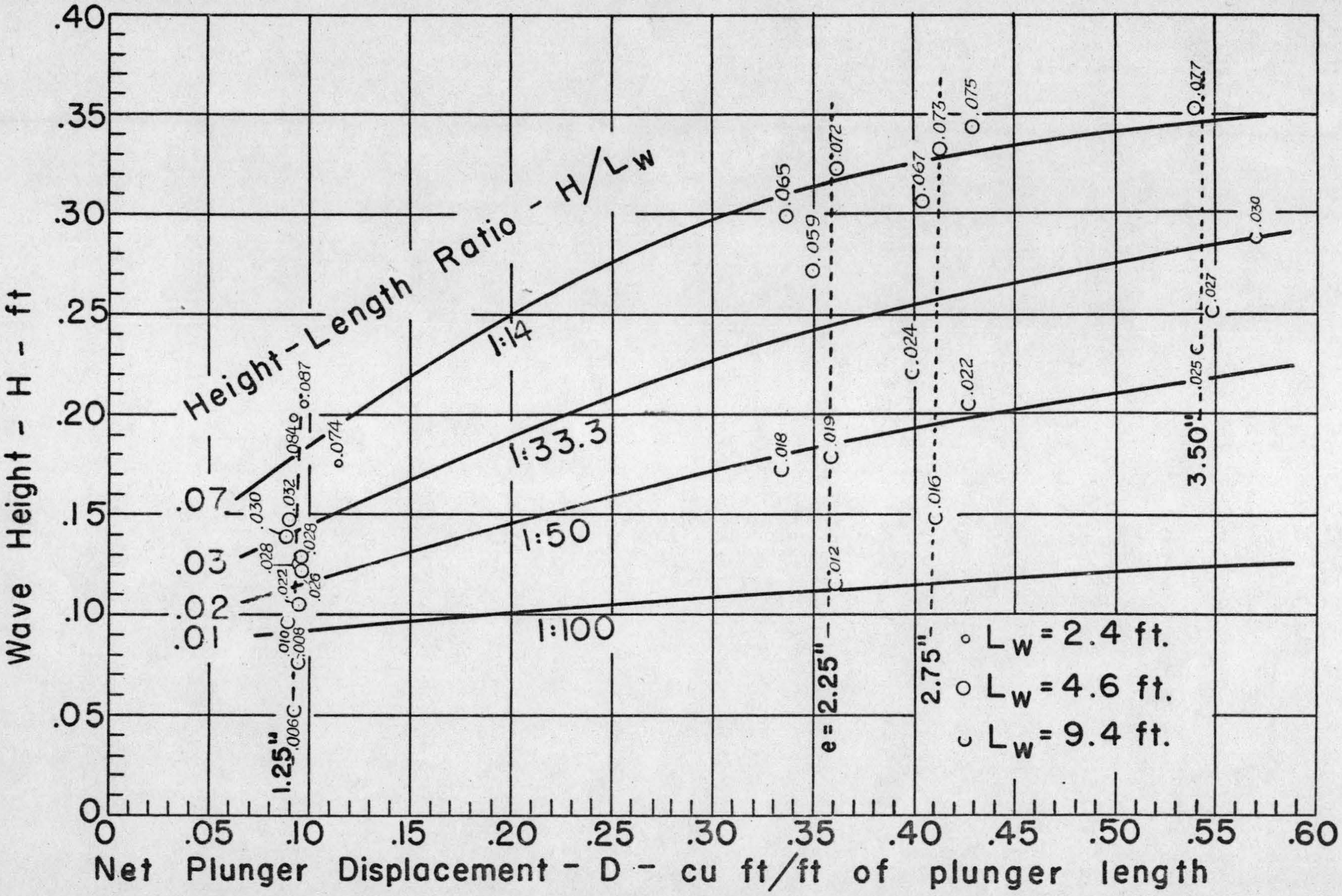

Fig. 3-WAVE GENERATOR PERFORMANCE

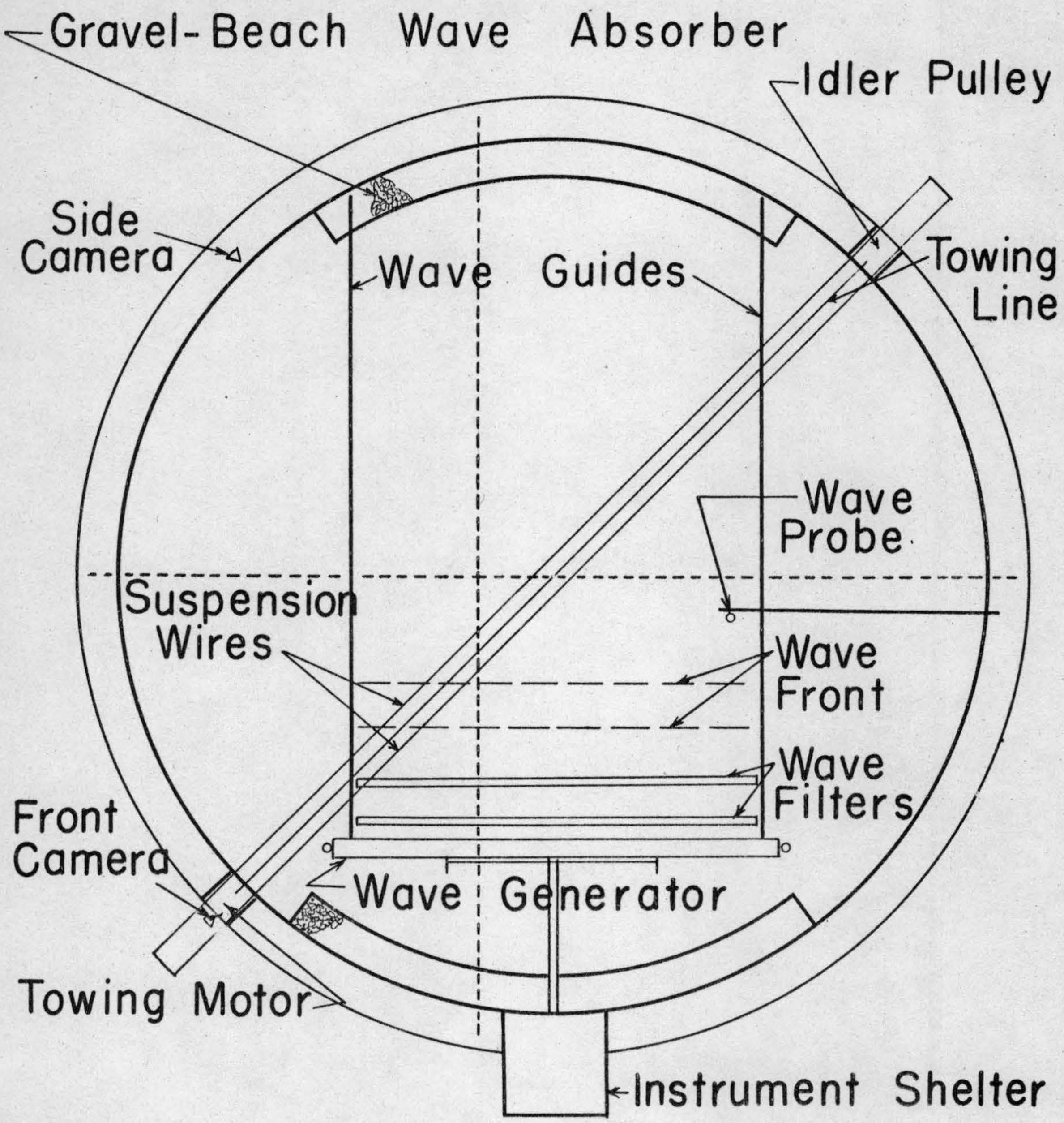

Fig. 1

ARRANGEMENT OF WAVE BASIN

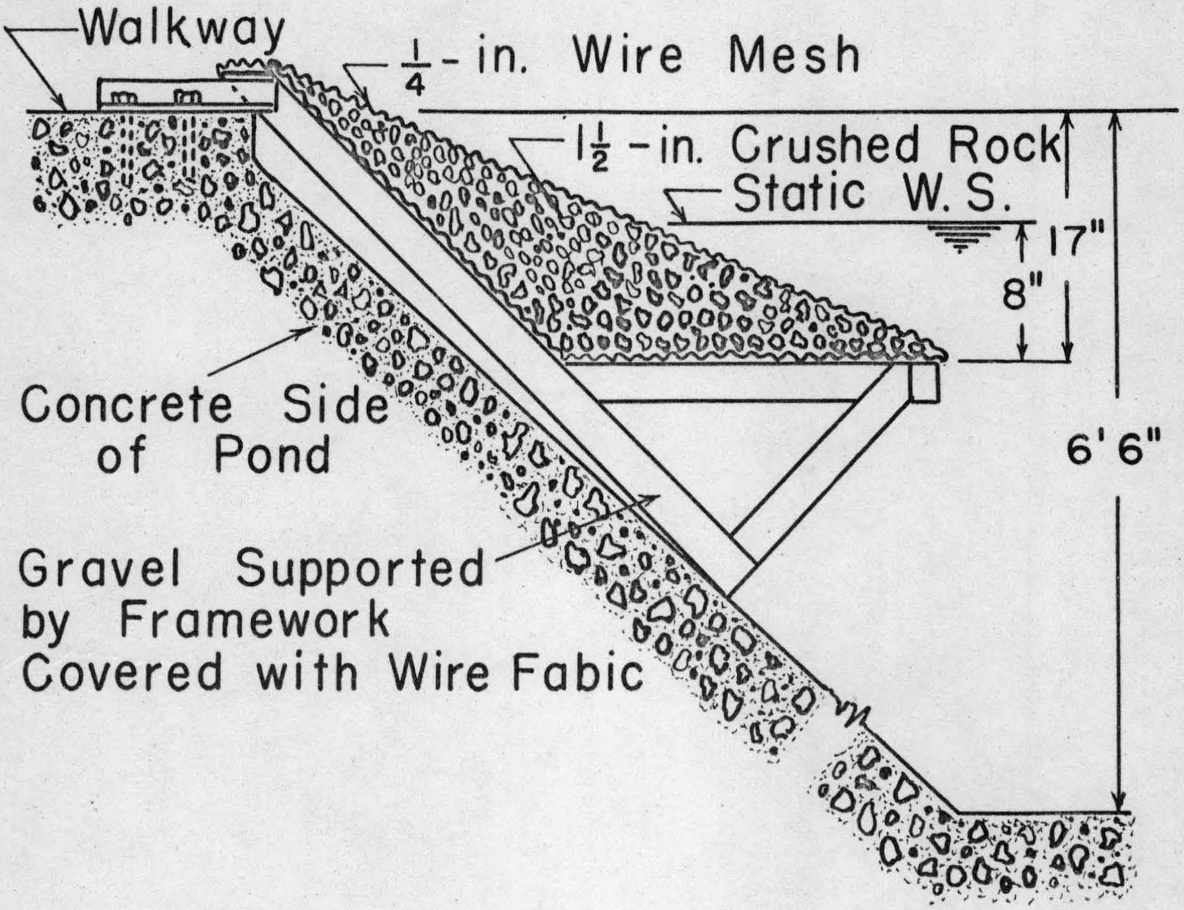

Fig. 2

CROSSECTION OF GRAVEL-BEACH WAVE ABSORBER