CHAPTER 15

LABORATORY FACILITIES FOR STUDYING WATER GRAVITY WAVE PHENOMENA

by

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ABSTRACT

Details are given of the design of laboratory facilities at the University of California for studying water gravity wave phenomena.

INTRODUCTION

During the past two decades a series of facilities have been designed and built by the College of Engineering, University of California, Berkeley, California, for the purpose of studying the generation and characteristics of water gravity waves and their effects on coastal sediments, marine structures, amphibious craft, and ships (including ships' moorings). At the present time the following facilities are in operation:

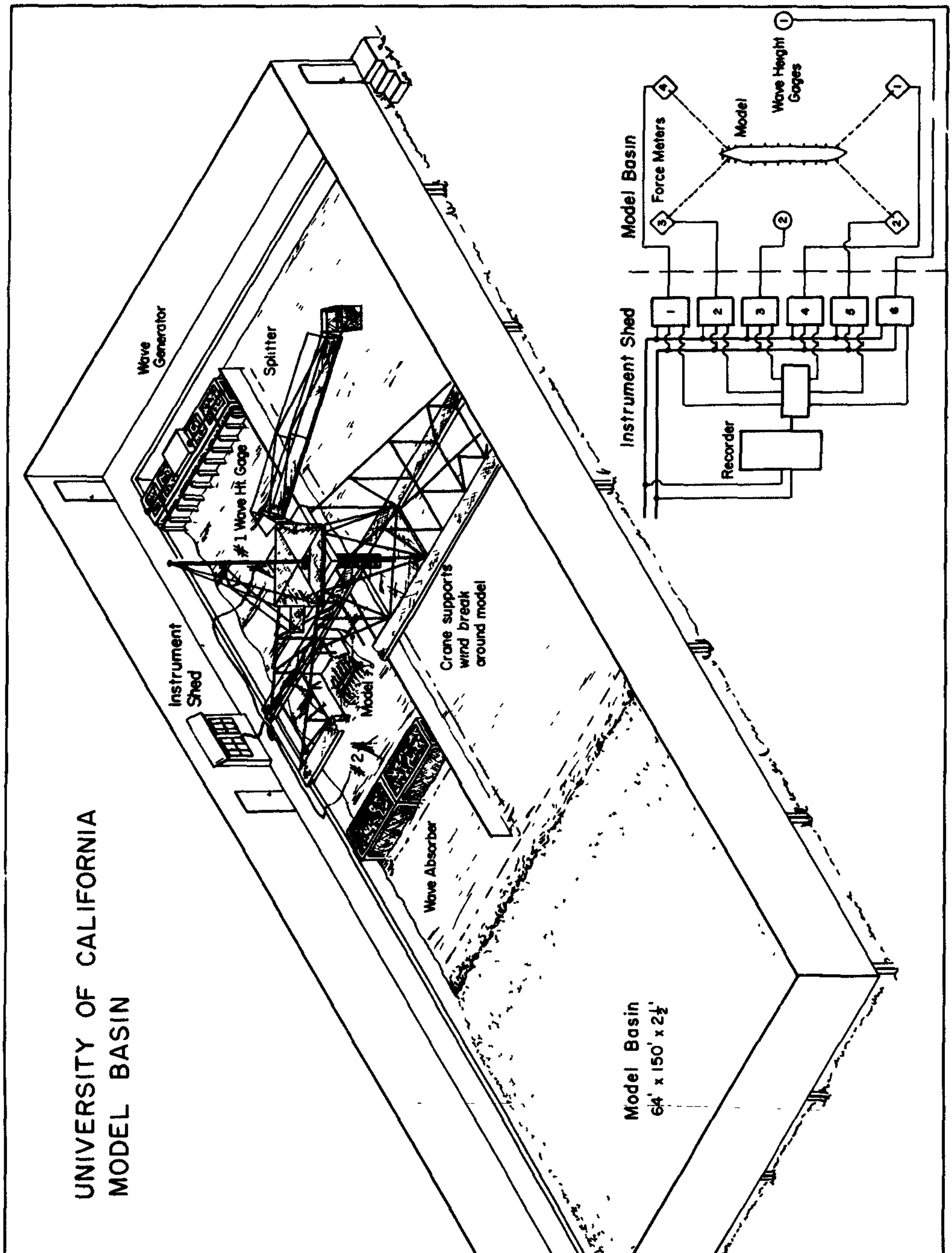
1. Model Basin, 64 ft. by 150 ft. by 2.5 ft. deep.
2. Wave-Towing Tank, 8 ft. by 200 ft. by 6 ft. deep.
3. Wave Channel, 1 ft. by 60 ft. by 3 ft. deep.
4. Wind-Wave Tunnel, 1 ft. by 60 ft. by 1.25 ft. deep.
5. Wave-Sediment Basin, 6 ft. by 12 ft. by 1 ft. deep.
6. Ripple Tank, 4 ft. by 20 ft. by 0.5 ft. deep.

The tanks and equipment have been designed over a period of years to study particular engineering problems. Experience gained in operating each facility led to improved designs for each succeeding one. Because of this, details will be given herein of only the latest designs while a minimum of information will be presented on the earlier equipment.

Several of the tanks are located at the Engineering Field Station of the University of California in Richmond, California (Bermel, 1955) while the remaining tanks are located on the Berkeley campus.

MODEL BASIN

The new model basin, located at the Engineering Field Station, is used to study the effect of groins on the deposition of sand on a beach, the refraction and diffraction of waves with respect to harbor and coastal structure design, the motion and mooring forces of a ship moored at an angle to waves, and other problems which require a large area. The basin, 64 ft. by 150 ft. by 2.5 ft. deep, is equipped with a movable wave generator, a movable photographic crane, and sand beaches and stainless steel filings for absorbing the wave energy. A corrugated aluminum fence, reaching $9\frac{1}{2}$ ft. above the top of the basin, surrounds the basin to pro-


UNIVERSITY OF CALIFORNIA
MODEL BASIN
Wave Generator
Splitter
#1 Wave Ht Gage
Instrument Shed
Crane supports wind break around model
Model
#2
Wave Absorber
Model Basin 64' x 150' x 2½'
Model Basin
Force Meters
Model
Wave Height Gages
Instrument Shed
Recorder

tect it from the wind. A schematic drawing of the basin is shown in Figure 1 which includes an instrument wiring diagram for a sample experimental set-up. Details of the basin construction, designed by K. J. Bermel and N. A. Jensen, are shown in Figure 2.

The flap-type wave generator (See Suquet, 1951, for definitions of wave generator types) used in the original model basin, located on the Berkeley campus, was used in the new model basin until a piston-type wave generator, designed by C. M. Snyder, was constructed. This piston-type wave generator is basically the same type as the one used in the wave-towing tank except for required size modifications and the addition of a remote control system for operating the amplitude mechanism. Both the wave amplitude and wave period can be varied while the wave generator is in operation.

The gear box (Figures 3 and 9) is the same in principle as the gear box in the wave generator used in the wave-towing tank, except that instead of using a hand wheel to operate the input shaft of the amplitude control mechanism a motor was substituted so that it can be controlled by power. On the input shaft there is an electric brake to keep the amplitude from drifting when the motor is not running. A double-ended miter gear box is connected to the amplitude control shaft with a sylsyn generator on one side and a limit switch on the other (See Figure 4 for the wiring diagram). A forward and reverse push-buttom station and sylsyn repeater which drives a counter were installed in the operation building.

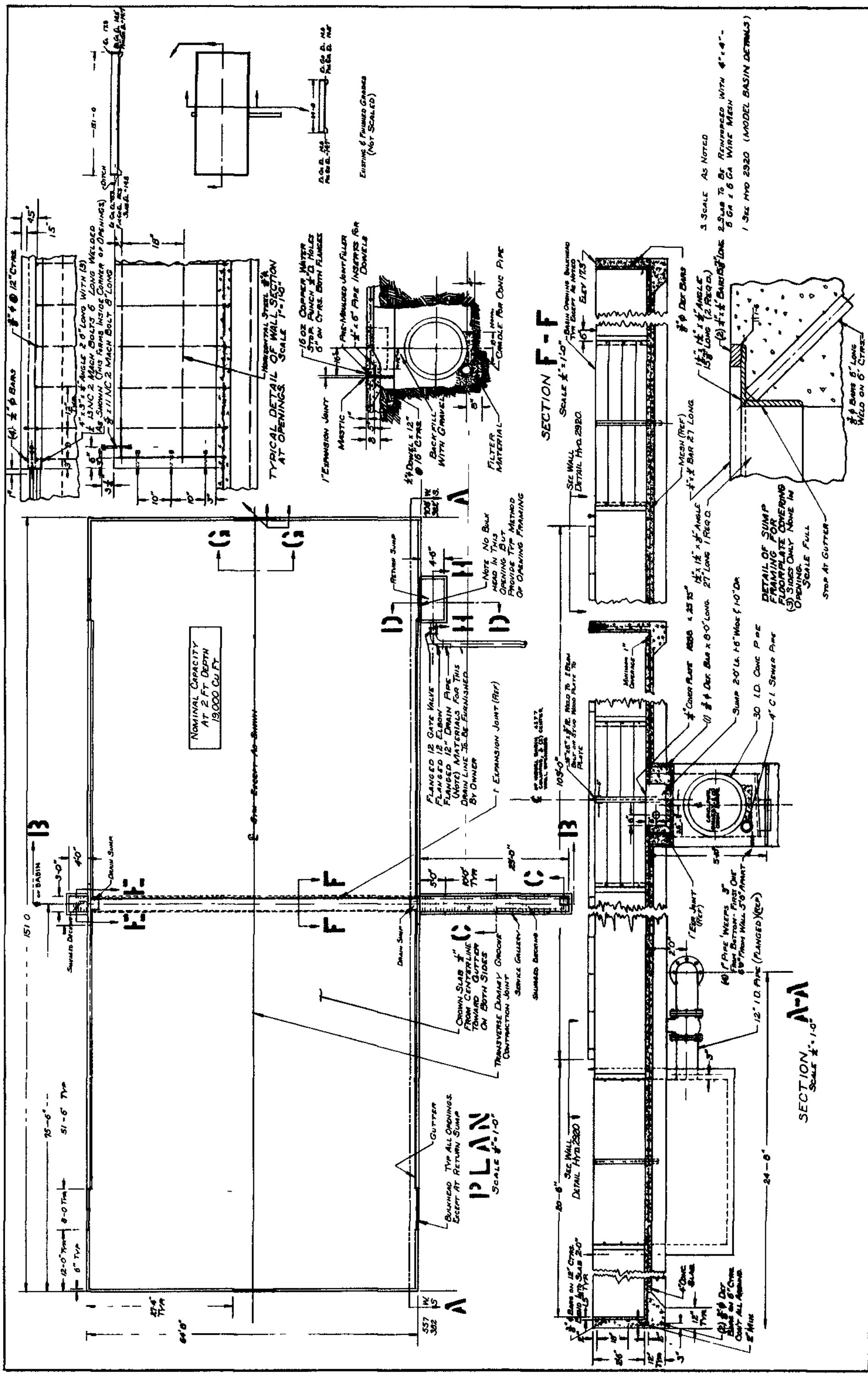
The main motor speed control is obtained by a modified Ward-Leonard system. This has a 5 hp shunt motor which has its field excited by an electronic power supply. The motor armature current is supplied by an electronic exciter motor generator set. This type of drive has an advantage in that it is quite stable and has a large speed range. Wave periods from 3/8 second to at least 10 seconds have been obtained by this drive.

The wave generator was built in three sections. Each section was made 21' 2-1/4" long. The sections (Figure 5) consist of a box-like steel girder frame, with a piston that rides in a channel track. The box frames can be connected to each other by a set of pin connectors. The pistons are linked through a rocker arm shaft. This shaft is in turn linked to the gear box on the center section crank by a connecting rod. This design allows the generator to be made up into three different lengths 21' 2-1/4", 42' 5-3/4", and 63' 7". The center section is the power section.

The flap-type wave generator has been retained so that it is possible to generate "cross seas" using the two generators simultaneously.

WAVE-TOWING TANK

As a part of the program to move large engineering facilities from the Berkeley campus to the Engineering Field Station, it was necessary to move the ship model towing tank. Because of the type and condition of the tank it was decided to design a new tank which would include a wave generator so that experiments involving water gravity waves


PLAN
SECTION A-A
SECTION F-F
TYPICAL DETAIL OF WALL SECTION AT OPENINGS
NOMINAL CAPACITY AT 2 FT DEPTH 19,000 CU FT
DETAIL OF SUMP FRAMING FOR FLOORPLATE COVERING

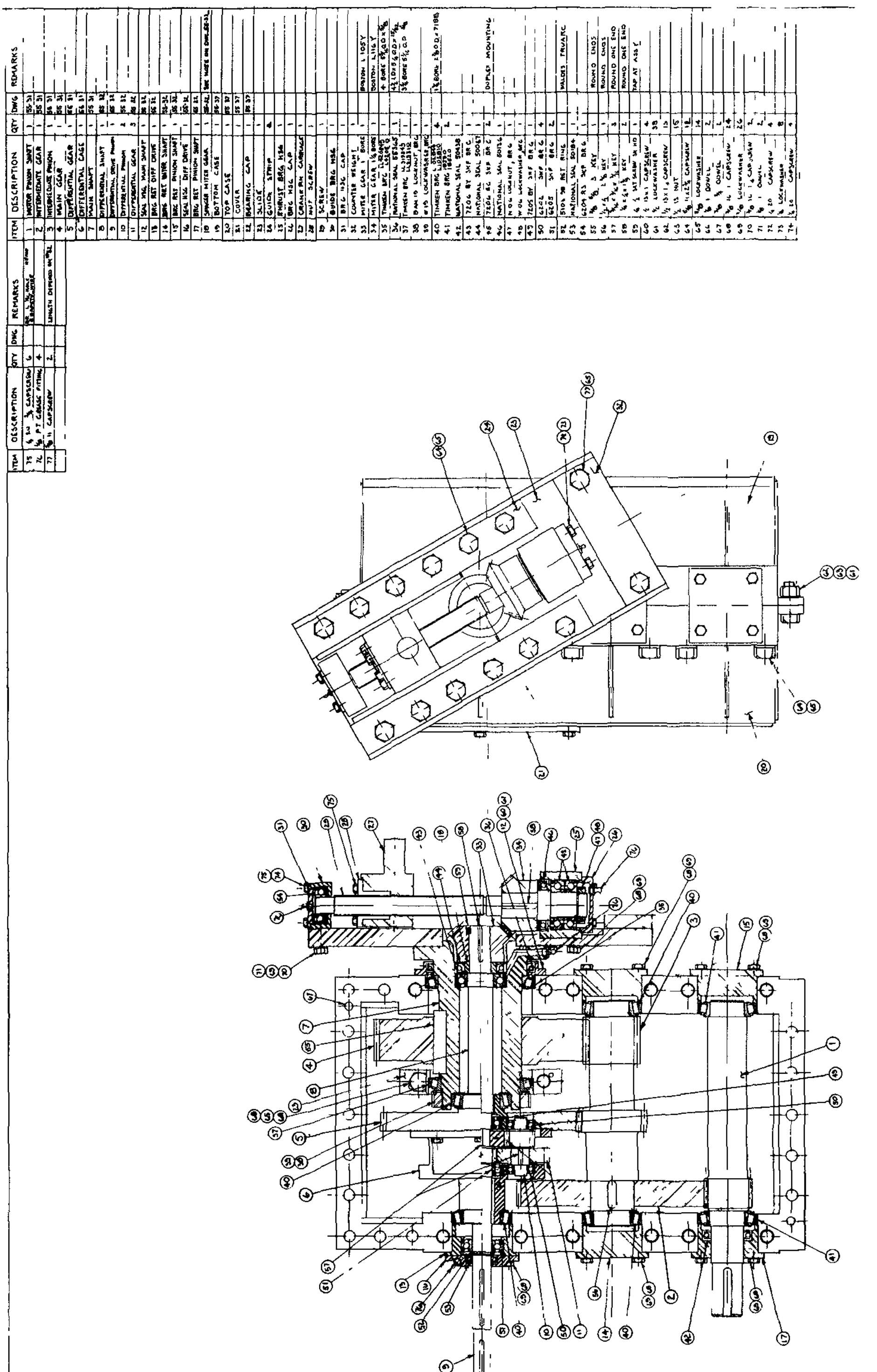


Fig. 3. Gear box assembly, model basin wave generator.

could be performed on a larger scale than was possible with the other wav tanks at the University. The overall dimensions of the tank were determined by economic and engineering considerations and were fixed at 8 ft. by 200 ft. by 6 ft. deep. A schematic drawing of the tank is shown in Figure 6, which includes an instrument wiring diagram for a sample experimental set-up. The tank is housed in an all-metal industrial building. The tank is equipped with piston-type wave generator, a stainless steel filing beach for absorbing the wave energy, two sections of observation windows along one side of the tank, a towing carriage, an overhead travelling crane system, a camera pit, and a bank of photographic lights. The general arrangements can be seen in Figure 7. The tank was designed by K. J. Bermel and N. A. Jensen and the wave generator was designed principally by C. M. Snyder.

WAVE GENERATOR SPECIFICATIONS

The dimensions of waves needed by naval architects were small; hence, the sizes of the waves to be generated were fixed by considerations of other problems. Laboratory studies of the behavior of waves in shoaling water and their effect on the motion of sand and the study of wave forces on marine structures pointed up the limitations of the wave generating facilities then in existence. Working from the given dimensions of the tank (8 ft. x 200 ft. x 6 ft.), it was decided that the maximum wave should have a period of five seconds and a height of two feet. A review of the studies by the Beach Erosion Board (1949), together with past experience at the University, led to the decision to use a piston-type wave generator. Using the portion of the work of the Beach Erosion Board (1949) for a piston-type generator, it was estimated that the wave generator stroke should be approximately one and a half feet.(total motion of three feet). The minimum wave period for design purposes was about one-half second with the wave height being the value associated with the maximum possible wave steepness, which fixed the wave height at less than one-tenth of a foot (Suquet and Wallet, 1953).

The power of the generated waves was determined from wave theory (O'Brien, 1942), where

$$\text{Wave power} = \frac{\text{Group velocity} \times \text{Wave energy}}{\text{Wave length}}$$

The electro-mechanical power necessary to generate waves of a given power was estimated from the experimental work of the Beach Erosion Board where the relationship between the actual power-time history of the generator and the wave power was determined experimentally for a model piston-type wave generator. The Beach Erosion Board studies (1949) showed that the average power needed was almost that of the wave horsepower but that the peak power needed for certain waves was approximately three times the wave power. Because of the fact that a motor can be overloaded for a small portion of the cycle the motor chosen was only a 15 horsepower, 230 V.D.C., 350-1750 RPM shunt motor.

Motor speed control is obtained at present by adjusting a field reostat, giving wave periods from 3/4 to 3-3/4 seconds. If

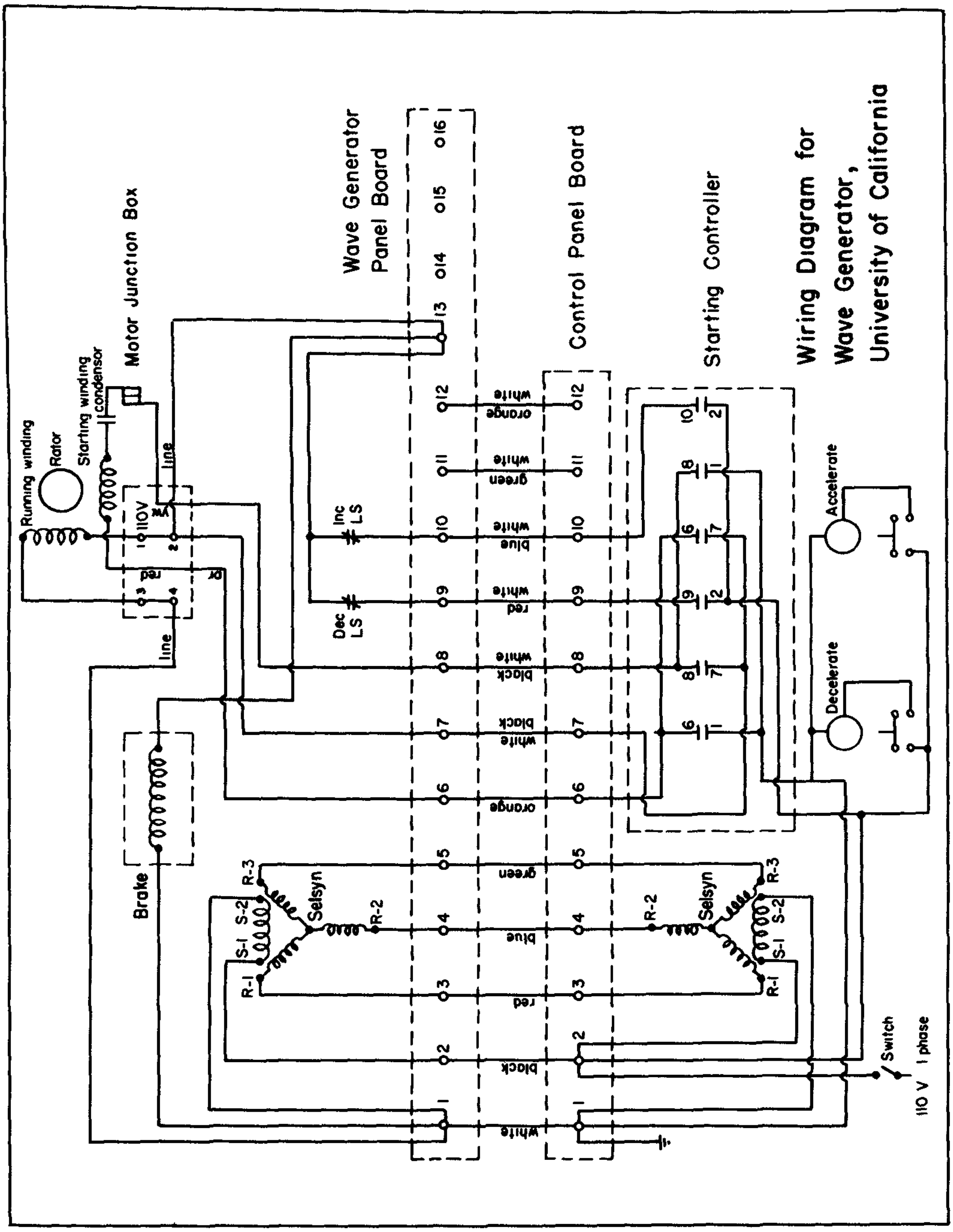
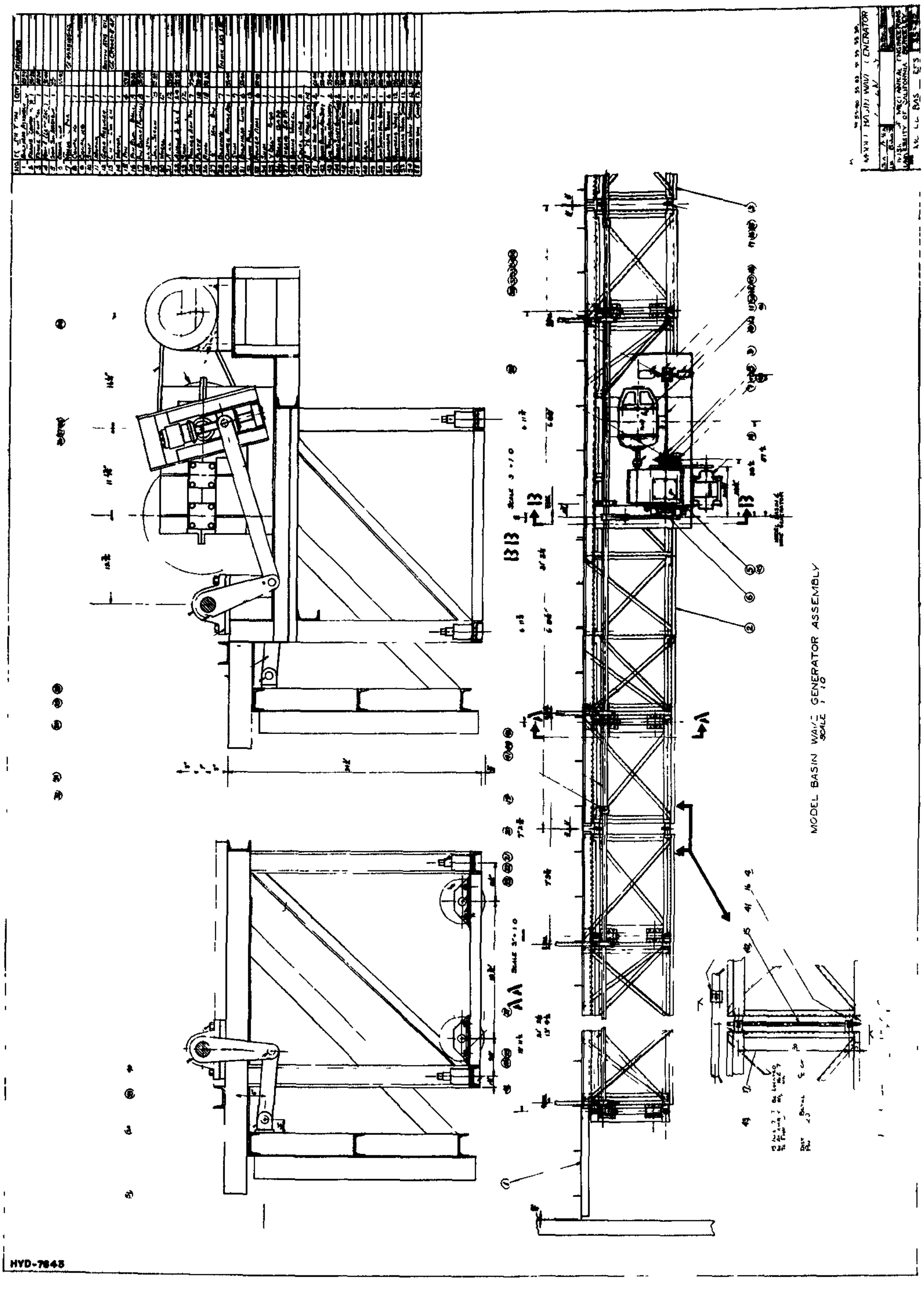

Wiring Diagram for
Wave Generator,
University of California
Wave Generator
Panel Board
Control Panel Board
Starting Controller
Motor Junction Box
Running winding
Rotor
Starting winding
Starting winding condensor
line
110V
red
Brake
Selsyn
R-1
R-2
R-3
S-1
S-2
Inc LS
Dec LS
Accelerate
Decelerate
Switch
110 V 1 phase
white
orange
green
blue
red
black

Fig. 4


MODEL BASIN WAVE GENERATOR ASSEMBLY
HYD-7645

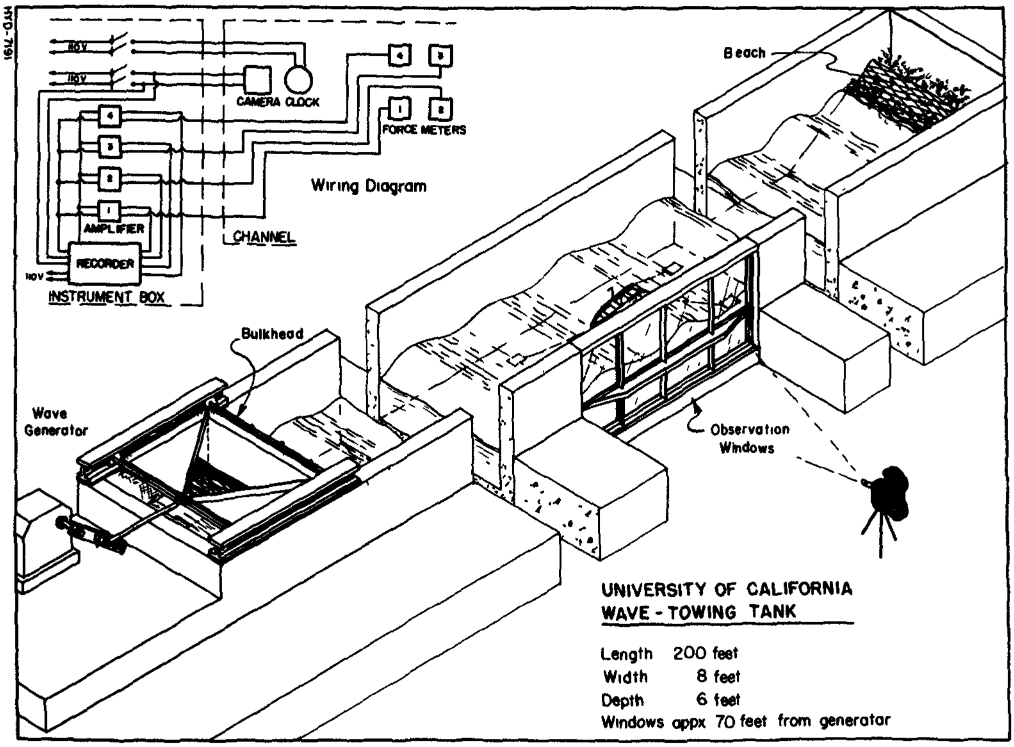


Fig. 6

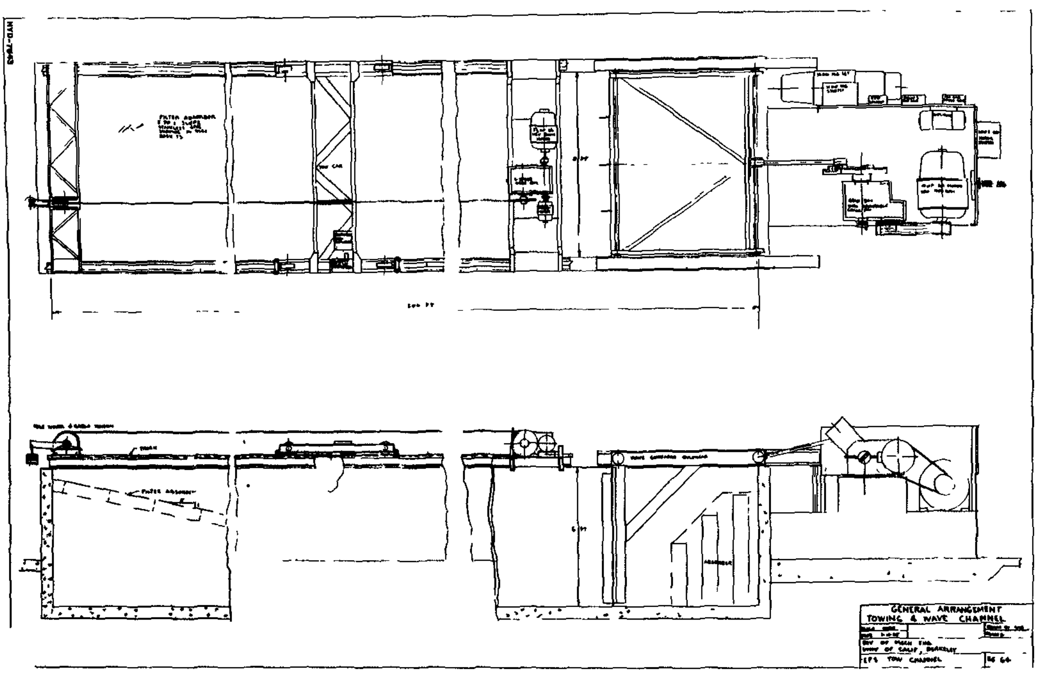
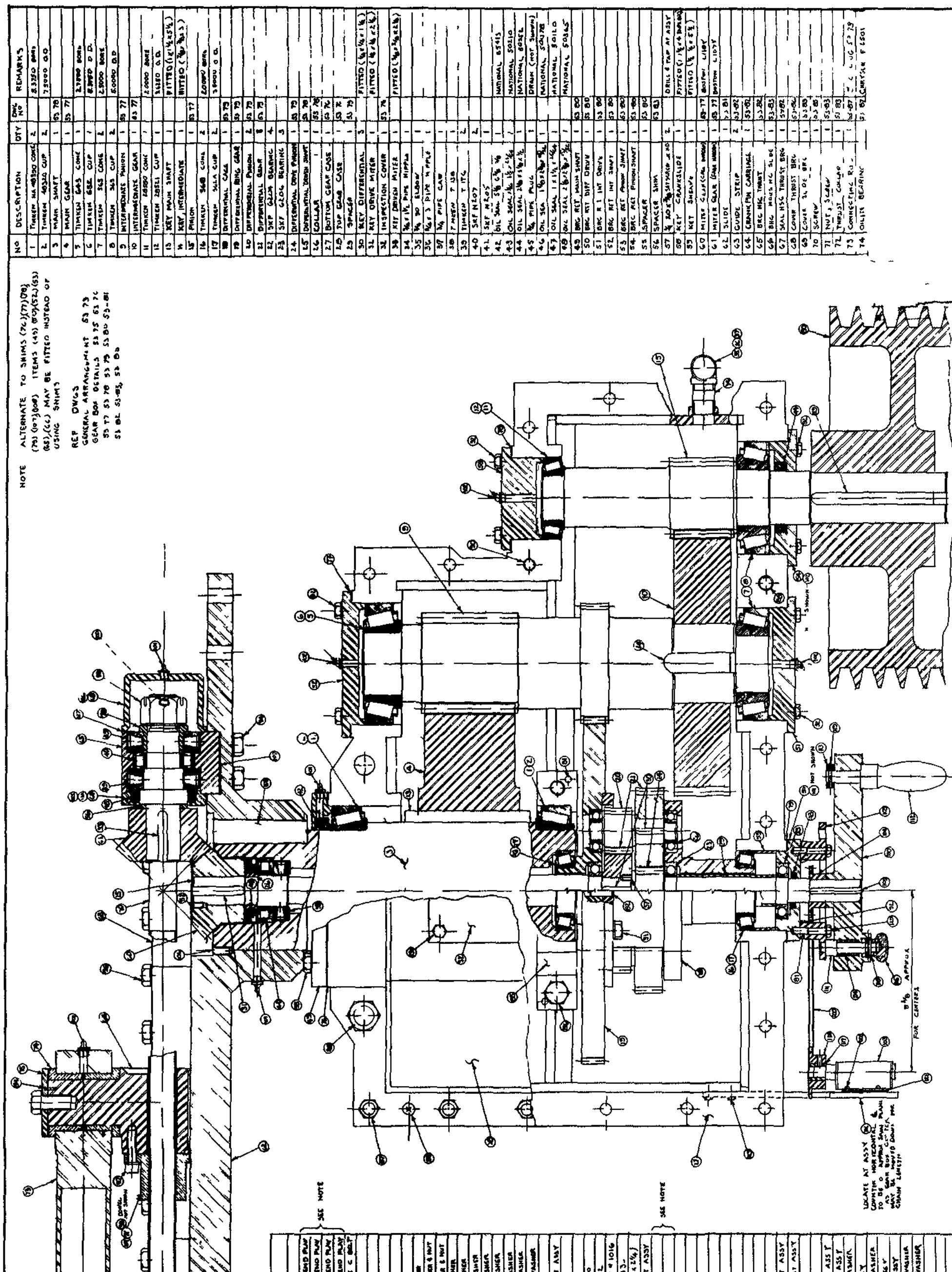


Fig. 7. General arrangement, towing and wave channel.



Gear case assembly, wave generator

it becomes necessary to have a greater range, the drive can be modified by changing pulley sizes.

Power for the wave generator at present is furnished by a 230 V, 50 Kw motor generator set.

PISTON-TYPE WAVE GENERATOR

The generator consists of a welded steel piston (bulkhead) which is connected by a connecting rod to an adjustable crank mounted on a specially built gear box (Figure 7).

The gear box (Figure 8) was designed to allow for adjustment of the crank-pin position while running. This was accomplished by using an epicyclic gear train. This allows shaft Q to turn at the same rotation and angular velocity as shaft G when shaft U is held stationary (Figure 9). When shaft U is turned, it causes a change of rotation speed of Q with respect to shaft G causing screw T to move the crank-pin. The gear ratios were selected to allow one complete turn of U to increase the amplitude of the piston by 1/10 of an inch. The gear ratios which were used in the wave-towing tank generator and the model basin generator are tabulated in Figure 9.

The piston (Figure 7 and 10) was fabricated from 1/8" plate and 6" channel. The wheels on which the unit rolls were mounted above the water line; the wheels on one side of the piston were grooved and the wheels on the other side of the piston were flat. Special double track was constructed to keep the wheels in a confined path. Mounting the bearings, etc., out of the water eliminated the excessive wear and corrosion which has occurred in previous wave generator designs. The piston was connected to the crank through a connecting rod.

The stroke of a piston-type wave generator can be computed by an equation developed by Biesel (1951). The equation is stroke = wave height divided by 2K, where K is a function of the ratio of wave length to water depth, and the stroke is measured from its mean position.

MEASURED CHARACTEISTICS OF WAVE GENERATOR

Two sets of measurements were made on the wave generating equipment: (1) the wave generator stroke necessary to produce different wave heights and periods; and (2) the horsepower input to the electric motor necessary to generate waves of different wave heights and periods. The data are presented in Figure 11. It can be seen that Biesel's (1951) equation for the necessary stroke predicts correctly the required stroke. Use of the Beach Erosion Board data (U. S. Army, 1949) results in an overpowered system by about a factor of 4/3. It can be seen that except for low values of wave horsepower a factor of three will permit the prediction of peak horsepower where the horsepower is taken as the horsepower to the motor minus the tare horsepower of the motor and the gear box. It is fortunate in that the tare horsepower decreases to about one horsepower for the longer wave periods which are the one requiring the greatest net horsepower. Later tests by the Beach Erosion Board (Caldwell, 1955) also showed that the peak load for this type of wave generator was approximately three times the average wave horsepower.

TOWING CARRIAGE

The towing carriage mounted on the tank is a light-weight aluminum carriage, designed to tow cylinders with relatively high speeds compared with ship model speeds and with rapid acceleration in order to obtain data on drag and inertia forces (Laird and Johnson, 1956). The four-wheeled carriage is pulled by a cable that spans the length of the tank. It rides on special rails and is guided laterally by means of horizontal guide wheels which bear on the machined sides of the rail. The rails were machined 100-lb. rail obtained by the University as surplus property from the Bureau of Ships, U. S. Navy. The rails were leveled using the water level in the tank as the datum, and their level is checked periodically.

A $7\frac{1}{2}$ horsepower shunt-wound D. C. motor is used to drive the towing carriage through a two range gear box (See foreground of Figure 10). The two speed ranges are 0.5 to 5 and 2 to 20 feet per second. Power for the drive motor comes from a 10 KW motor generator set which is excited by a General Electric Co. Electronic Amplidyne. A tachometer is mounted on the motor pinion shaft of the carriage gear box. This furnishes a voltage that is balanced against a reference voltage in the electronic circuit of the Amplidyne. When the output voltage of the tachometer equals the reference voltage, the carriage is running at constant speed. Any change in speed will cause the Amplidyne to force the field of the generator which, in turn, adjusts the speed of the motor. Close speed regulation is obtained. It is in the order of 1/10%. Speed adjustment is attained by the setting of a 10,000 OHM, 10-turn micro-potentiometer which adjusts the reference voltage level. The car is stopped by the Amplidyne's reversing the power to the drive motor and limiting the current. When the carriage is running at maximum speed, it can be stopped within a distance of 20 feet. If the operator does not push the stop switch in time, the braking is actuated automatically by limit switches located at the proper distance from the two ends of the tank. The carriage, drive, and braking system were designed by C. M. Snyder.

The speed of the towing carriage is measured similar to the method used by the Massachusetts Institute of Technology (Abkowitz and Paulling, 1953).

The carriage has an idle wheel that runs on the rail. The diameter of the wheel is such that it turns at 1 rps. when the speed of the carriage is 1.000 knots. A disk is attached to the wheel that has 1,000 equally spaced slots 0.010" wide. A light source on one side of the disk is focused on a 0.010" slot in front of the disk. When the disk slot and the other slot line up the light passes through and is picked up by a photoelectric cell. The impulse picked up by the photocells are amplified and feed into a digital electronic counter.

The counter counts the number of impulses against a crystal control time base that has an accuracy of the order of a few millionths of a second. The counter in turn is coupled to a digital recorder that prints the number of impulses on a tape for the permanent record of the speed. The counter is limited to counting the number of impulses to ± one pulse which limits the accuracy of measuring the speed of the

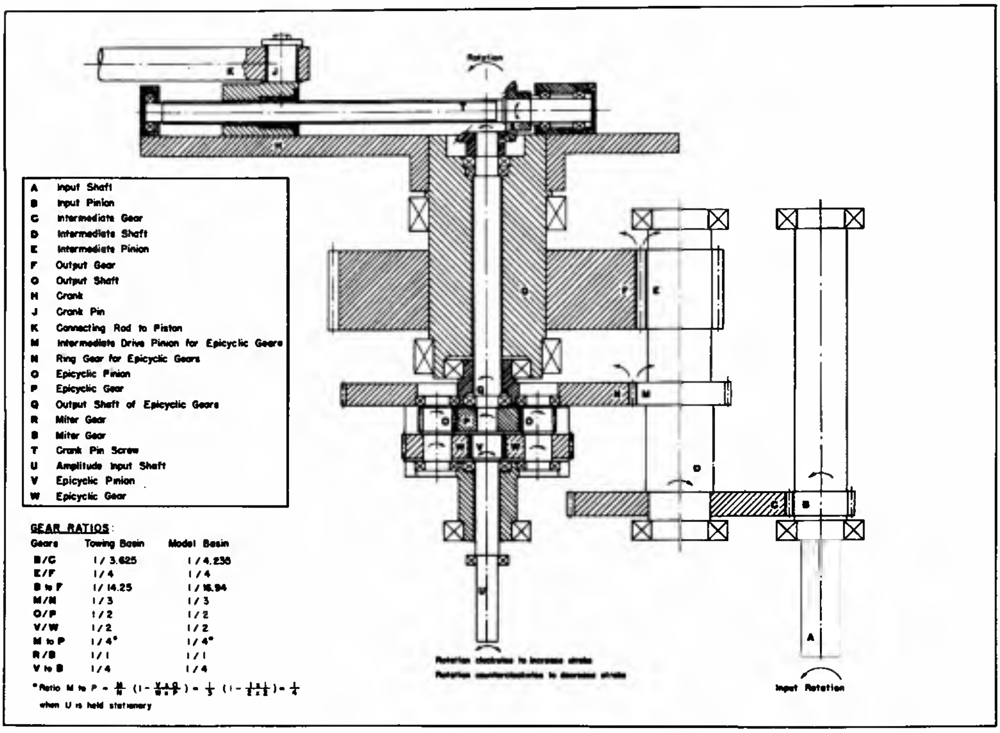


Fig. 9. Schematic drawing. Gear box for wave generator.

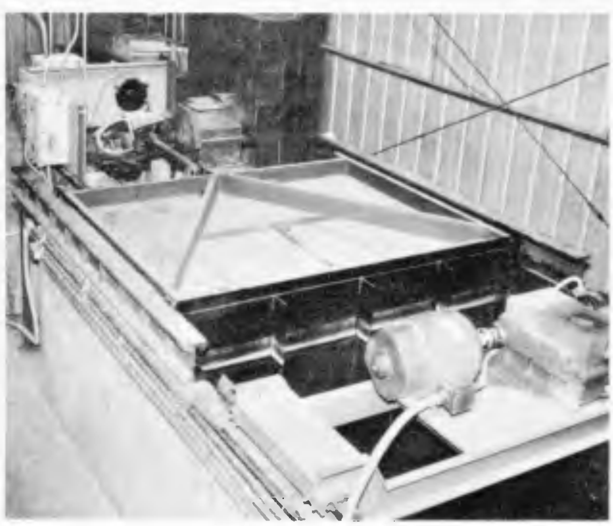
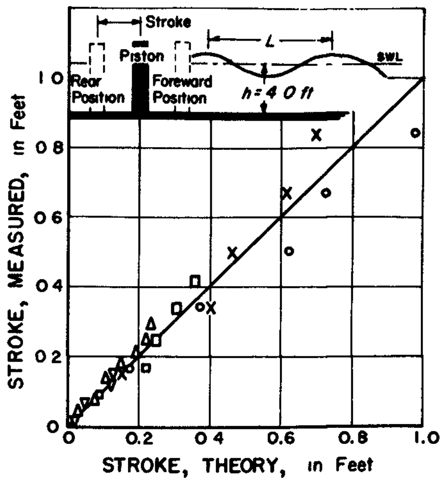
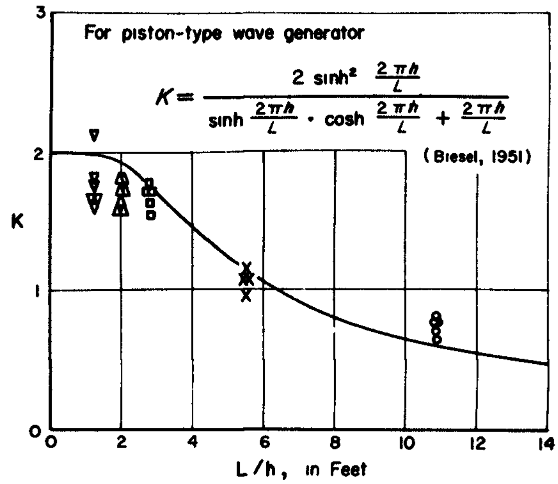


Fig. 10. Photograph of wave-towing tank wave generator.

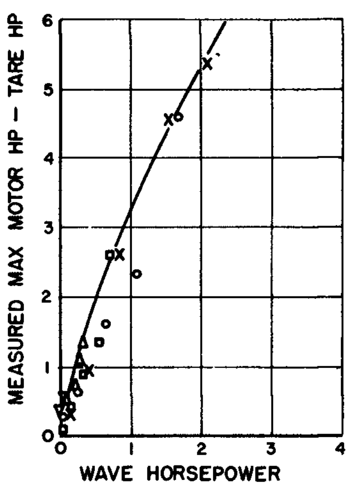


Computed stroke compared with measured stroke

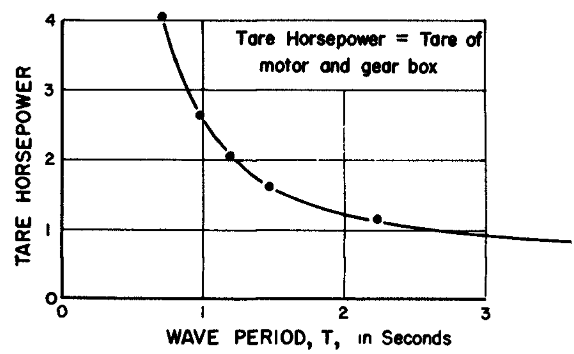


Theoretical amplitude-stroke function compared with measured values

o	T = 3.68 sec
X	2.21
□	1.48
Δ	1.20
∇	0.99



Maximum motor horsepower (less tare) compared with wave horsepower



Tare horsepower (motor plus gear box)

Fig. 11. Characteristics of the wave-towing tank wave generator.

carriage to within ± 0.001 knot.

The electronic counter and digital recorder were built by the Berkeley Scientific Company of Richmond, Calif. The speed measuring wheel amplified and photocell system were built by the University of California. The amplifier used was basically the same as that used by the Massachusetts Institute of Technology with the exception that the power supply was specially designed.

WAVE CHANNEL

The 1 ft. by 60 ft. by 3 ft. deep wave channel was the first wave tank built at the University (Figure 12) and was designed by M. P. O'Brien. The wave generator first used in this wave channel was of the flap-type with a motor-driven crank moving the top of the flap back and forth and with the bottom of the flap hinged in a fixed position. The wave generator (Figure 13) was redesigned by A. B. McIntyre and F. M. Sauer so that the top and bottom of the flap could be moved simultaneously by motor-driven coupled crank (Boucher, 1947). The amplitudes of the top and bottom motions of the flap can be set at the horizontal amplitudes of the water particle orbits of the wave to be used. The amplitude can be changed only while the unit is stationary and is accomplished by turning the screws on the two horizontally mounted flywheels. The period can be adjusted by means of a Vari-drive unit attached to the D. C. motor which drives the wave generator.

The channel is equipped with a series of observation windows through which motion pictures can be taken of the wave action.

Absorption of wave energy is usually accomplished by means of a sloping aluminum beach (with a slope of 1:10 or less) covered with sand, gravel or crushed rock.

WIND-WAVE TUNNEL

The wave channel described above was also used as a wind-wave tunnel (Johnson and Rice, 1952). However, due to a heavy work load it was necessary to build a separate unit for studying wind tides (Sibul, 1955). A schematic drawing has been given in Figure 14, together with sketches of an experimental set-up for measuring wind pressure distribution, waves, and wind tide. The tunnel and equipment was designed by J. W. Johnson, K. J. Bermel and O. J. Sibul.

The tunnel was constructed of wood, with one side made of plate glass for observation and photographic purposes. The wind was generated by a blower mounted on one end of the channel, driven by an A-C motor. The wind velocities could be varied from zero to fifty feet per second by varying the air intake area at the blower. A honeycomb section was installed between the blower and the channel to straighten the wind flow. Sloping wood planks were installed at both ends of the channel to guide the wind onto and off of the water surface. The plank at the exit end of the channel was covered with burlap to absorb the energy of the relatively small wind waves generated by the blower.

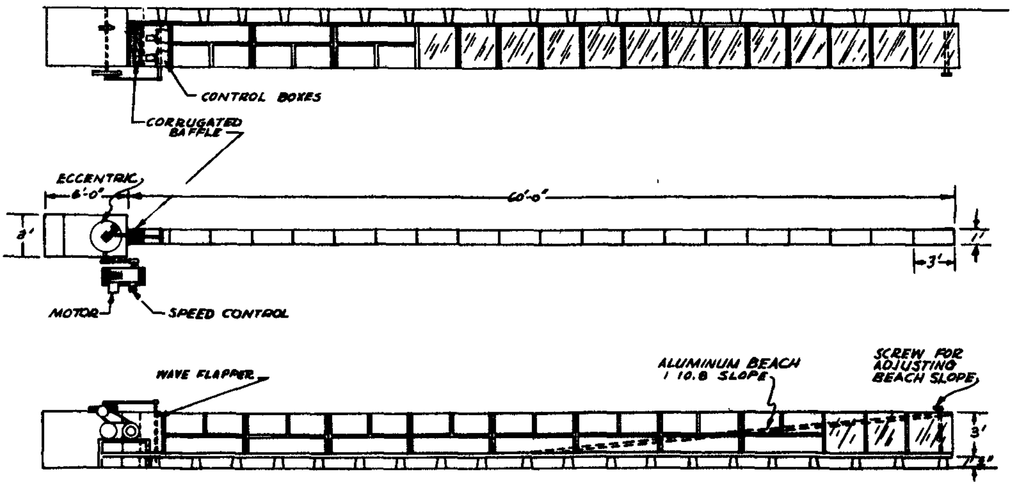


Fig. 12. One-foot wide wave channel.

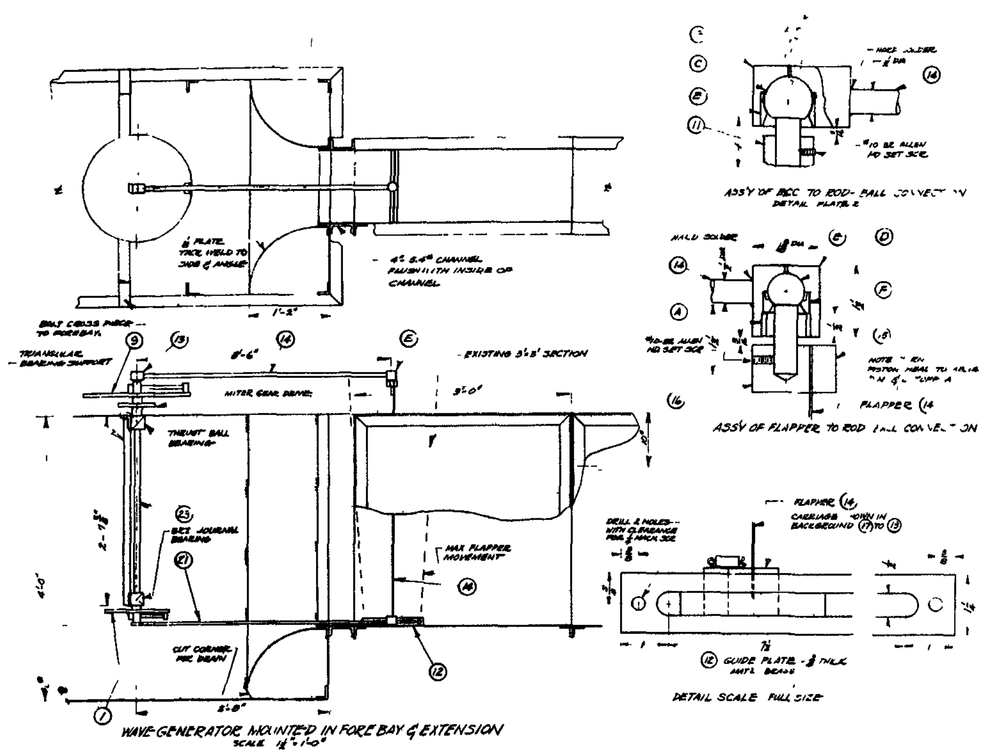


Fig. 13. Wave generator, one-foot wide wave channel.

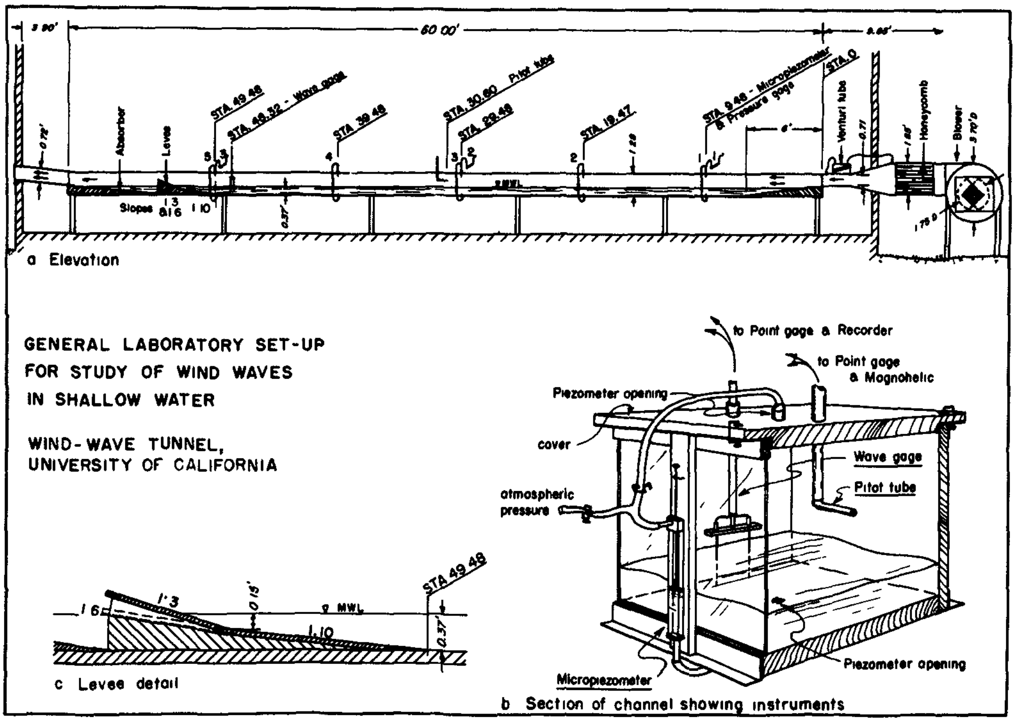


Fig. 14. Channel for studying wind waves in shallow water.

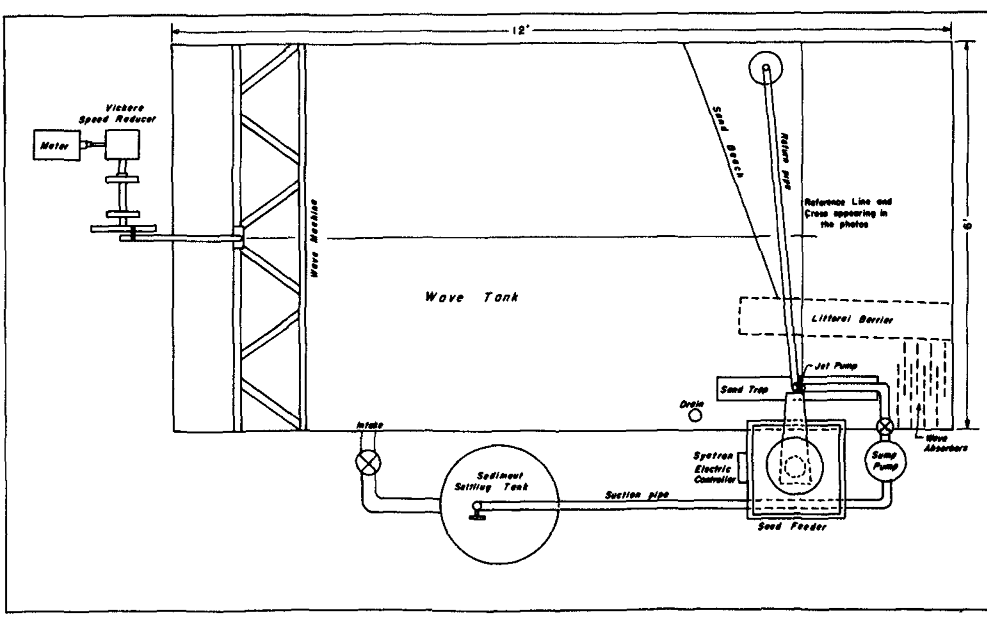


Fig. 15. Sketch of wave-sediment basin.

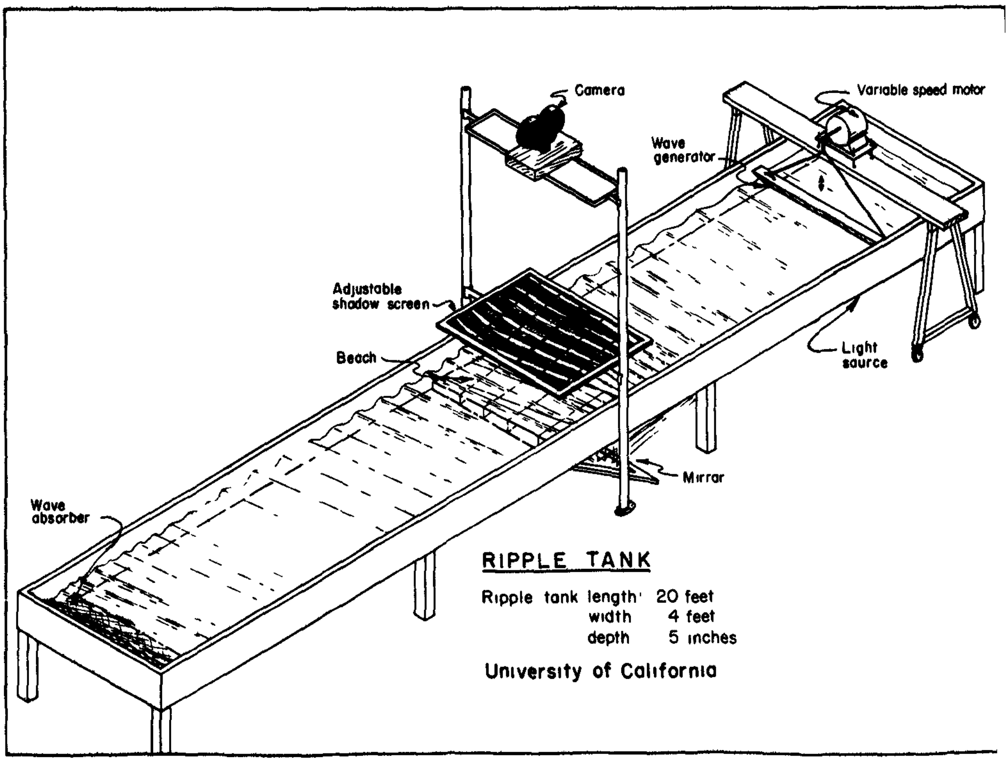


Fig. 16. Ripple Tank.

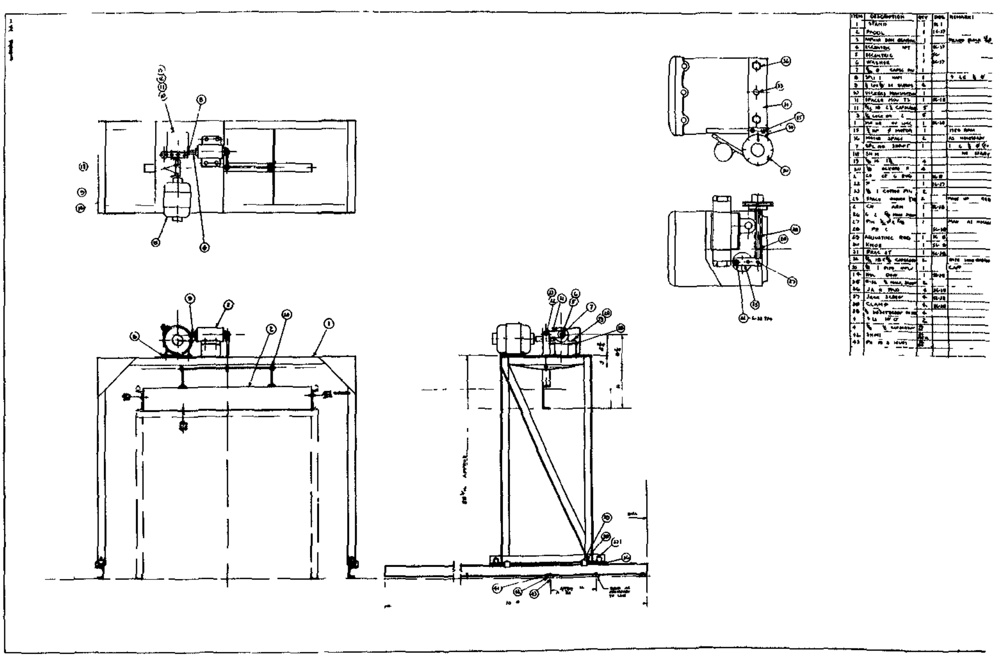


Fig. 17. Wave generator, ripple tank.

LABORATORY FACILITIES FOR STUDYING WATER GRAVITY WAVE PHENOMENA

WAVE-SEDIMENT BASIN

A small tank was designed by A. B. McIntyre for studying the effect of a littoral barrier on a sandy coast (Chien and Li, 1952). The tank is 6 ft. by 1 ft. deep. A piston-type wave generator is located at one end of the basin (Figure 15) which is driven by an A-C motor. The period of the wave generator is controlled by a Vickers speed reducer mounted between the motor and the drive crank, and the amplitude of the wave generator is controlled by an adjustable eccentric. At the opposite end of the tank a triangular-shaped sand trap was installed at the "downcoast" side of the beach which collected the littoral drift of sediment. This sediment was pumped to the "upcoast" end of the beach by a jet pump and again injected into the littoral system.

RIPPLE TANK

The ripple tank is 4 ft. by 20 ft. by 0.4 ft. deep with a 45 in. by 72 in. by 3/8 in. glass section located at the middle of the tank bottom (Figure 16). A mirror oriented at 45 degrees with respect to the vertical reflects light from a point source through the glass section, and the waves focus the light on an adjustable shadow screen. A carbon arc lamp is the source of light (Chinn, 1949). Wave energy is absorbed by means of a sloping plank covered with thick burlap. The equipment was designed by H. A. Einstein and A. J. Chinn. The wave generator has been redesigned by C. M. Snyder (Figure 17) to give a greater range of wave dimensions and more accurate control of wave direction.

The equipment was modified by Ralls and Wiegel (1956) as shown in Figure 18 to study the three-dimensional problem of the generation of short-crested waves by wind. Sections of 3/4 in. plywood, coated with a water resistant material, were placed on top of the tank to form a rectangular duct. A 44 in. by 39 in. by 3/8 in. plate of glass was placed directly above the glass section mounted in the tank bottom. The top was mounted flush with the inside of the tank to prevent generation of disturbances in the air stream, and was fabricated in sections, permitting the air intake to be placed at several positions to vary the fetch. Gaskets at the joints made the sections airtight, and the whole top was fastened to the tank with C-clamps. Modeling clay placed at the joint prevented air leakage.

Intake and exhaust units were made of 18-gauge galvanized iron, according to NACA specifications (McLellen and Bartlett, 1941). A 100 mesh strainer cloth (Dryden, 1947) was installed on top of the intake unit to help prevent irregularities in the velocity distribution. A honeycomb section was placed inside the tank just downstream from the intake unit as an air-straightening section (Prandtl, 1953) to ensure that the air entering the test section would be parellel to the walls. A suction fan was connected to the exit development piece by a piece of flexible rubber which prevented fan vibration from being transferred to the walls of the tank.

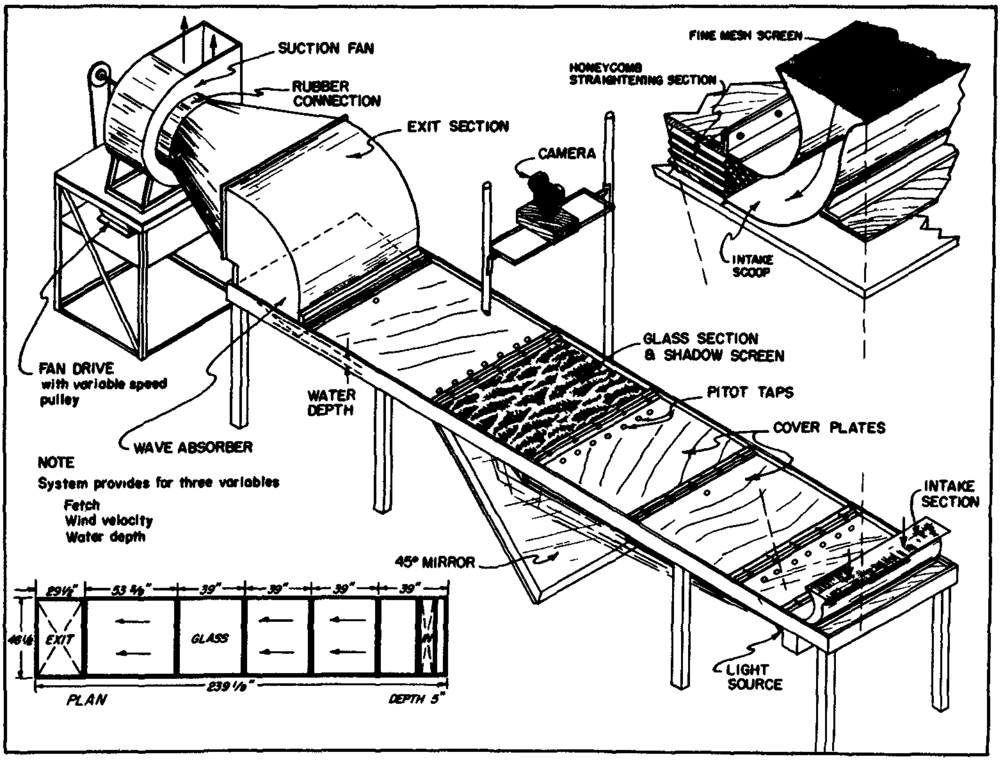


Fig. 18. Ripple tank modified to wind tunnel.

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