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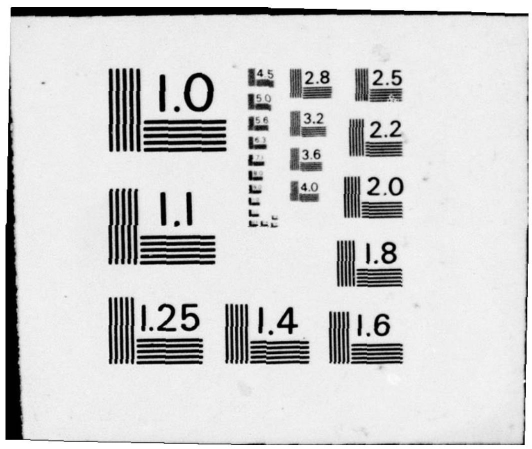

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NRL Memorandum Report 3352

A New Wave-Wind Channel for Fluid Dynamics Research at the Naval Research Laboratory

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August 1976

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A new multipurpose wave-wind channel facility has been constructed for use in the support of on-going fluid dynamics research programs at the Naval Research Laboratory. This facility has been designed to accommodate experiments ranging from the study of wind and wave effects on ocean structures to the dynamic interactions between the wind and ocean waves. The channel has been equipped initially with a mechanically-driven regular wave generator and a wind tunnel for the generation of wind waves. The laboratory facility, the wave channel and

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wave generators, and the research programs for which the laboratory has been constructed are described in this report.

CONTENTS

A NEW WAVE-WIND CHANNEL FOR FLUID DYNAMICS RESEARCH AT THE NAVAL RESEARCH LABORATORY

INTRODUCTION

During the past decade, ocean-oriented experimental fluid mechanics research has been underway in the Oceanology Area of the Naval Research Laboratory. As one example, basic studies of flow-induced structural vibrations and flow effects on structures have been underway since 1967 and form part of the applied mechanics program of the Ocean Technology Division. An overview of many of the findings from this program has recently appeared [1]. Laboratory-scale radar oceanography experiments to elucidate the energy transfer mechanisms between oceanic winds and wind-generated waves have been underway at NRL since 1966, and since 1973 these wind-wave interaction studies have formed part of the physical oceanography program of the Ocean Sciences Division. Many of the salient findings of this research program also recently have been summarized in the literature [2].

In order to provide at a relatively modest cost an experimental facility in keeping with NRL's expanding basic research programs in fluid mechanics, construction was begun during 1975 on a multipurpose wave-wind channel facility. The project is a joint venture of the Ocean Science and Ocean Technology Divisions (Codes 8300 and 8400 of NRL) and the facility has been designed to accommodate experiments ranging from the study of wind and wave effects on ocean structures to the dynamic interactions between the wind and ocean waves. The channel has been equipped initially with a regular wave generator and a centrifugal fan-powered wind tunnel for the generation of wind waves. The

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laboratory facility, the wave channel and wind generators, and the research programs for which the laboratory has been constructed are briefly described in this report. A separate report will discuss in further detail the operational characteristics and capabilities of the tank, wind generator and their associated equipment and instrumentation systems.

A GENERAL DESCRIPTION OF THE FACILITY

The wave channel facilities are housed in an enclosed laboratory constructed within a much larger NRL structure designated as Building A59. A floor area approximately 154 ft (47 m) by 56 ft (17 m) has been enclosed and includes a high-ceilinged tank room which is ventilated for summer use and heated in winter, and an adjacent laboratory equipment room which is both heated and air-conditioned for year-round environmental control. The tank room is nominally 154 ft (47 m) by 36 ft (11 m) and comprises a total of 5540 ft^2 (520 m^2) in floor area. The ceiling elevation of this high bay area varies between 33 ft (10 m) and 38 ft (11.5 m) from the floor level. The laboratory equipment room is 110 ft (33.5 m) by 18 ft (5.5 m), for an enclosed area of 1980 ft^2 (184 m^2) with a ceiling height of 8 ft (2.4 m). The latter area provides a temperature-controlled environment for small-scale laboratory experiments, equipment calibration and the location of sensitive measurement and data acquisition systems for use with the adjacent wave channel.

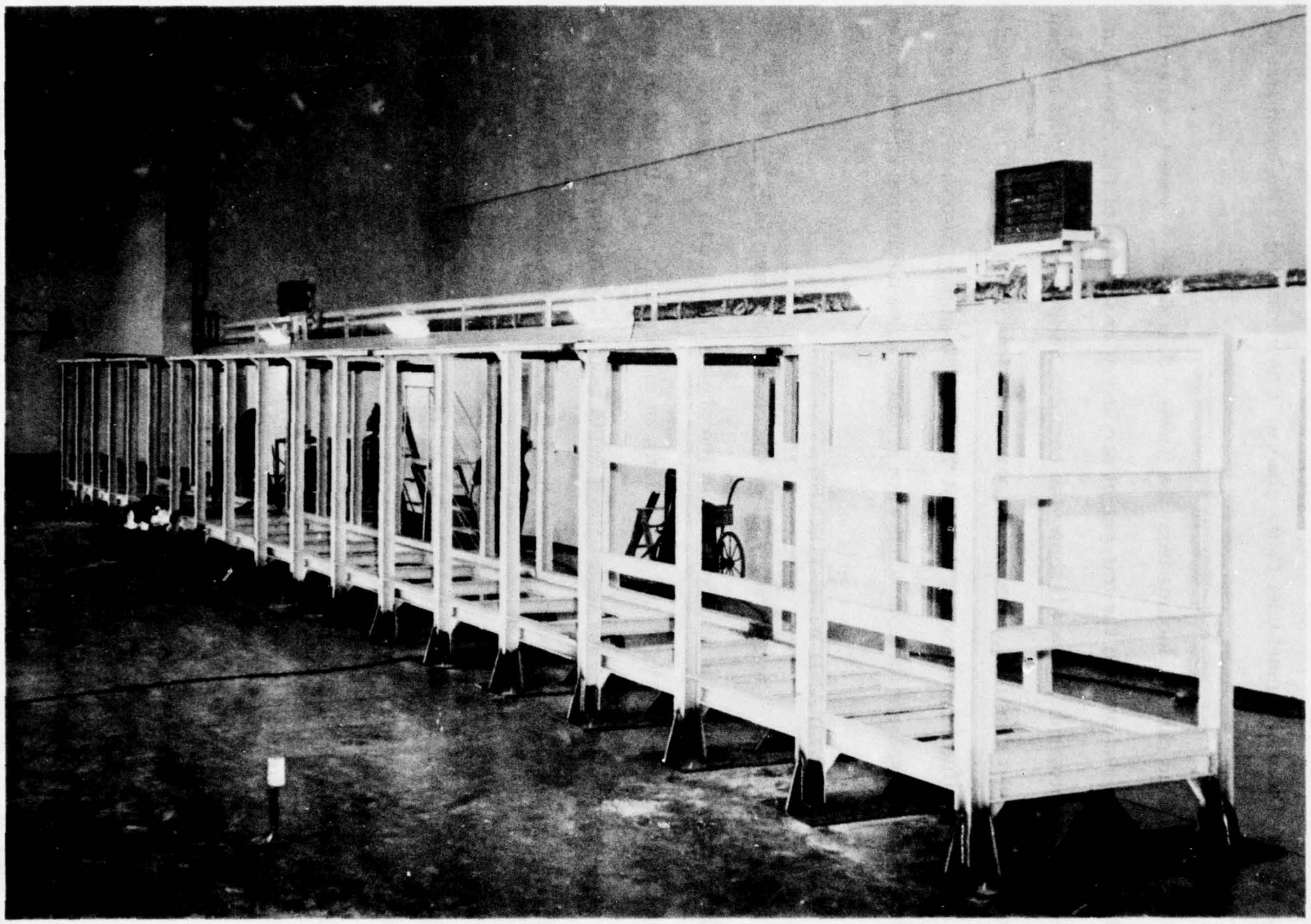
The facility presently houses a 100 ft (30.5 m) multipurpose research channel with its associated wind generator system. There is also adequate floor space available for the installation of additional facilities in the future. Figure 1 shows several photographs taken during various stages of the construction of the channel. The view (a) shows the 12 ft (3.7 m) long welded-steel frame subsections of the channel being welded to the steel floor plates. View (b) shows the wavemaker framework being assembled. A bulkhead regular-wave generator is mounted on this structure which can be moved along the floor rails and fastened in position with heavy-duty brakes. Both the drive and the control mechanisms for the wave generator are now mounted over the tank on the structure which is shown in the figure. The wind tunnel inlet to the channel is now installed in the open area at the end of the tank.

The completed channel, looking from the beach end, is shown in view (c) where the stainless steel end sections and the transparent acrylic center sections of the channel are visible in the photograph. View (d) shows the completed wind-tunnel inlet duct and fan assembly. The inlet duct is mounted on the wavemaker end of the tank and is connected to the large centrifugal fan shown at the right in the photograph. Also shown on the left side in the photograph are the completed wave generator drive mechanism and controller.

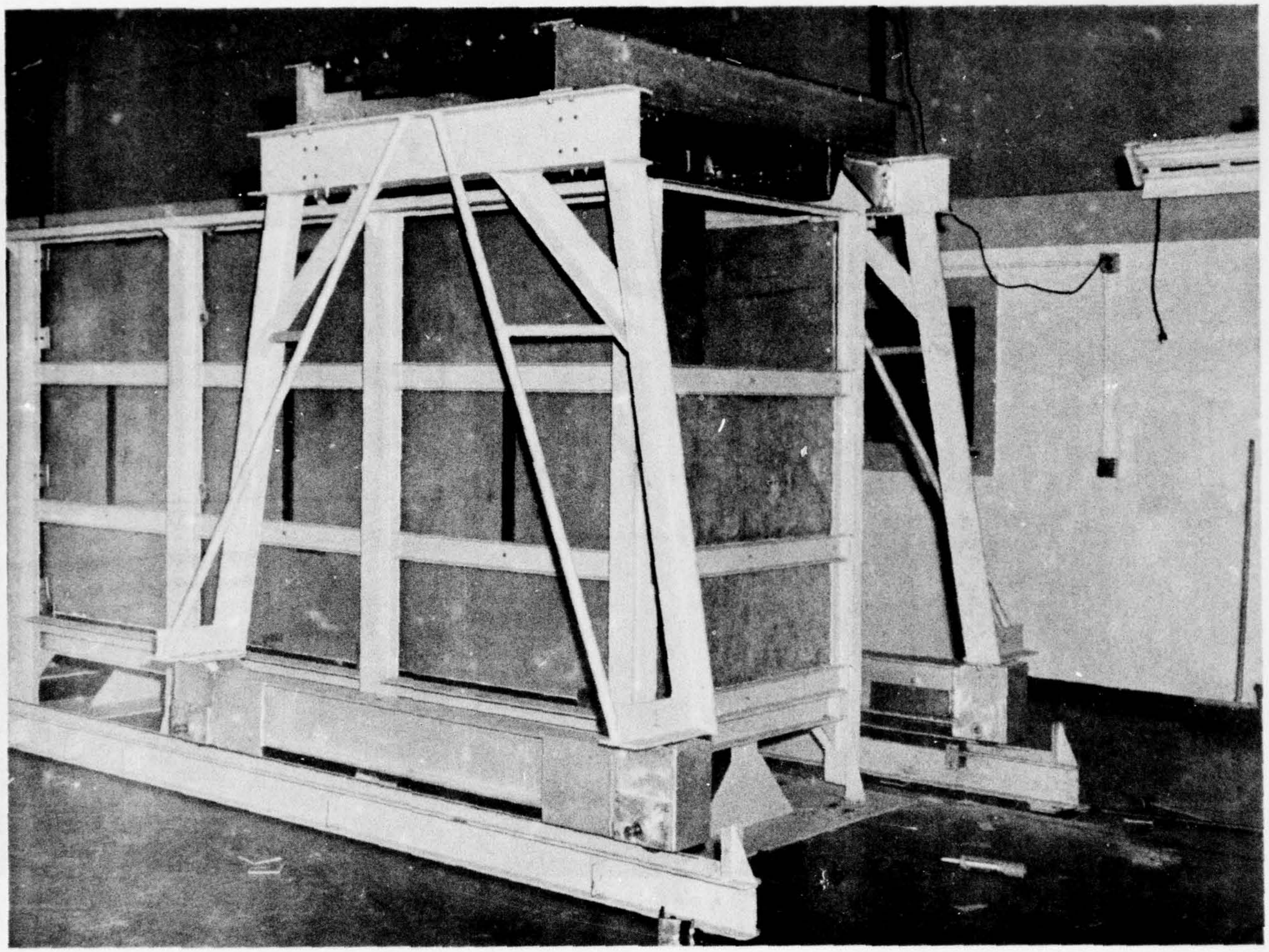
THE WAVE CHANNEL AND WIND TUNNEL SYSTEMS

The wave channel. The general layout of the channel is drawn in Figure 2 and some details of its construction can also be noted in the photographs shown in Figure 1. The channel has an interior length of 100 ft (30.5 m), an interior width of 4 ft (1.2 m) and a total depth of 6 ft (1.8 m). The design water depth is 5 ft (1.5 m) but the typical operating condition consists of a water depth of 3.5-4 ft (1.0-1.2 m) or less and a wind channel of 2-2.5 ft (0.6-0.8 m) or greater measured from the still water level. The beach end of the tank is equipped with three vertical baffles which serve to maintain constant water depths of 1.5, 3 and 3.5 ft (0.5, 0.9 and 1.1 m). Provision has been made at the beach end of the tank for the future installation of a second fan system for the generation of wind waves in a direction opposite to the regular wave motion.

The framework of the channel is constructed of welded steel I-beams and angle sections with the channel bottom raised 18 in. (0.5 m) above the concrete floor to provide access to the underside of the tank for photographic, lighting and instrumentation purposes. The vertical frame members of the channel are spaced 4 ft (1.2 m) on center and provide high rigidity at the design water depth, i.e., a deflection of 1.3 (10^{-4}) in $(3.3(10^{-3})$ mm) at the still water level of 5 ft (1.5 m). The horizontal frame members

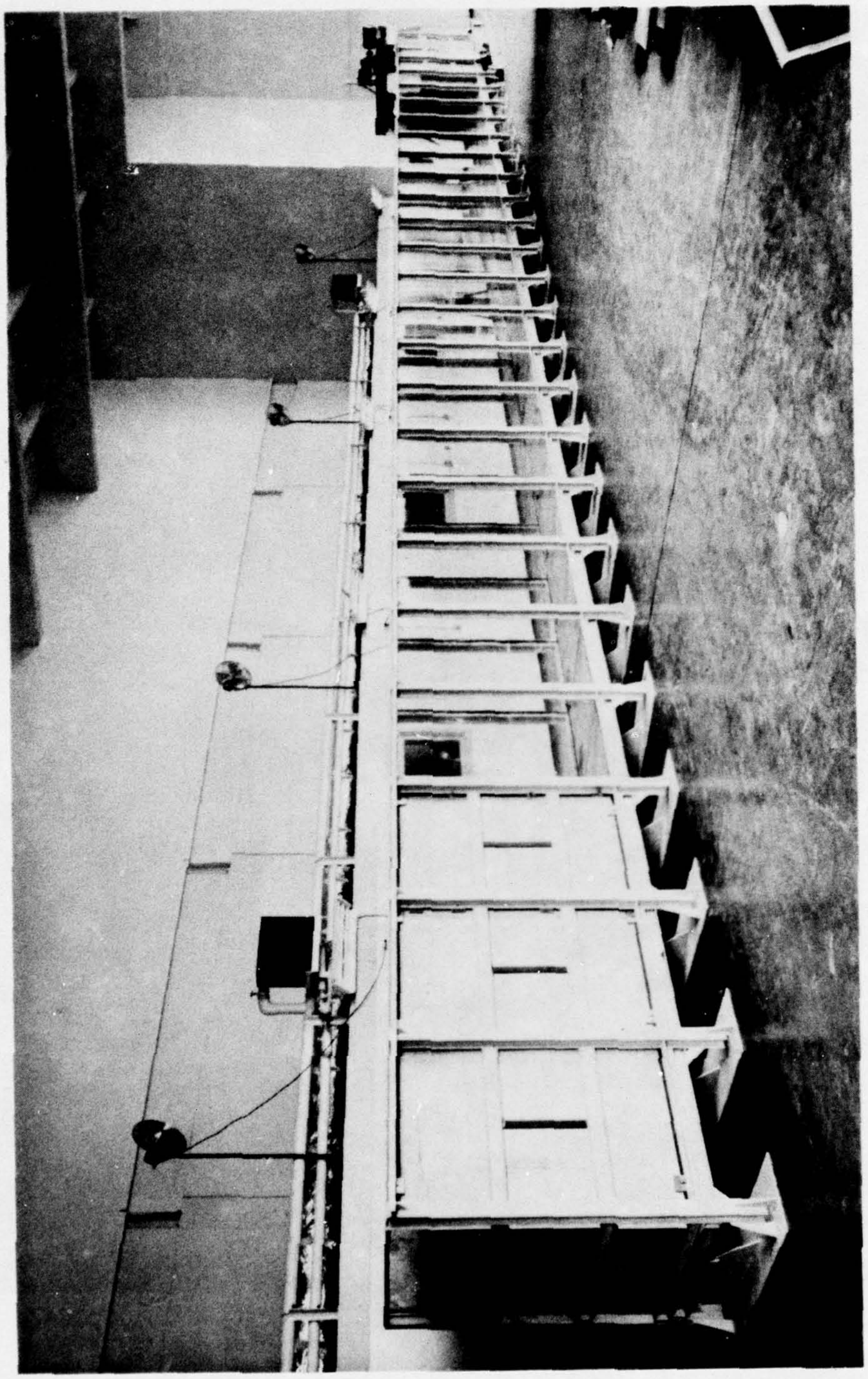


(a) Welding of the steel frame sections for the channel

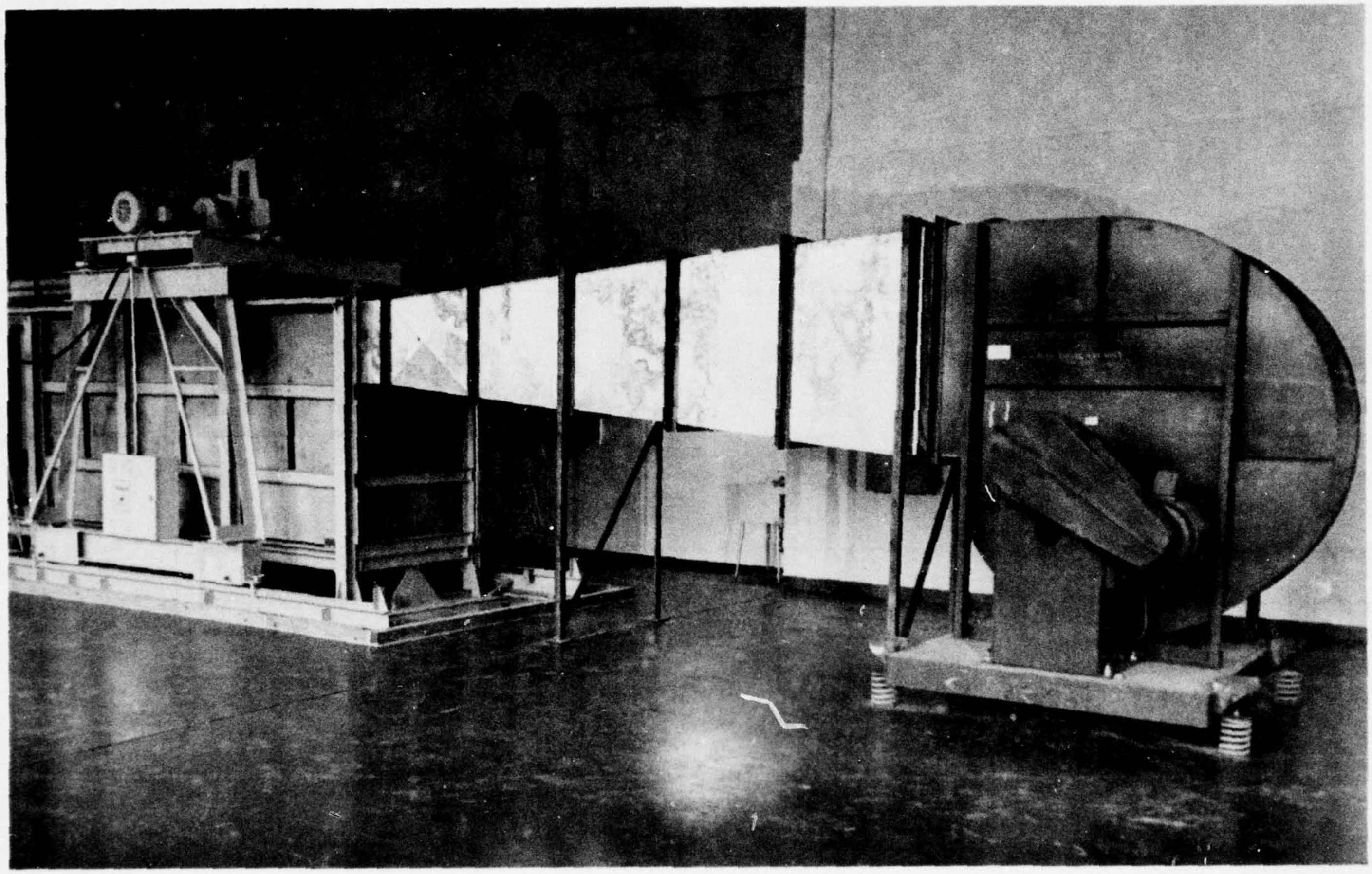


(b) Assembly of the wave generator

Fig. 1—Selected stages of the wave channel construction



(c) The completed channel



(d) A close-up view of the wind tunnel and fan assembly

Fig. 1—Selected stages of the wave channel construction (Continued)

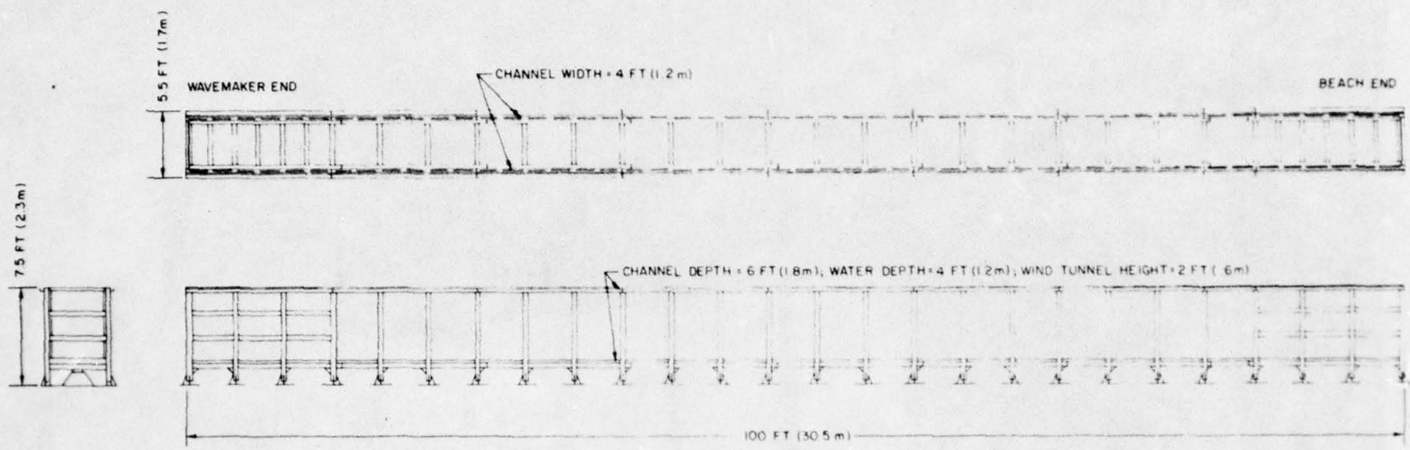


Fig. 2—A line drawing of the wave channel

which run along the top of the channel contain fixtures for mounting the wind tunnel roof in several configurations. Two horizontal tracks for the movement and location of equipment carriages are welded to the vertical framing along the entire length of the tank.

The walls and floor of the beach and the wavemaker ends of the channel are constructed of 0.25 in. (6.2 mm) thick stainless steel plates, 12 ft (3.7 m) long, which are backed with stiffeners, bolted in place and caulked with epoxy and fiberglass tape. The interior channel walls are constructed of 1.0 in. (25 mm) transparent acrylic sheets nominally 4 ft (1.2 m) by 6 ft (1.8 m) in size and the channel floor is constructed of the same material nominally 4 ft (1.2 m) by 4 ft (1.2 m) in size. Both floor and walls rest on a thin rubber pad which is held to the steel framing by an adhesive backing. The acrylic plates were machined to size in order to yield an equal spacing of 0.38 in. (9.6 mm) after installation. Joints between the bottom and side plates of the tank consist of a layer of polysulfide-based industrial caulking over a layer of flexible neoprene foam rubber. A bead of RTV sealant beneath the bottom plates and side panels near the edge of the steel framing provides additional sealing. The walls and floor of the tank are nominally level and straight within ±0.1 in. (2.5 mm).

The wave generator. The channel facility has been equipped initially with a carriage-mounted, mechanically-driven bulkhead for the generation of regular waves. A photograph of the completed system is shown in Figure 3. The bulkhead is suspended on a precision ball bushing and shaft system and is driven by a solid state control-motor-variable speed drive system which drives the bulkhead through a scotch-yoke mechanism mounted on the carriage and suspension. The clearance between the wavemaker and the tank walls is nominally 0.12 in. (3.2 mm) and spring-loaded *teflon* wipers provide low-friction contact between the walls and the bulkhead. The drive units for the generator mechanism are mounted above the tank and the bulkhead is attached to vertical struts for compatibility with the wind tunnel inlet to the channel. The wave generator carriage, which can be

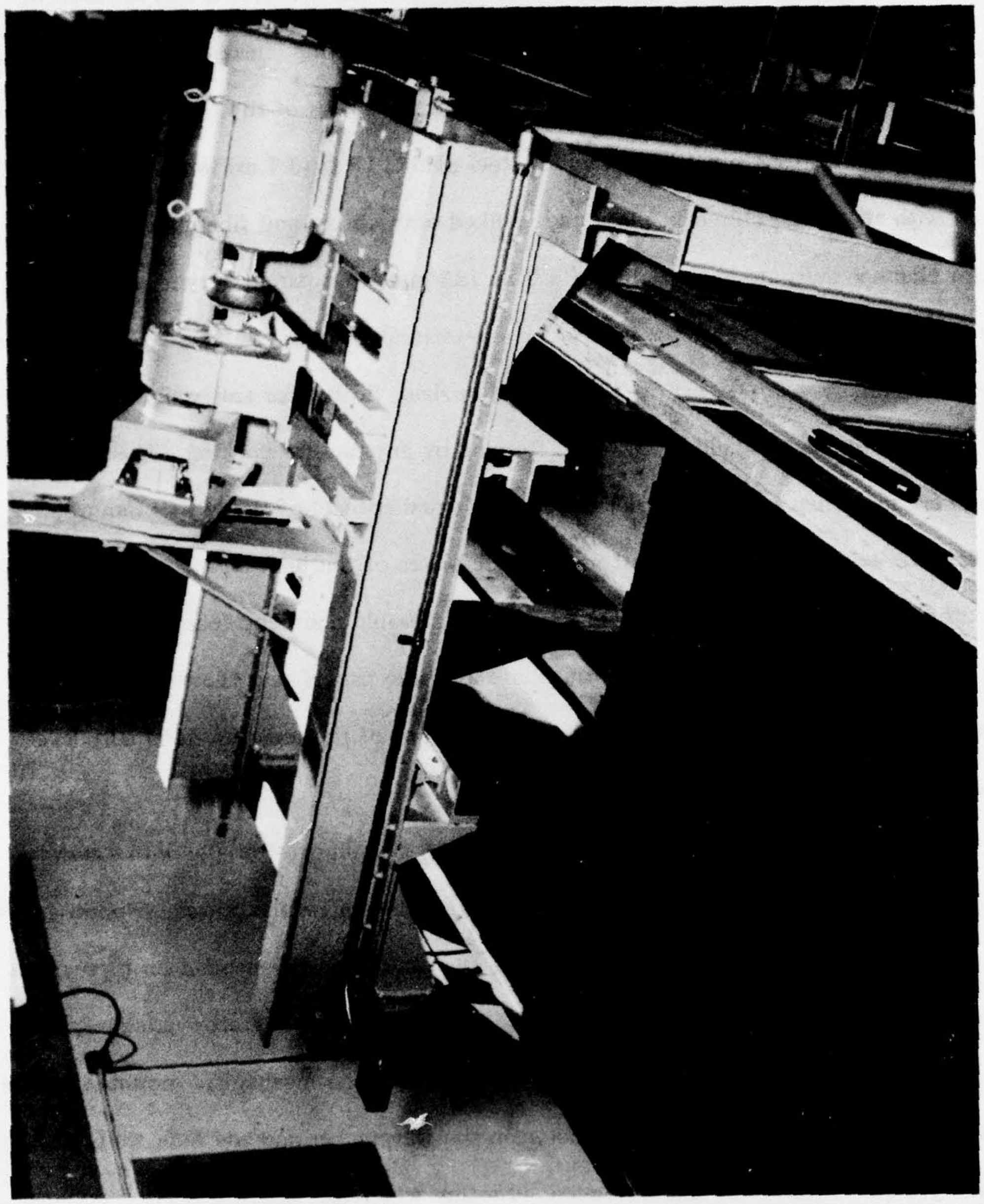


Fig. 3—A close-up photograph of the completed wave generator

moved along the floor rails by means of a rack and gear system, allows the equilibrium position of the wave generator assembly to be located at various displacements from the end of the channel and provides access for the installation and removal of the wind tunnel sections. A perforated wall breakwater type of wave absorber to dissipate the fluid motion behind the bulkhead is mounted on the rear wall of the tank beneath the wind tunnel inlet.

The stroke of the wave generator can be continuously varied by means of a precision worm gear actuator which is mounted on the scotch-yoke mechanism and which can be remotely controlled and monitored from the floor level. Likewise, the period of the wave generator can be continuously controlled and monitored from the floor level. The maximum stroke of the unit from equilibrium is 9.5 in (240 mm) and it is designed to operate at frequencies up to 4 Hz. At a still water level of 3.5 ft, deep water waves are generated at frequencies in the range $0.8 \leqslant f \leqslant 4.0$ Hz and intermediate waves in the range $0.1 < f < 0.8$ Hz.

The wind tunnel system. The wave-wind channel facility is equipped with a generator for the production of wind waves both singly and in combination with the regular waves. A line drawing of the inlet duct-fan system is given in Figure 4 and the location of the system relative to the channel is shown by the photograph in Figure 1(d). The wind tunnel is powered by a 25 hp (18.6 kw) constant-speed centrifugal fan with a variable inlet shutter, and the fan is mounted on the concrete floor by means of a spring-supported, concrete and steel inertial base. The fan outlet is connected through a flexible section to a 1.4:1 contraction duct, 14 ft. (4.3 m) in length, which in turn exits into the channel proper as shown in Figures 1(d) and 4.

The wind channel roof is composed of 3/4" (18 mm) thick plywood sections each 4 ft (1.3 m) long. The roof sections can either be clamped to the upper horizontal frame members of the tank or suspended within the tank on removable frames.

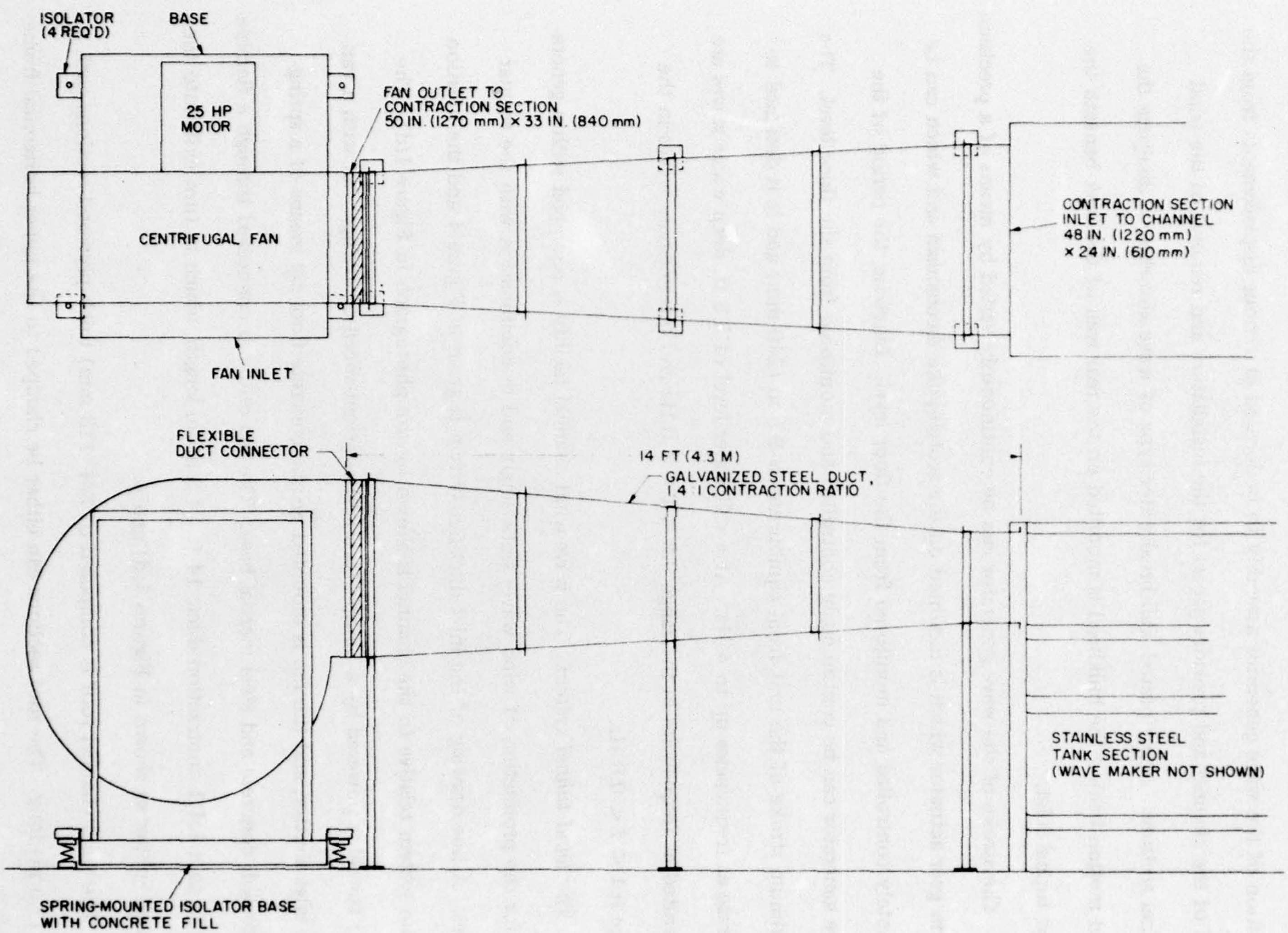


Fig. 4—A line drawing of the wind tunnel inlet duct and fan system

The wave absorber. The sloping beach wave absorber is shown in Figure 5. A beach made of 1/2 in. (12.7 mm) acrylic sheets is supported by a framework of slotted steel angles which are coated with an epoxy-based marine paint. An array of equally-spaced 3 in. (76 mm) holes have been cut in part of the beach surface. This provides a porosity of 30 percent over the upper half of the beach length in order to assist in the attenuation of the incident wave energy. A blanket of fibrous material is planned for installation over the acrylic sheets in order to provide optimum wave attenuation.

The beach is 24 ft (7.3 m) in overall length and 4 ft (1.2 m) in height at the downstream tank wall, and is comprised of two sections of different slopes. One section is 6 ft (1.8 m) in length and has a slope of 15 degrees, while the remainder of the beach is 18 ft (5.5 m) in length and has a slope of 7 degrees. When in place in the channel, the beach framework fits over the constant-depth baffles and rests on rubber mountings. Vertical frame members provide a means for fastening the beach structure to the steel channel framing.

INSTRUMENTATION AND DATA ACQUISITION SYSTEMS

Wind-generated wave systems are investigated at NRL using coherent microwave scattering and photometric techniques as well as more conventional wave probes. Measurements of Doppler spectra using focused parabolic antennas [3] at microwavelengths of 0.4, 1.25, 3.2, 7 and 16 cm allow the detailed study of wind-generated waves 2 mm to 40 cm in wavelength by exploiting the Bragg scattering principle. Modulation of the wind wave system by regular mechanically-generated waves will provide the means for studying wind wave equilibria. Real-time spectral analysis and correlation with dynamic ranges up to 56 dB are available as well as a digital acquisition capability with a sampling rate of 12,500 per second at 12 bits. Diffraction analysis of water wave photographs is used to measure directional slope spectra for wavelengths between 1 mm and 10 cm.

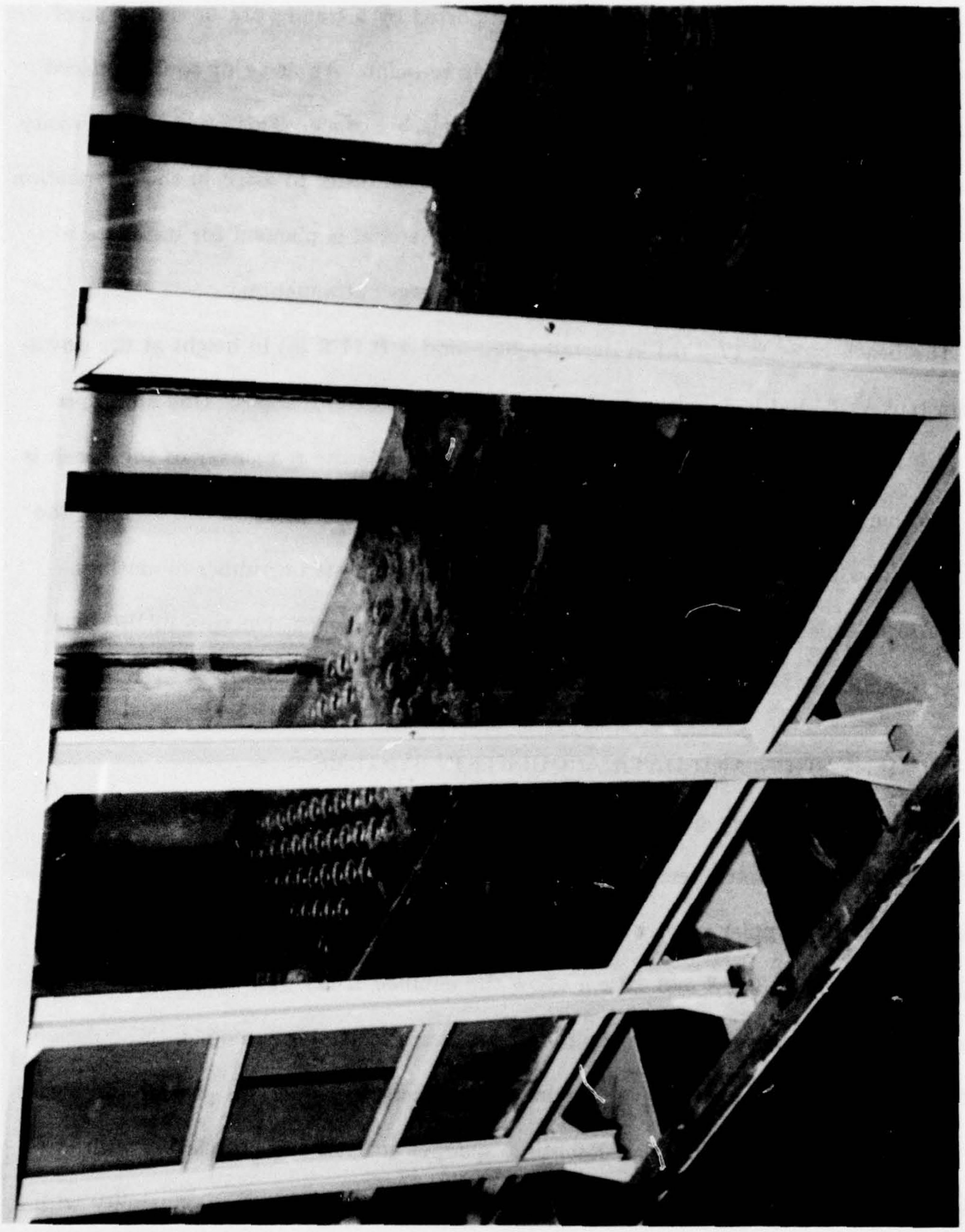


Fig. 5—The beach assembly installed in the channel

A wide range of more or less conventional instrumentation and data acquisition systems is also available for flow and fluid-structure interaction measurements. Six channels of linearized hot-wire and hot-film anemometry sensors and the associated signal conditioning equipment are available for measurements both in air and in water, and these flow measuring devices are supplemented by additional correlation and spectral measuring, recording and direct plotting equipment. Three channels of bi-axial and single axis electro-optical displacement sensors and their associated signal conditioning equipment are available for monitoring the steady and unsteady motions of floating and submerged models. Details concerning the operation of the available flow and displacement measuring systems are described elsewhere [4].

Several channels of voltage-gradient and capacitance wave height sensors together with the appropriate signal conditioning and recording systems have been calibrated for use in connection with on-going experiments at the facility. A small tank, 20 ft (6 m) in length, is also equipped with a regular wave generator and is available for the calibration of the conventional wave probes.

RESEARCH PROGRAMS AT THE FACILITY

Current radar oceanography research in the Ocean Sciences Division is aimed at characterizing short gravity wave equilibria, and the transfer of momentum and energy from the atmosphere to ocean waves [5, 6]. The perturbation of wind-generated short gravity and capillary waves by larger scale fluid motions is also studied. Because microwave scattering is the principal experimental tool, the channel is also available for radar scattering studies. Calibration of microwave, photometric and other types of wave probes used in allied measurements on the ocean will also be carried out.

The Ocean Technology Division for several years has had an on-going program to study flow effects on structures. The aim of this program is to study the generation of oscillatory flows, the mechanisms of vortex formation and fluid-elastic interactions between fluid motions and bluff structures [7, 8]. These basic programs have already led to the development of engineering models for predicting the vortex-induced vibratory response of cables and other bluff body shapes. The completion of this new channel presents an opportunity to study from a basic perspective the mechanisms by which winds and waves interact with floating and submerged structures and structural members, and to develop advanced methods for predicting the forces which act as a result of these interactions.

ADDITIONAL COMMENTS

The construction of the laboratory facility was begun in April 1975 and completed in October of that year. Assembly of the wind tunnel, channel and wave generator was begun in November 1975 and was completed during April and May 1976. Upon completion of the preliminary testing, the channel was filled and placed into operation. The generation of regular waves during the operation of the facility in early June 1976 is shown in Figure 6.

A program of detailed calibration and characterization experiments is planned for the summer and fall of 1976, and the results of these experiments will be presented in a later report.

ACKNOWLEDGMENTS

The authors wish to acknowledge the funding support of the NRL Directorate for the construction of the channel and laboratory facilities. Detail design and installation of the channel and wave generator were executed respectively by the Mechanical Engineering and Drafting Branch and the Industrial Services Branch of the Engineering Services Division. The laboratory facility and wind tunnel were designed and installed by the Public Works Division of NRL.

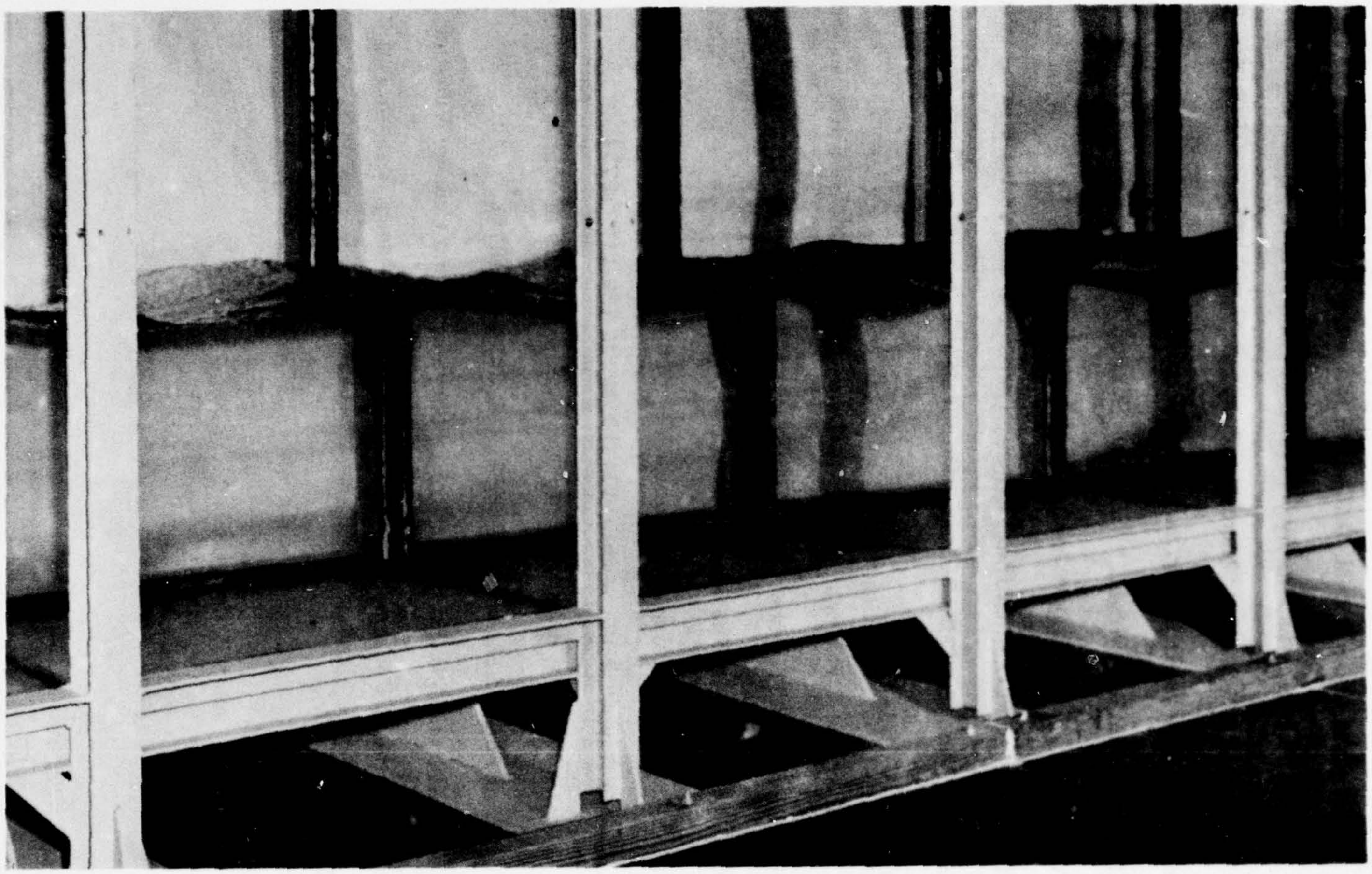


Fig. 6—Combined wind and regular generation in the channel during the initial stages of its operation

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