UNIVERSITY OF MINNESOTA
ST. ANTHONY FALLS HYDRAULIC LABORATORY
LORENZ G. STRAUB, Director

Technical Paper No. 17, Series B

The St. Anthony Falls Multi-Purpose Test Channel

Preprint of Paper to be Presented at the
American Towing Tank Conference, David Taylor Model Basin,
Washington, D.C., September 12 to 14, 1956

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LORENZ G. STRAUB and C. E. BOWERS

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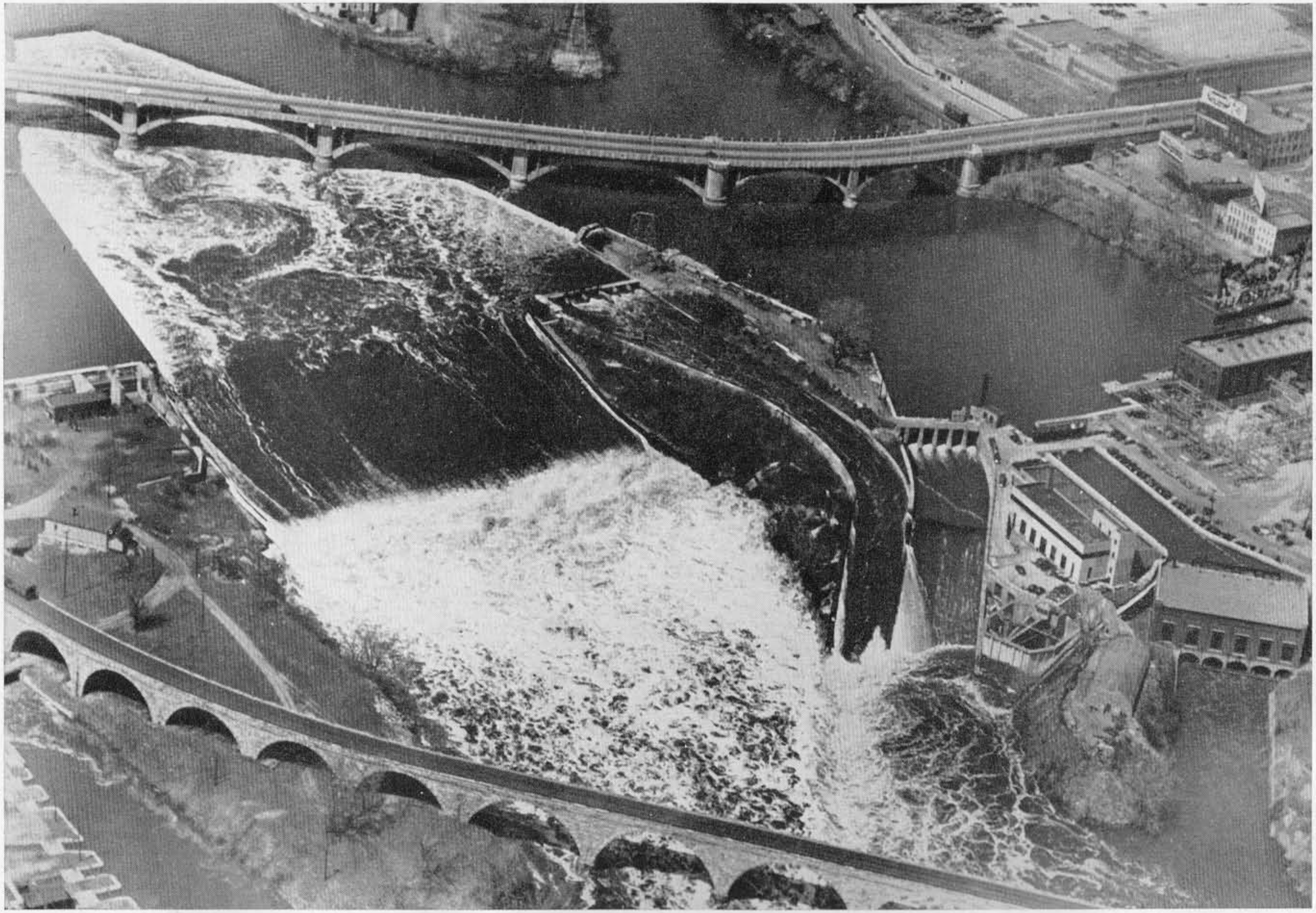

The St. Anthony Falls Hydraulic Laboratory Environment on the Mississippi River.

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ABSTRACT

In its original concept the design of the St. Anthony Falls Hydraulic Laboratory provided for a Multi-Purpose Test Channel which would be a main feature of the gravity flow research facility on the Mississippi River at the Falls. This channel has been used for many test programs and has been progressively developed for a wider range of applications since the completion of the Laboratory structure in 1938. It is now approaching its ultimate development by the installation of towing facilities which are soon to be completed.

The channel is about 300 ft long, 9 ft wide, and 6 ft deep. It is designed for use alternatively as a gravity flow-through channel under varied and closely controlled flow conditions, a wave basin, and a towing tank. Eventually, the facility will be adapted for use in any one of its separate functions or alternatively for any combination of the three operational functions simultaneously. This paper describes the general character of the facility and some of its uses.

CONTENTS

LIST OF ILLUSTRATIONS

THE ST. ANTHONY FALLS
MULTI-PURPOSE TEST CHANNEL

INTRODUCTION

The St. Anthony Falls Hydraulic Laboratory of the University of Minnesota is located at the historic "Falls of St. Anthony" on the Mississippi River about one mile upstream from the main campus of the University. It was designed to utilize the natural 50-ft drop at the Falls to permit diversion of water from the Mississippi River through the Laboratory and back to the River below the Falls. An overflow weir of horseshoe shape in plan (Frontispiece), nearly half-mile long built on the rock ledge forming the Falls, assures little fluctuation in headwater pool level in the gravity flow system. The main facilities of the Laboratory are designed to accommodate flows from the River in excess of 135,000 gal per min, a rate of flow which can be precisely measured continuously by interception in large twin volumetric basins at the discharge end of the Laboratory structure. Several independent circulating systems supplement the river diversion system for some types of flow studies, and other facilities are available for investigations requiring fluids other than water.

A main feature of the Laboratory is a test channel with an over-all length of about 300 ft, a width of 9 ft, and a depth of 6 ft. Although initially designed and built as a flow-through test facility with arrangement for precise measurement of flow rates by twin volumetric basins, provisions had been made in the channel for its subsequent adaptation to other requirements. Since the completion of the Laboratory structure in 1938, the channel has been used for diverse flow-through tests of spillways for dams, full-scale culverts, river bank revetments, sediment samplers, and current meter equipment, and other test purposes such as hydrofoil research. An electrically adjustable weir gate at the discharge end of the channel permits flow-through depth to be adjusted readily, and facilitates use of the channel alternatively as a towing and wave basin.

In 1954 a wave generator was installed in the channel and has been utilized for several large-scale wave studies. It is so designed that it can readily be moved to various locations along the length of the channel, and the hinged plate wave generator can be completely removed to permit the test facility to serve as a flow-through channel. There is now also being installed a towing system, thus additionally permitting the facility to be used as a towing tank. The eventual development calls for an adaptation which will permit any one of the three functions of the facility to be used separately or in combination with the other functions; that is, it will serve as a flow-through channel, a wave basin, a towing tank, or simultaneously any combination of the three.

FLOW-THROUGH SYSTEM

Figure 2 is a sketch showing the main features of the experimental channel when used for flow-through studies.

Water enters the channel by diversion from the Mississippi River through a self-cleaning mechanical screen, down a drop shaft 20 ft deep and then through a pressure tunnel and several control devices to the experimental channel. After passing through the channel, the water enters an enclosed flume leading to twin volumetric tanks, each with a capacity of 35,000 cu ft; these tanks may be used for precise measurement of the total discharge passing through the channel.

The discharge can be controlled by a head-gate at the upper pool level or a flow-control baffle in the pressurized tunnel. The depth of flow can be controlled by either the sluice gate at the inlet end of the channel or a tail gate at the exit end, dependent on whether subcritical or supercritical flow is desired.

The electrically-operated gates and the hydraulic flow-control baffle are operated from a remote control station which can be positioned at any location along one edge of the channel. The gate positions and the water depth at several points are indicated on the control panel by a system involving selsyn transmitters. As a result, the operator can control the flow conditions from a vantage point near the area of major interest.

The maximum discharge which can be passed through the channel is in excess of 300 cfs or about 135,000 gal per min. The velocity of flow is dependent on the discharge and depth of flow, with the combination of a low depth and a high discharge producing velocities up to about 25 fps.

A good velocity distribution can be achieved near the entrance by use of the flow-control baffle, honeycomb, and contraction in the pressurized tunnel. The baffle is adjustable and can absorb up to 600 hp from the flowing water, which tends to equalize the velocity distribution and stabilize the discharge.

The nature of the over-all system is such that it is applicable to a fairly wide variety of tests, and it has proven to be very useful in the general research program of the Laboratory.

WAVE SYSTEM

The experimental channel is used for wave studies by closing gates at both ends of the channel, installing a hinged plate and absorbers, and filling the basin with water from the city supply or the river.

The wave generator consists of the aforementioned hinged plate, plus a drive system, involving a D-C motor, truck transmission, chainbelt reduction, a crank arm, and a connecting rod. The D-C motor receives power from a motor-generator set and is controlled by a Ward-Leonard system.

The plate is hinged on the bottom of the channel and can be oscillated with a maximum stroke of 3 ft at the upper edge of the plate. The system has been designed to permit replacement of the hinged plate with a pendulum-type unit if the need develops. For the same stroke, the pendulum type would have a maximum displacement almost twice that of the hinged plate; consequently, larger waves could be generated.

The length and period of the waves can be varied by changing the speed of the D-C motor and the reduction ratio in the transmission, and wave height controlled by variations in the crank radius or stroke.

The minimum wave length which can be achieved is 2 ft. For practical purposes the maximum wave length is on the order of 40 ft, although longer waves of low steepness can be obtained if desired. The water depth can be varied around the nominal value of 4.5 ft.

The maximum wave steepness obtainable near the wave generator is 1 to 10 for wave lengths up to 18 ft long; beyond this value, the maximum steepness decreases with increasing length due to the limitation on the displacement of the hinged plate. With regard to limiting values of wave steepness, it has been found that steep waves less than 10 ft long sometimes become unstable before they travel the complete length of the basin. This instability may consist of variations in wave height of only a few per cent or complete breaking of the wave. By decreasing the wave steepness, the desired stability can be obtained. Thus, for tests involving precise measurement of wave height at a distance of about 150 ft from the generator, the maximum steepness may range from 1 to 25 for a wave length of 3 ft to about 1 to 12 for wave lengths in excess of 10 ft and less than 18 ft.

The cause of this instability is not known, but it has been encountered in most long-wave channels, regardless of the type of wave generator employed.

A wave absorber consisting of a 6-in. layer of permeable material over an impermeable surface is located at the end of the channel opposite the wave generator. The slope of the absorber is 12 degrees. The permeable material consists of a system of rectangular wooden bars spaced to produce a porosity of about 70 per cent.

Wire-mesh filters are available for use when reflections from a test model are detrimental to the conduct of the tests.

The over-all performance of the system is considered quite satisfactory in that stable, uniform waves can be achieved within the limits mentioned above. The hinged-plate generator closely approximates the horizontal component of the orbital velocity for L/d values in the vicinity of 2.0 and should perform best in this region. However, no serious deficiencies in wave shape have been noted over the test range of $0.5 < L/d < 6$ which has been utilized most frequently thus far. On the basis of available theory, it would be expected that the inertia forces developed with the higher L/d values would be quite large, but the drive system is apparently of a size sufficient to overcome such forces with no adverse effects.

Several other wave channels of smaller size are also available, permitting flexibility in the conduct of wave studies. For example, in some instances a large portion of the experimental work on a research project has been conducted in one of the smaller channels and the large channel used to check the over-all results and investigate scale effect. This procedure resulted in significant savings and produced data on scale effect which were not obtainable with a single channel. For some studies it would be desirable to utilize the largest channel available, but in many others, a combination of large- and small-scale tests can be quite helpful in speeding up the test program; the large-scale tests being used as spot-checks on the more comprehensive small-scale series.

TOWING SYSTEM

When used as a towing basin, the experimental channel will have an effective length of 253 ft. This distance will be shortened by about 30 ft if the wave equipment is used in conjunction with towing tests.

Following a review of the various types of towing systems which could be installed in the basic channel, it was concluded that the most versatile type for general-purpose tests would be a self-propelled carriage capable of carrying a light dynamometer and other equipment, plus one observer. In the original construction, inserts had been cast into the concrete walls for subsequent installation of rails, which was a strong factor in favor of this type of system.

On the basis of these considerations the following design criteria were adopted:

(a) Carriage weight, including observer and some equipment: 1100 lbs.

(b) Maximum speed: 25 fps.

(c) Acceleration: 0.16 g.

(d) Normal deceleration: adjustable up to 0.4 g.

(e) Settling-out period for motor: less than 2.5 sec.

(f) Minimum test period: 3 sec (at top speed).

(g) Motor-speed control: ± 1/2 per cent of full load speed for all load conditions; preset to within ± 2 per cent of desired speed of carriage.

One of the primary problems was the design of an inexpensive rail system which could be installed with reasonably accurate alignment. The design finally adopted consisted of (a) a 10-in. channel at 33 lbs per ft with the 4-in. legs upward, anchored every 4 ft to the concrete wall by means of the slotted inserts which were originally cast into the wall, and (b) a rail 1-1/2 in. by 2 in. of cold-rolled stainless steel, supported every 18 in. by cross ties which were attached by both vertical and horizontal adjusting screws to the 10-in. in 5 ft. It was thought that the dimensional tolerance was quite acceptable, and that the curvature of this magnitude could be eliminated to a large extent in the alignment process. Upon receipt of the bar stock, it was found that the cross-sectional dimensions were within a tolerance of ± 0.002 in. and the curvature was very minor except for occasional sections which were slightly curved near the end. An accurate check of the first 100 ft of rail installed indicated a variation in elevation of about ± 0.01 in. over the complete length and variations from a straight line over any 5-ft length of about ± 0.005 inch.

As the experimental channel is used for a variety of purposes, there was concern over possible damage to the rails and for this reason they were set below the level of the legs of the 33-lb cap channels, as shown in Fig. 10. This necessarily restricts the size of the guide wheels and may be somewhat of a problem.

From past experience in the Laboratory, it is felt that the higher initial cost of stainless steel as rail material will be more than offset by lower maintenance costs.

The towing carriage has been patterned in some respects after some of the carriages at the David Taylor Model Basin. It consists of a tubular steel framework 12 ft long, 10 ft wide, and 30 in. high, designed around a dynamometer bay 6 ft long and 2 ft wide. The drive wheels, guide wheels, and brakes are located along one side of the carriage, all operating on the same rail; two supporting wheels are located on the opposing side. The unit will be self-propelled by two 5-hp D-C motors which receive power from overhead trolley wires.

Square tubing was selected for the frame because it greatly simplified the cutting and welding of the ends of the individual members.

The drive system consists of the two 5-hp D-C motors, a Thy-mo-trol control panel to rectify the A-C power and control the motors, a tachometer generator for supplying a speed signal to the regulator system, and auxiliary equipment, all supplied by the General Electric Company. The maximum speed of the motors is 3,450 rpm. The system is designed so that the speed can be preset, after which the starting button can be pressed and the motors will accelerate to the desired speed automatically. As noted earlier, the speed regulation is specified as 0.5 per cent of full-load speed for 100 per cent change in load torque.

Relatively high speed motors were selected in an effort to save weight, but necessitating a 3.5- to 1-belt reduction between the motors and drive wheels.

The Thy-mo-trol system is equipped with an adjustable current limit which may be used to limit the applied torque at the wheels. This feature was considered desirable because of uncertainties concerning the allowable friction coefficient of the wheels. A high friction coefficient is desirable to reduce the accelerating distance and a wheel design was developed which incorporated Neoprene "O"-rings as partial tires. The design produced a static friction coefficient of about 0.35 and appears to have sufficient merit to warrant final tests on the carriage. If the design is acceptable, a high torque can be utilized; if not, it may be necessary to reduce the allowable torque, at least temporarily. With a manual control system the operator would make the necessary adjustment to prevent slipping of the wheels; however, with the semi-automatic system of the type selected, it is necessary that some adjustment be provided in the control system.

The braking system consists of two spring-loaded friction brakes, one for normal operation and the second for emergency use, plus an arresting gear.

Eight trolley wires have been provided, 4 for D-C power, 2 for A-C power, and 2 as a feed-back from the tachometer generator to the control system. The two for the feed-back or speed signal are separated from the other 6 by the width of the channel, to reduce possible interference effects. The trolley wires are of the figure-eight type.

At the present time the rails have all been installed and the aligning is about 50 per cent complete. The trolley wires and the Thy-mo-trol control system have been installed and are ready for use. The carriage frame and most components such as brakes, wheels, drive elements, and related items are available but have not as yet been assembled as a unit.

It is anticipated that the towing system will be completed in the near future at which time over-all performance data will be obtained. If it performs according to expectations, the range of test conditions which can be achieved in the basic experimental channel should be materially increased.

ACKNOWLEDGMENT

The authors acknowldege significant contributions to the design of features of this equipment by various members of the Laboratory staff, including particularly John F. Ripken, Frank Dressel, Ernst Elguther, John B. Herbich, John Killen, James A. Ross, and J. M. Wetzel. Editing and reproduction of this report were performed under the direction of Loyal A. Johnson.

FIGURES 1 to 11

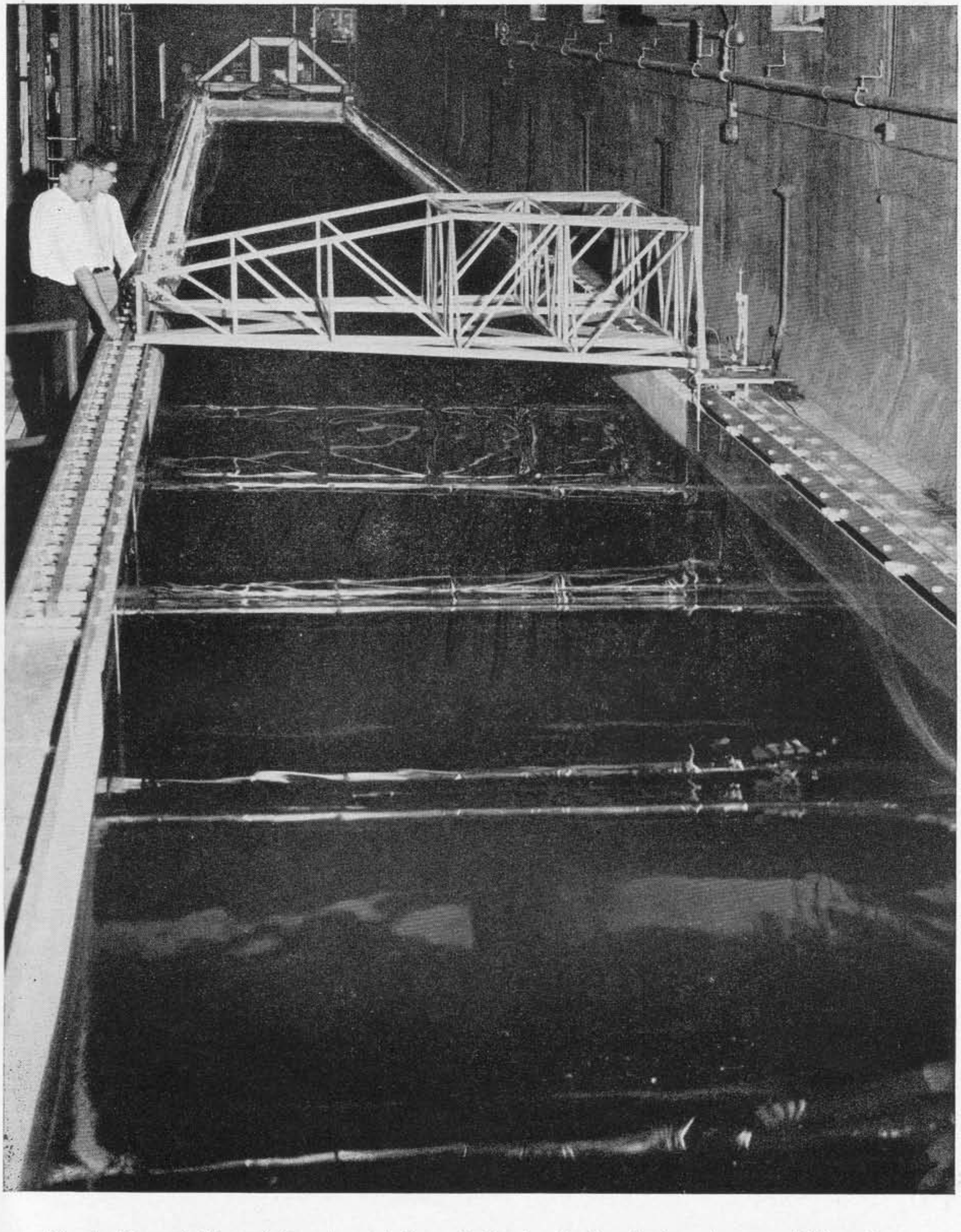


Fig. 1—General View of Experimental Channel Showing Towing-Carriage Frame and Wave Generator. The waves were about 12 ft long and 0.75 ft high. Installation of the rails was under way and about 75 per cent complete at the time photograph was taken.

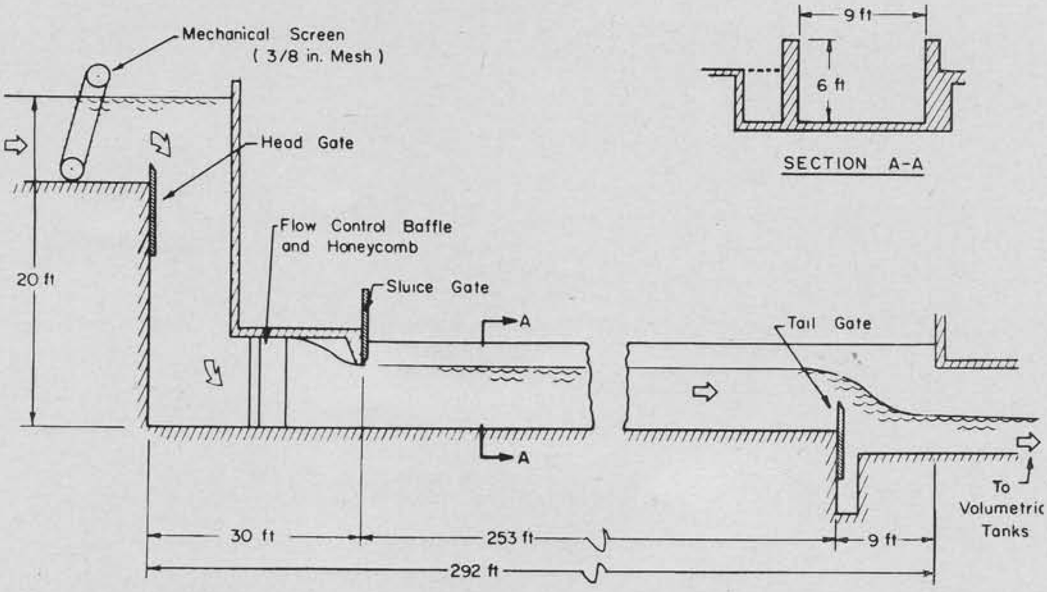


Fig. 2—Diagrammatic Sketch of Experimental Channel Showing Flow-Control Features.

Fig. 3—View of Dihedral Hydrofoil with Discharge of 225 cfs.

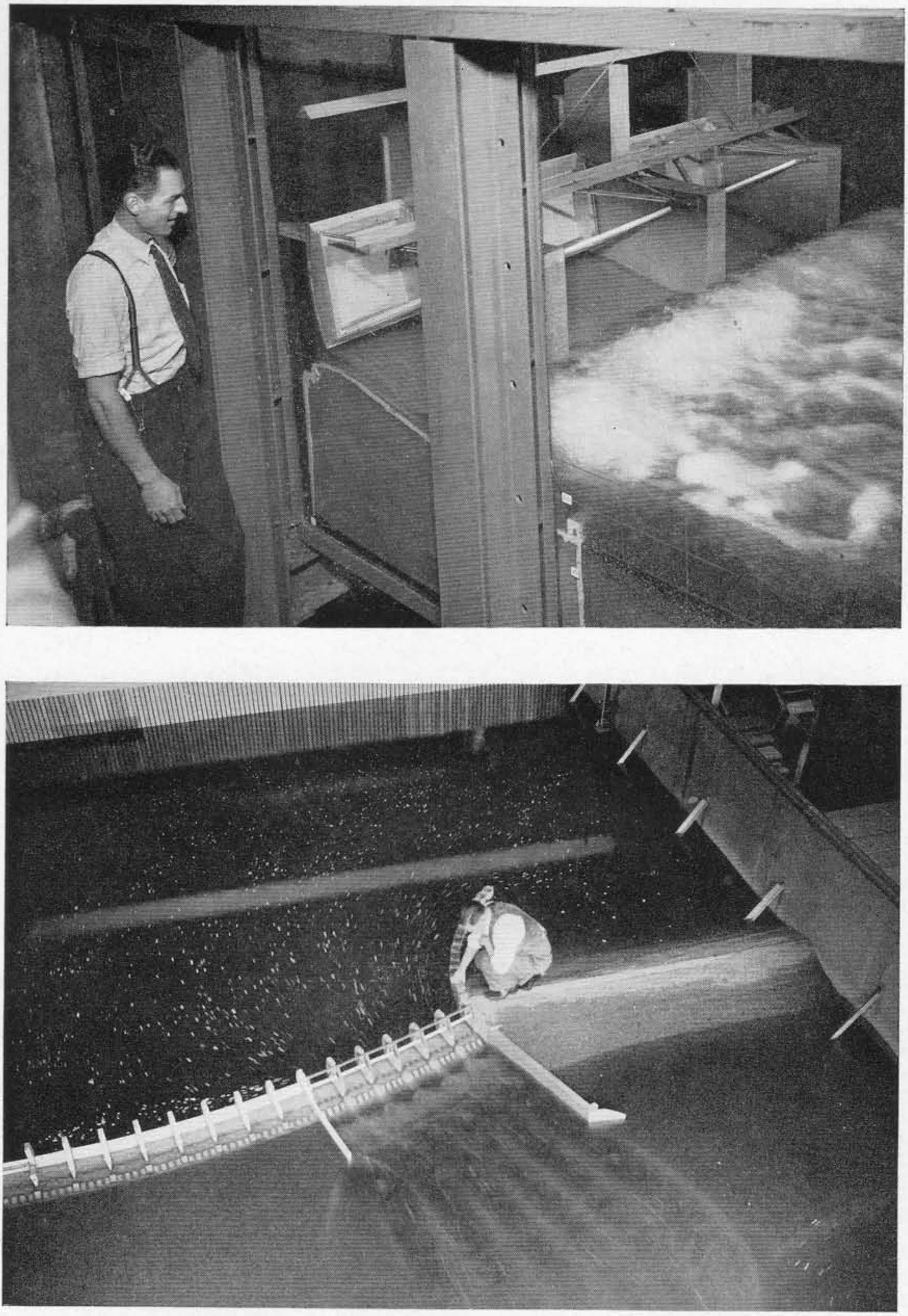


Fig. 4—Flow Studies of Spillways for Dams. Upper photograph shows sectional model of spillway in the experimental channel. Lower photograph shows comprehensive model of same spillway to smaller scale in another test basin.

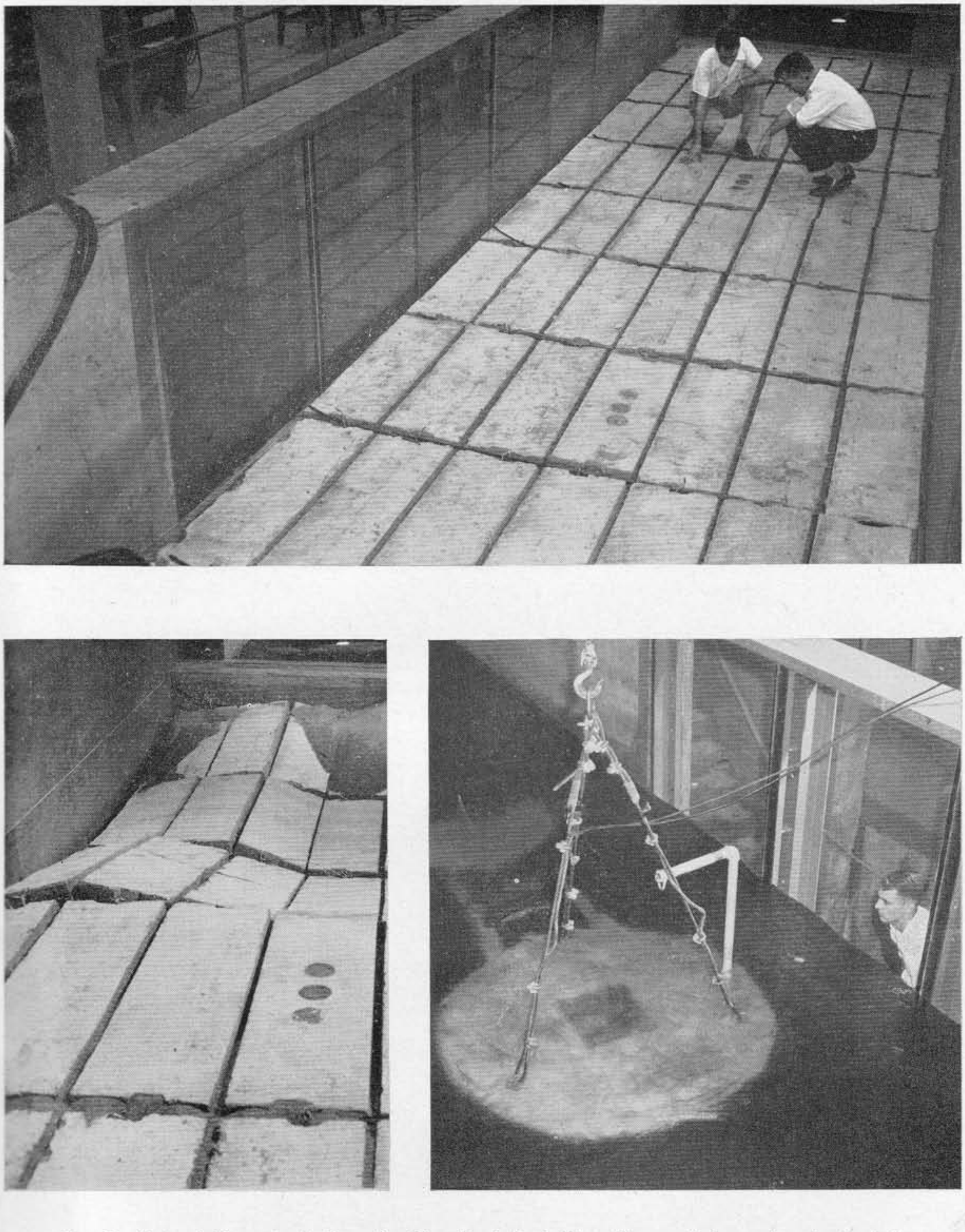


Fig. 5—Tests of Concrete Mattress for River-Bank Protection. Upper photograph prior to test. Lower photographs show settlement of mattress as a result of scouring of sand bed beneath mattress by the flowing water, and observer looking through glass sidewall during test with hydrodynamic pulsimeter in stream above mattress.

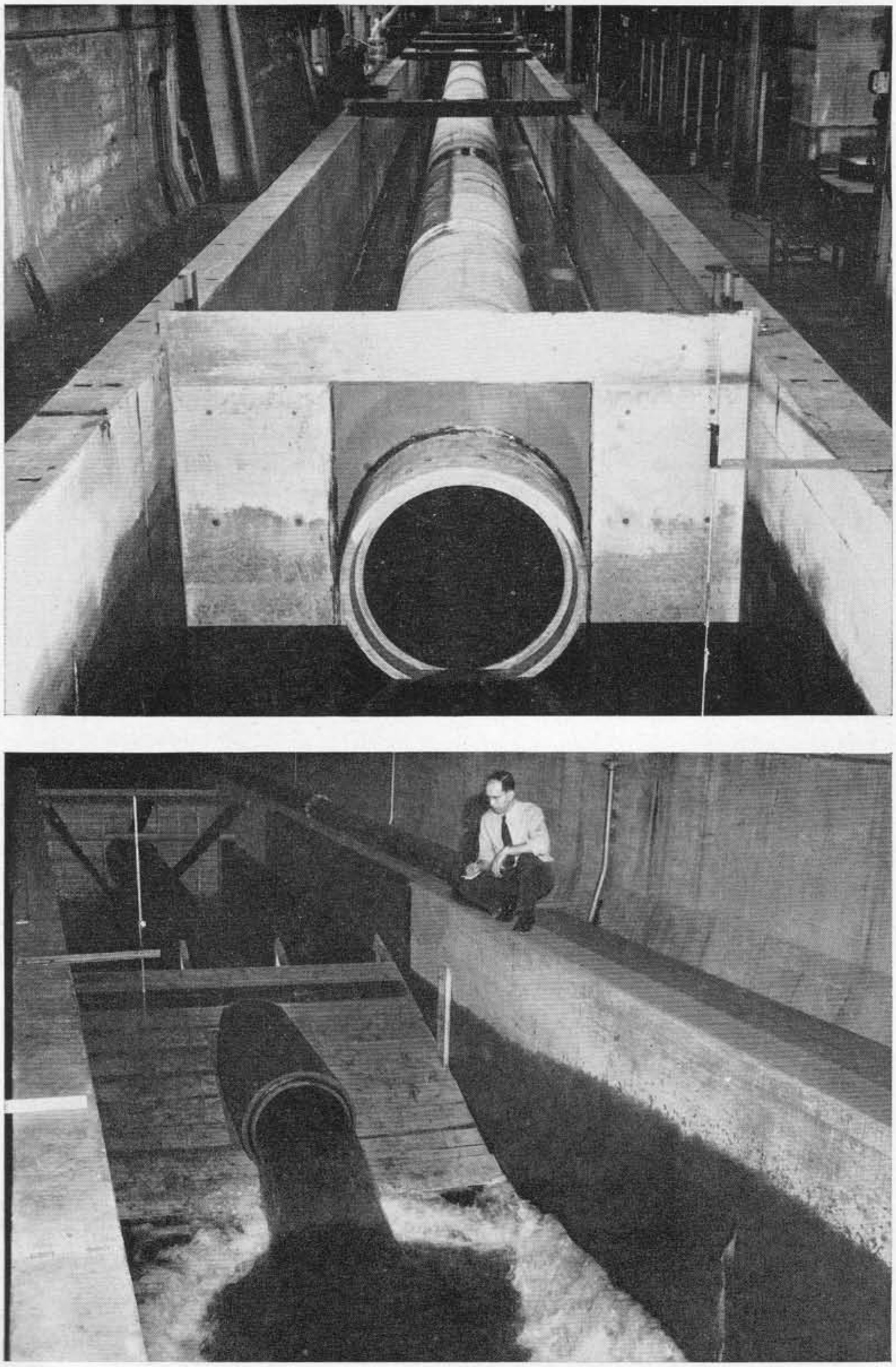
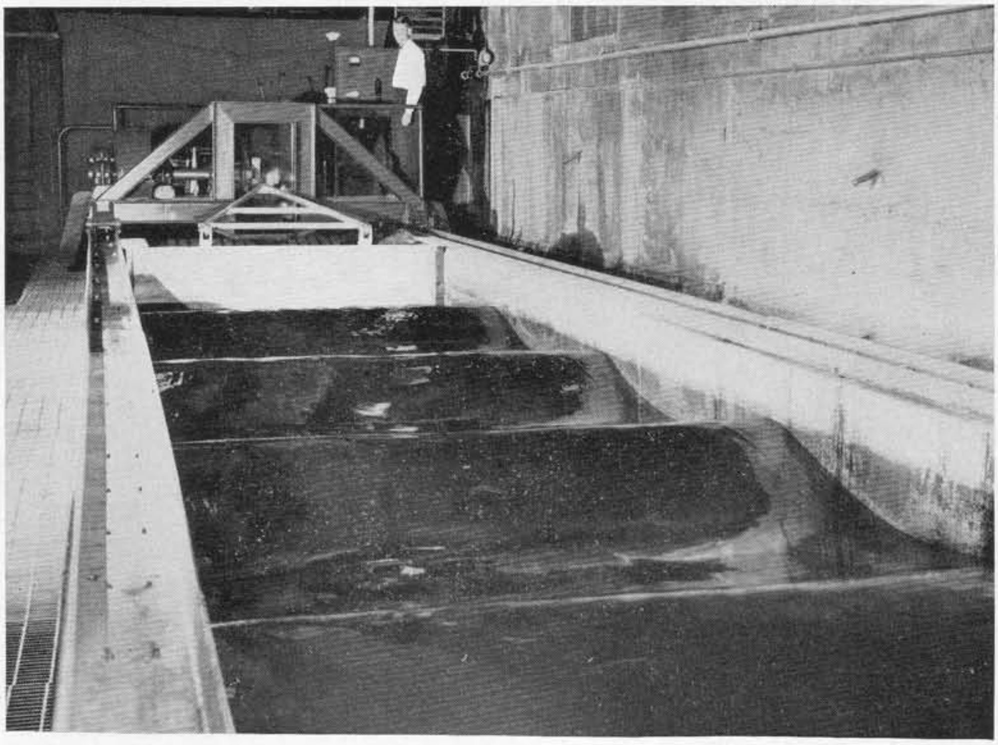


Fig. 6—Tests of Full-Scale Concrete Culverts. Upper photograph shows 3-ft diameter concrete culvert 193 ft long installed in main channel. Lower photograph shows discharge from typical 2-ft diameter culvert.



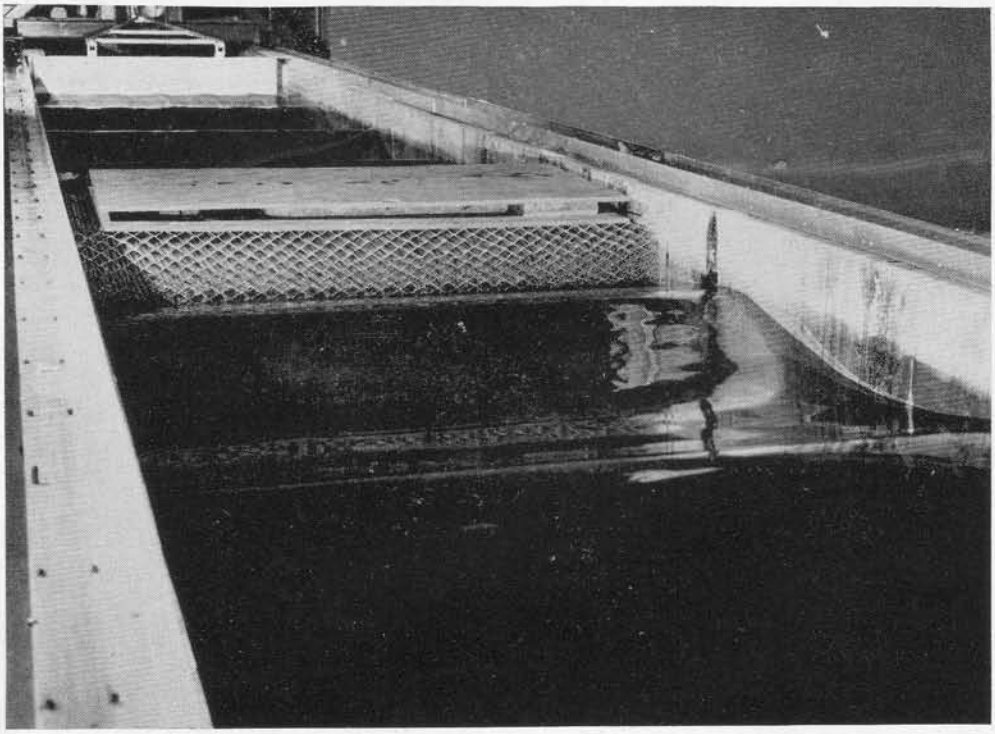
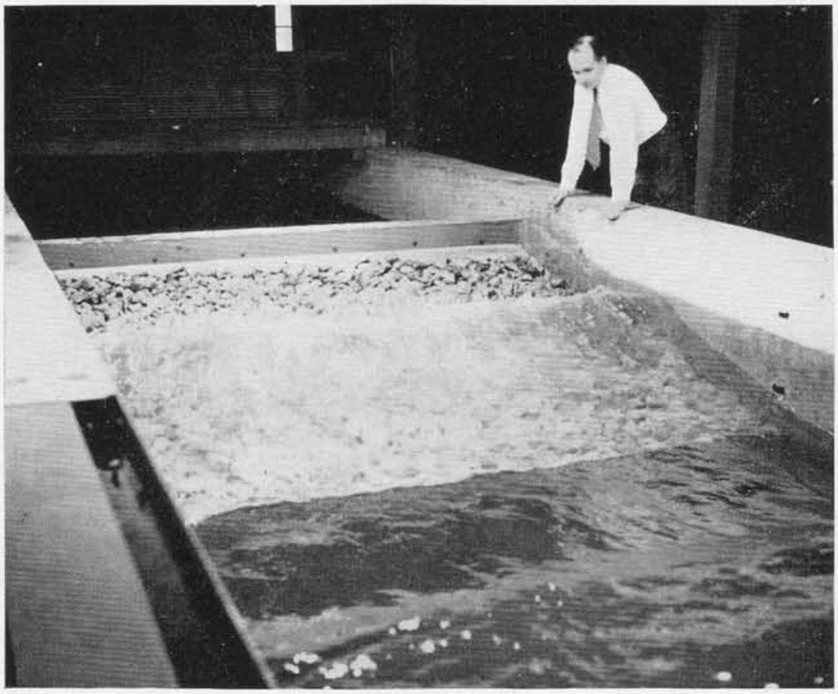


Fig. 7—Views of Wave Generator and Filters. Upper photograph shows generator producing waves about 12 ft long and 1 ft high. Lower photograph shows wave filters which are beneficial when severe reflections are introduced by test model.



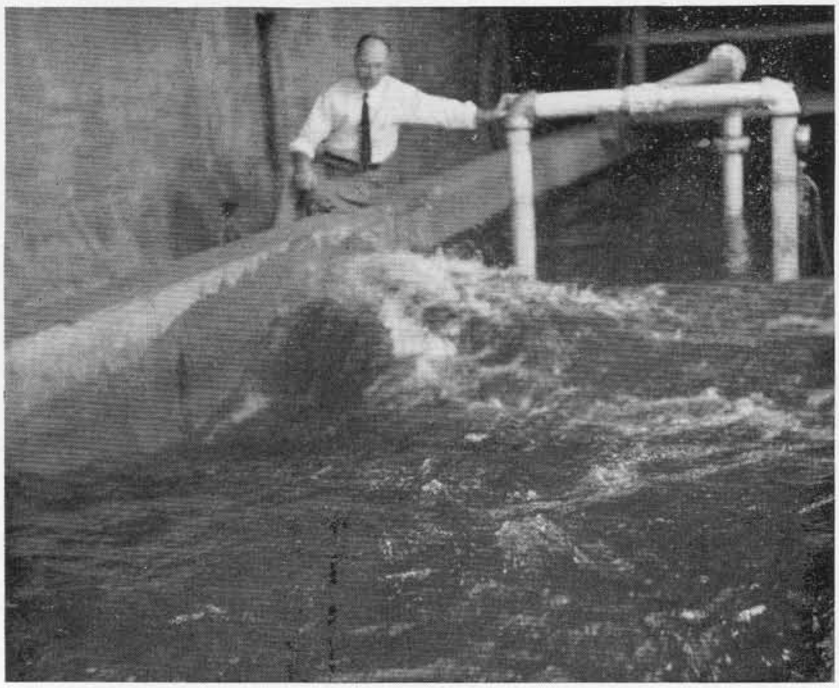
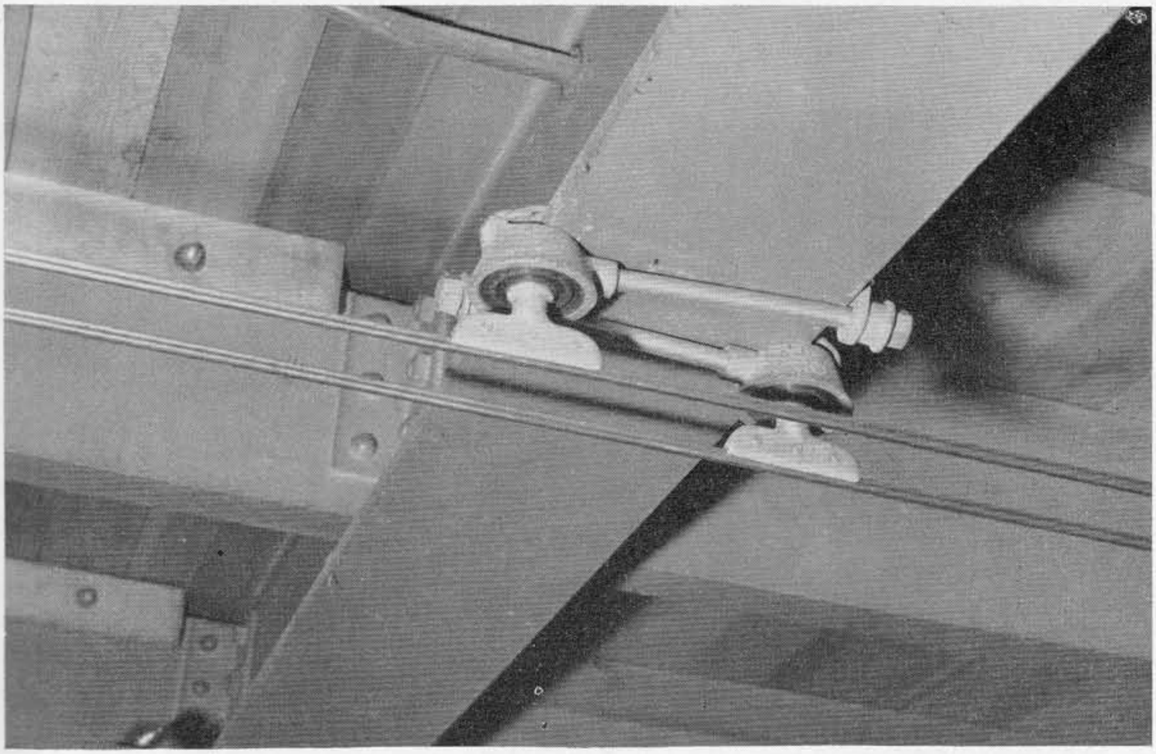


Fig. 8—Wave Tests in Experimental Channel. Top: Wave action on a crushed-rock wave absorber. Bottom: Hydraulic breakwater, consisting of a single row of horizontal water jets, stopping waves about 15 ft long.

Fig. 9—Towing Carriage Frame Prior to Installation of Wheels and Drive System. Over-all dimensions are length—12 ft, width—10 ft, and height—30 inches. Unit is constructed of square tubing varying in size from ⅞ inch to 1¾ inches.



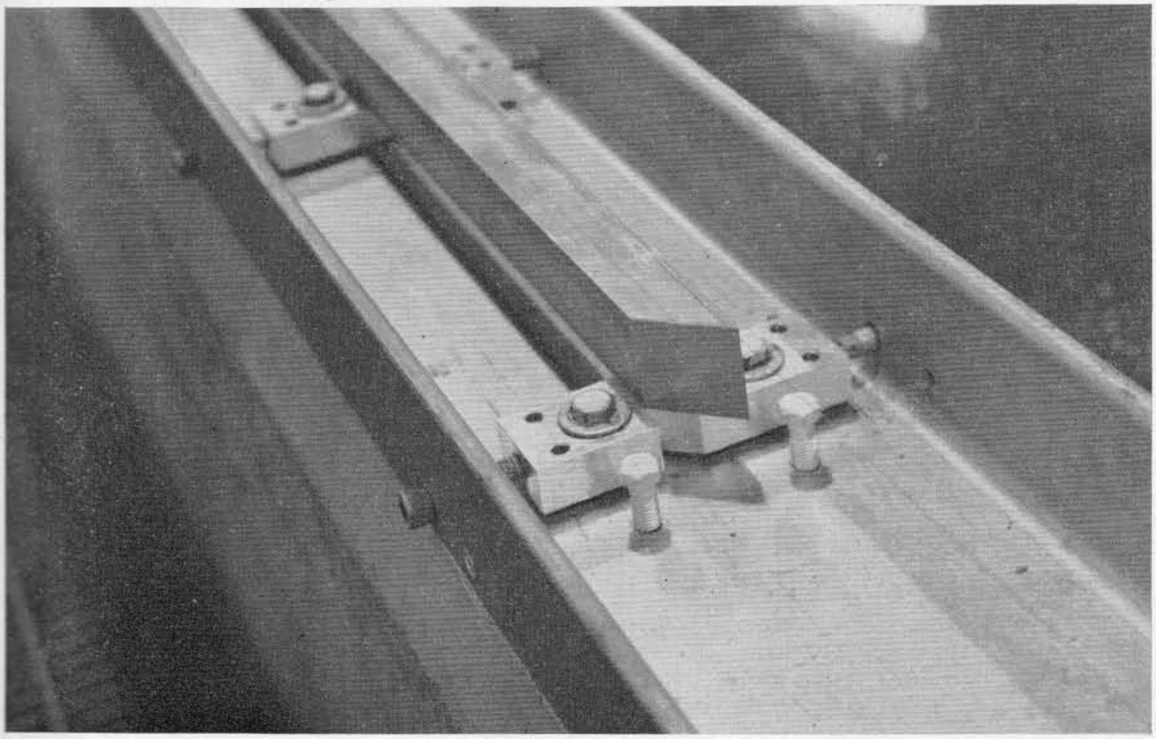


Fig. 10—Views of Trolley System and Rails. Top: Figure-eight trolley wire and insulator supports for feedback to control system. Bottom: Joint in 1½ in. by 2 in. stainless-steel rails, showing miter-cut ends and anchoring system.

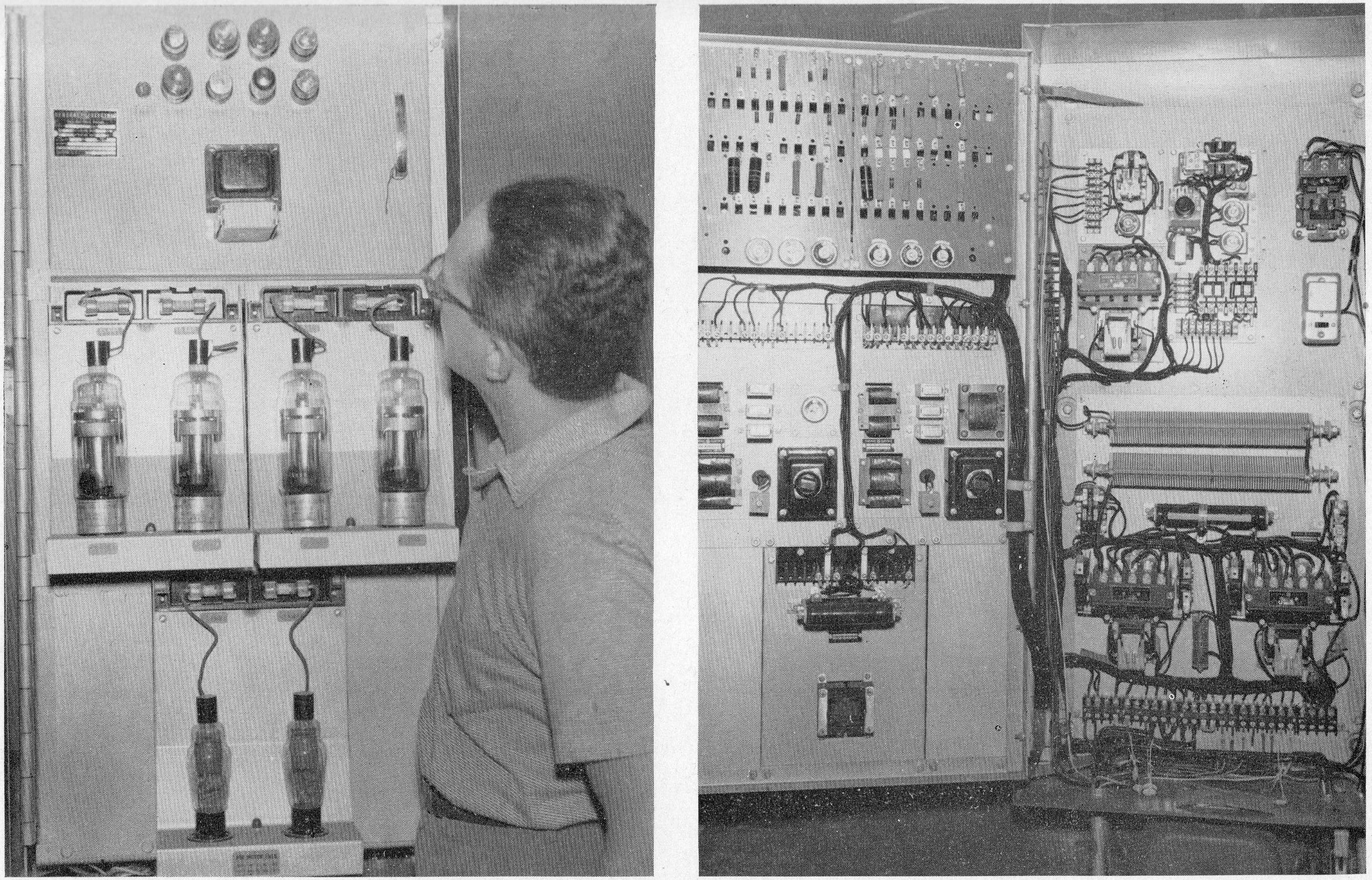


Fig. 11—Thy-mo-trol Power Supply and Control System. Left: View of Thyratron tubes. Right: Interior of cabinet, showing control elements.