THIRD DECADE OF HYDRAULICS
AT THE
STATE UNIVERSITY OF IOWA

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THE IOWA INSTITUTE OF HYDRAULIC RESEARCH

Organization

History

Earliest plans for a hydraulics laboratory at the University of Iowa had their inception in 1904, during construction of a dam on the Iowa River at Burlington Street, when provision was made for an opening in the west end for an experimental sluiceway. Drawings were eventually prepared for a 10-foot channel and a 24x24-foot laboratory building, and finally in 1918 a legislative grant made construction of these facilities possible. Some nine years later plans were announced for a new three-story building to replace the smaller one. This addition, which comprises the north wing of the present Hydraulics Laboratory, was ready for occupancy in 1928.

The Iowa Institute of Hydraulic Research was formed in 1931 in order to bring to bear upon hydraulics problems the full scientific power of the University, without respect to departmental lines. The original organization consisted of a research staff, a board of consultants drawn from other departments of the University, and an advisory committee of prominent practicing engineers. Before the Institute had completed its first year of operation, the existing laboratory space had become inadequate. In 1932 the tower and south wing of the present Hydraulics Laboratory were added, and very shortly the entire available space was in use.

As described in greater detail in Bulletin 30 of the University of Iowa Studies in Engineering, the growth of the Institute and of its activities was closely associated with the endeavors of a number of individuals and the organizations which they represented. Professor Floyd A. Nagler, first director of the Institute, was primarily responsible for its initial vigorous development. Professor Sherman M. Woodward, head of the University Department of Mechanics and Hydraulics, and Messrs. David L. Yarnell, of the
U. S. Department of Agriculture, and Martin E. Nelson, of the U. S. Engineer Department, collaborated closely with Professor Nagler throughout the early years. Dean C. C. Williams became director following Professor Nagler's untimely death in 1935, and was in turn succeeded by Dean F. M. Dawson in 1936. Under Dean Dawson the activities of the Institute continued to flourish through the numerous contributions of Professors F. T. Mavis, E. W. Lane, J. W. Howe, C. J. Posey, A. A. Kalinske, and Hunter Rouse. In 1944 Professor Rouse succeeded Dean Dawson as director.

Early investigations of the Institute included such fields as model studies of rivers, spillways, and locks; full-scale tests on culverts, embankments, and current-meter rating; and development of experimental plots for long-term hydrologic records. Through Dean Dawson and Professor Kalinske considerable attention was given to the hydraulics of plumbing systems. Professors Mavis, Lane, and Kalinske promoted extensive research in the field of sediment transportation, and under Professor Lane six Federal agencies collaborated with the Institute in a broad program of sediment investigations. Interest in the broader problems of fluid mechanics, particularly those of fluid turbulence, was stimulated by Professors Kalinske and Rouse. Professor Rouse also undertook a general reorganization of instructional methods and equipment.

With the onset of war in 1941, the Army and the Navy turned to many of the university laboratories for technical assistance. Institute contributions included research on the drag of stationary ships in flowing water; air-tunnel studies of fog dispersal for military airfields, the diffusion of smoke and gas in urban districts, and wind structure over mountainous terrain; water-tunnel investigations of cavitation around undersea bodies; and the development of fire monitors for naval vessels. These projects were conducted primarily under contract with the Office of Scientific Research and Development, the Navy Bureau of Ships, and the Army Air Forces. After cessation of hostilities several of the contracts on fundamental research were continued, in order that the supply of research results and of trained investigators would not be interrupted.

In addition to the Department of Agriculture and the Engineer Department, which contributed largely to the initial development of the Institute, local offices of the U. S. Weather Bureau and the U. S. Geological Survey were also quartered for extended periods in the Institute laboratory. The district office of the Survey's Water
Resources Division, under Mr. L. C. Crawford, continues to occupy the fifth floor of the building and greatly augments Institute endeavors in the field of hydrology. The sub-office of the Engineer Corps, which resumed its extensive activities after the war, eventually came to require more space than the post-war size of the Institute’s own program left available; by mutual accord this agency withdrew in the summer of 1948 to quarters nearer the St. Paul district office.

Space released by the Engineer Corps, together with that made available by the construction in 1948 of a new Hydraulics Laboratory Annex, at once made possible a wide-spread relocation of facilities and the addition of new equipment. The present description of the Institute thus serves as a timely supplement to Bulletin 30, bringing up to date the record of its physical plant, staff, and research projects.

**Present Organization**

In 1944 the original plan of organization of the Institute was modified to consist of the active staff, drawn from the College of Engineering, and a single board of consultants, chosen primarily from organizations outside the University. The staff is headed by the Director, who is ultimately responsible for all Institute endeavors, including staff activities, laboratory facilities, research procedure, reports, and finances. He is assisted by one or more Associate Directors and Consulting Engineers, chosen from the University faculty and from staffs of cooperating agencies permanently located at the Hydraulics Laboratory. Research engineers, who are also staff members of the Department of Mechanics and Hydraulics, directly supervise the various Institute projects and student investigations. The remaining members of the technical staff are the research associates and assistants, who conduct the actual tests and evaluation of test results; they are usually graduate students employed on a part- to full-time basis, but also include several students on part-time scholarships from the Graduate College. A non-technical staff, consisting of secretaries, shop supervisor, machinists, mechanics, assistants, and part-time laborers as needed, is maintained. At the time of writing, the staff of the Institute was as follows:
The Institute Board of Consultants is composed of prominent engineers and scientists from various parts of the country who are chosen because of their interest in or direct association with the
research activities of the Institute. Their three-year terms of serv­ice are so arranged that one-third of the membership will change each year. The functions of the Board are purely advisory, being directed primarily toward the strengthening of the research pro­gram and the development of outstanding conference sessions. The Dean of the Engineering College acts as Chairman. At the time of writing, the Board consisted of the following members:

BOARD OF CONSULTANTS

Chairman, P. M. Dawson
Dean of Engineering
State University of Iowa

B. A. Bakhtiyetoff (1951)
Professor of Hydraulic Engineering
Columbia University

H. L. Dryden (1949)
Director of Aeronautical Research
Natl. Advisory Com. for Aeronautics

C. F. Izzard (1951)
Highway Research Engineer
Public Roads Administration

W. H. Leahy (1951)
Assistant Chief for Research
Office of Naval Research

M. E. Nelson (1949)
Consultant, St. Paul District
Corps of Engineers

M. L. Nichols (1950)
Chief of Research, SCS
U. S. Dept. of Agriculture

C. G. Paulsen (1950)
Chief Hydraulic Engineer
U. S. Geological Survey

K. E. Schoenherr (1949)
Dean, College of Engineering
University of Notre Dame

G. B. Schubauer (1950)
Chief, Aerodynamics Section
National Bureau of Standards

Research Policy

Institute policy regarding research and testing has developed along two general lines. In the case of investigations to determine the solution of specific problems, contracts are entered into with the agency concerned, the financial arrangements varying with the degree of participation required of the Institute staff. Such participation has ranged from a minimum in the case of projects conducted by engineers of the outside agency, to full responsibility for planning and carrying projects to completion. In accepting specific re­search problems, priority is given to those considered most produc­tive of useful information, while routine testing is undertaken only when men and facilities are temporarily available. All contract
charges are based upon actual costs plus overhead, without financial profit to the University.

As a result of the strong and continuing interest of the Institute in fundamental research, many long-term investigations have been supported in full or in part by Institute funds, and its staff and facilities have frequently been placed at the disposal of organizations interested in sponsoring such work. The technical societies, The Engineering Foundation, and the Office of Naval Research are typical organizations of this nature. An excellent opportunity for basic investigations of rather broad scope arises from the participation of the Institute in graduate instruction, since students conducting advanced research in fluid motion are advised by staff members, and it thus becomes possible for related phases of a particular problem to be investigated by different students either simultaneously or in successive years. The Institute itself generally employs a number of selected students for staff projects, and the same procedure has on several occasions been adopted by cooperating agencies. Moreover, research assistantships granted by the Graduate College also provide part-time employment of graduate students for fundamental projects. Thus, the service of able, technically trained men is continuously at hand for a broad research program.

CURRENT ACTIVITIES

Research Projects

Although the wartime demand for immediate test results has long since ceased, the magnitude of the Institute program has remained at its wartime level. Certain pre-war projects were continued through the war years. Others, necessarily discontinued as hostilities began, have since been resumed. Many of the studies undertaken for the armed forces have proved of such basic interest as to warrant their continuation on a long-term basis. And, finally, various new investigations have been begun since the war. All are described briefly in the following paragraphs, and reference is made to the latter portion of this bulletin for antecedent information.

Hydrologic studies on Ralston and Rapid Creeks, in collaboration with the U. S. Geological Survey, the Soil Conservation Service, and the Weather Bureau, have been uninterrupted since their inception in 1924 and 1941, respectively. These projects are usually handled by Graduate Assistants, who frequently select particular
aspects of the records for thesis investigations. Professor Howe has been in charge of the hydrologic phases of the Institute program for the past eight years.

Water-tunnel studies of a series of torpedo head forms under varying degrees of cavitation, begun with construction of the first water tunnel in 1943, have been extended both analytically and experimentally to include a wide variety of boundary forms in both two and three dimensions. Present activities involve extension of the von Kármán method to axisymmetric bodies of arbitrary form; use of the Southwell relaxation method for similar bodies and also for free jets; application of the electrical analogy to axisymmetric conduit transitions and free-surface flow; determination of the pressure-distribution at gate slots of various proportions; and an evaluation of the noise characteristics produced by the cavitation of submerged jets. This portion of the program, now partially supported by the Office of Naval Research, has been under the direction of Professor McNown for the past six years.

In addition to correlative use of the water tunnel and the air tunnel in the foregoing projects, a number of independent studies have been in progress in the present air tunnel for several years. The principal one of these represents an evaluation of the effect of lattice and perforated screens upon the pressure distribution, velocity distribution, and turbulence of the air stream. A subsequent project has involved the detailed measurement of the pressure distribution upon model buildings of both the block and hangar types for a systematic variation of the building proportions and wind orientation. A continuing project upon jet diffusion, originally restricted to two- and three-dimensional jets in a semi-infinite fluid, has since been extended to abrupt expansions in both closed conduits and open channels. These various projects, which are sponsored in part by the Office of Naval Research, are under the supervision of Professors Rouse, Howe, and McNown.

Analytical and experimental investigations of sediment entrainment, transportation, deposition, and measurement have been actively resumed since the war. A continuing series of studies relating to the fall of particles has been directed by Professor McNown. Methods of determining size-frequency distributions of sediment samples have been developed under Professors Rouse and Boyer. A continuing project on scour at bridge piers and abutments is being sponsored by the Iowa State Highway Commission and the
Federal Public Roads Administration. The latter projects, as well as a fundamental program under the Office of Naval Research, are being supervised by Mr. E. M. Laursen.

Two new agreements with the National Association of Master Plumbers and the Housing and Home Finance Agency involve a continuation of pre-war investigations of the plumbing requirements of houses and the prevention of water pollution. In the latter regard, demonstration lectures are given throughout the year to medical students of the University on plumbing dangers and sanitation. This phase of the program is under the supervision of Dean Dawson and Professor Metzler.

New instrumentation, particularly in the electronics field, is demanded by the continuation of Institute interests in the study of fluid turbulence. Under Mr. P. G. Hubbard the measurement of rapidly fluctuating velocities and pressures in an air stream has been greatly facilitated, and the methods are being extended to the flow of water as well.

Miscellaneous projects not included in the foregoing general categories involve the following: the determination of pipe-manifold characteristics; an investigation of flow over lateral weirs, the current J. Waldo Smith Fellowship project of the A. S. C. E.; an experimental study of multiple-well characteristics; model tests for various units of a Brazilian power system of the Sao Paulo Tramway, Light and Power Company, Ltd.; the design of laboratory equipment for the Central University of Venezuela; and procurement of the last items of equipment for the new hydraulics laboratory of the National University of Colombia, designed by the Institute in 1945-6.

At the time of writing, construction by the Institute of four major items of equipment under sponsorship of the Office of Naval Research is nearing completion: a variable-pressure water tunnel, a low-velocity air tunnel, a scour flume, and a recirculating sediment-transport flume. Following their completion the present air tunnel will be rebuilt, thereby improving its usefulness as a test facility and freeing space for other air-flow equipment as well as a dynamometer for pump tests. The instructional laboratory equipment, originally located at the north end of the first floor, has been moved to the central portion of the building, thus permitting the addition of several essential units. Within the coming year these units all will be placed in operation.
Conferences and Publications

Important among the continuing activities of the Institute is its series of Hydraulics Conferences. The first, held in 1939, brought together nearly 250 hydraulic engineers in a four-day meeting devoted to a resumé of current knowledge in various fields of hydraulics. Twenty-one papers were presented by recognized authorities and later published as *Proceedings of Hydraulics Conference*, Bulletin 20, Iowa Studies in Engineering. The second meeting, held in 1942 under wartime conditions, suffered somewhat in attendance but by no means in excellence. Twenty-four papers, showing the applications of fluid mechanics in many interrelated fields, were given by eminent engineers and scientists, and published as *Proceedings of the Second Hydraulics Conference*, Bulletin 27, Iowa Studies in Engineering. A third conference was held in 1946, with an attendance of 325. Twenty-four papers were presented at this meeting, with the general theme of post-war application of war research. These papers were published in *Proceedings of the Third Hydraulics Conference*, Bulletin 31, Iowa Studies in Engineering. The Fourth Hydraulics Conference, scheduled for 1949 directly following the appearance of this bulletin, will involve the discussion of thirteen preprinted chapters of a book on *Engineering Hydraulic*, which will be published by John Wiley & Sons after the conference.

In order to make available to the general public the results of all research conducted at the Institute, the series of bulletins containing abstracts of all graduate theses, staff publications, and reports of associated agencies is being brought up to date herewith. Bulletin 19, *Two Decades of Hydraulics at the University of Iowa* (1939), was the first of this series; the second was Bulletin 26, *Investigations of the Iowa Institute of Hydraulic Research, 1939-1940*, which contained in addition four original papers by staff members. In the present bulletin, *Third Decade of Hydraulics at the State University of Iowa*, the abstracts contained in Bulletin 26 have been repeated for purposes of completeness. At the end of the bulletin will be found a complete list of Institute publications.

Physical Plant and Basic Equipment

Laboratory Structures

The Hydraulics Laboratory of the Iowa Institute of Hydraulic Research is situated on the west or right bank of the Iowa River
immediately downstream from the University dam. It consists of two structures: the main building, completed in 1933, and an annex across the highway and a hundred yards to the south, completed in 1948. Their general location is shown in Fig. 1.

The laboratory proper is a steel-frame and concrete-deck building with brick and tile walls. It is rectangular in plan, 164 feet long and 45 feet wide through the central portion, with the river on the east side and State Highway 218 on the west. The over-all height is 90 feet at the central tower (Fig. 2), where the building has five floors above the street level and reservoirs and river channels below. The two wings rise three stories above the street level.

The laboratory annex is a single-story, steel-frame and concrete-block building, 122 feet by 72 feet in plan and 24 feet in maximum height, to which is appended along the northwest quarter a recirculating low-velocity air tunnel, trapezoidal in plan, 76 feet long and varying from 16 to 26 feet in width.

The working space within the main laboratory is divided among the four primary functions of administration, instruction, research, and construction and maintenance. Administrative offices of the Institute are located on the fourth floor, and office and drafting quarters for junior staff members on the third. The fifth floor is occupied by the Iowa District Office of the U. S. Geological Survey. Instructional facilities include the undergraduate and graduate laboratory on the first floor, and a lecture hall and student shop on the third. General research facilities are found on the first, second, and third floors and in the large channels beneath the building. An electronics laboratory and a small sedimentation laboratory also occupy space on the third floor. Other shop facilities for construction and maintenance are located on the first floor and in the basement. Figures 3 and 4 on pages 18 and 19 indicate the general layout of the various floors.

In the laboratory annex are two offices and a small shop, all to be used in connection with experimental work performed in that building. Aside from housing such permanent equipment as the air tunnel, the recirculating sediment-transport flume, and a scour flume, the floor space is arranged to accommodate a number of temporary installations for specific model studies. Figures 5 and 6 on page 21 indicate the general layout of the annex.

A water-stage recorder shelter and cableway adjacent to the laboratory were constructed in 1921 and are used in determining the
Fig. 2. Vertical section through central tower of main laboratory.
flow of the Iowa River past the laboratory. A long-distance recorder registers the river stages on an instrument in the Institute offices.

Water Supply

In the main laboratory a double circulation system supplies water for most of the experimental work on the first and second floors. Water from the University supply system is contained in two interconnecting reservoirs in the central portion of the first basement, each having an area of approximately 900 square feet and a depth of 6 feet. A common overflow section is provided on the river side of the building as a precaution against overfilling. The water is raised from the sumps to constant-level tanks on the third floor by three centrifugal pumps, capable of supplying a total flow of 15 cubic feet per second against a head of 50 feet. One 50-horsepower pump is located at the north end of the first basement, and a 25- and a 50-horsepower pump at the south end. Each pump is below the sump level so that priming is not required.

The constant-level tanks at either end of the third floor are supplied through 10-inch vertical lines. Each tank has a surface area of some 350 square feet and is equipped with a series of skimming weirs having a total crest length of 700 feet. Numerous independent take-off connections, from 2 to 12 inches in diameter, are available in the bottoms of the tanks for separate lines to the various experimental projects. The water in excess of that used flows out of the tanks over the weirs and is returned to the sumps through 12-inch lines. Because of the skimming weirs, a considerable variation in outflow requirements does not materially affect the elevation of the water surface. The tanks are interconnected, and hence may be used together or separately. Connections are arranged so that many projects may be run independently, as long as their combined capacity does not exceed the available supply.

Accurate determinations of rates of discharge are made possible by two large weighing tanks, mounted on Toledo scales. The scales have 5-pound graduations and an over-all capacity of 18,000 pounds each. Alternate use of the tanks by means of a manually controlled inlet diverter and hydraulically controlled outlet valves makes it possible to measure discharge rates up to 5 cubic feet per second.

The water-supply system in the laboratory annex consists of a 20x30x6-foot sump in the northeast portion of the building, to which water from each experiment is returned through a covered
Fig. 3. Plan views of second, third, fourth, and fifth floors.

Legend

1 — Offices
2 — Drafting rooms
3 — Janitor’s quarters
4 — Supplies
5 — Lavatories
6 — Research space
7 — Shops
8 — Classroom
9 — Silt laboratory
10 — Elevator
11 — Pump rooms
A — Constant-level tanks
B — Weighing-tank hopper
C — River-model flume
D — Weighing tanks
E — Pumps
F — Reservoirs
Fig. 4. Plan views of river channels, basement, and first floor.

Legend

a — Small glass-walled flume
b — Cavitation unit
c — Air-pipe assembly
d — Towing tank and wave flume
e — Water-pipe assembly
f — Oil-pipe assembly
g — Portable air tunnel
h — Air-jet table
i — Water jet

I — 10-foot channel
II — 16-foot channel
III — Large glass-walled flume
IV — Water tunnels
V — Low-velocity air tunnel
channel encircling the central test area. One 12- and three 6-inch pumps with 25- and 15-horsepower motors lift the water from the sump to the constant-level tank, located above the sump in the northeast corner of the building. This tank is 8x8 feet in plan and 5 feet deep, and maintains a water-surface elevation approximately 18 feet above the floor. Water is distributed from the tank through the building by means of light welded-steel pipe. A flow of 15 cubic feet per second is available.

**Shops**

Except for large units, fabricated for the Institute on contract, the major portion of the experimental apparatus is constructed in the laboratory shops, and facilities are at hand for the maintenance of all equipment. Since test requirements may involve precision turning or milling, welding, plumbing, carpentry, sheet-metal work, plastic forming, and masonry, it has been necessary to accumulate the machines and tools, the materials, and the skills for all such phases of construction. An instrument shop is located on the first floor, a general shop in the basement, and a student shop on the third floor of the main building, and there is a small shop in the annex. Staff and facilities for construction and maintenance of equipment are under the direct supervision of Mr. Dale C. Harris.

**Instructional Facilities**

*Undergraduate Instruction*

Since an important function of the Institute laboratories is the provision of demonstration and test equipment used by the Department of Mechanics and Hydraulics for teaching purposes, it is essential that such equipment illustrate the same basic principles as are emphasized in the classroom. The textbook used by all undergraduate classes, *Elementary Mechanics of Fluids* by Rouse, stresses the fundamental mechanical aspects of fluid motion rather than simply the empirical calibration of measuring devices. All equipment has therefore been devised to show in as graphic a manner as possible the primary characteristics of fluid behavior, whether through specially prepared motion-picture sequences, by visual observation during demonstration lectures, or in actual tests conducted by the students themselves.

The equipment either in operation or under construction at the
FIG. 5. PLAN VIEW OF LABORATORY ANNEX.

FIG. 6. SECTION A-A THROUGH NORTH END OF ANNEX.
time of writing consists of two flumes, pipe assemblies using water, air, and oil, a water tunnel, an air tunnel, a water jet, and an air jet. Each of the units provides the maximum possible visibility and flexibility of operation, and units as well as instruments are arranged for student operation. Means of measurement are learned incidentally through use in determining the detailed flow characteristics for various applications of the continuity, momentum, and energy principles.

**Flumes**

A glass-walled flume 12 feet long, 2 feet deep except at the 3-foot sluice-gate section, and 1 foot wide has been in constant use for many purposes since its construction in 1941. Rates of flow up to 2 cubic feet per second are measured by means of an elbow meter above the inlet to the head tank, and a tailgate at the downstream end controls the depth. The plate-brass floor contains a series of center-line piezometers, and a 13-tube manometer panel is at hand for pressure determinations. Longitudinal rails support a carriage and vernier gage on which may be mounted either a point or Pitot tube. Vertical slots are provided at three sections for the introduction of sluice gates, weirs, and various spillway sections, each of which is provided with piezometers. Experiments involve measurement of the surface profile, pressure distribution, and velocity distribution, and evaluation therefrom of discharge, momentum, and energy relationships in curvilinear flow under gravitational action.

The small towing tank previously used for the study of surface flow patterns and the calibration of instruments is being replaced by a combined towing tank and wave flume some 40 feet in length, with a cross section 18 inches square. Sides will be of glass, the slope will be variable, and rates of flow up to 2 cubic feet per second may be obtained. A hydraulically controlled towing carriage with speeds from zero to perhaps 3 feet per second will permit both the photographing of flow patterns around various boundary forms and the calibration of small instruments. Waves of the solitary, oscillatory, and surge categories may be investigated, as well as subsurface gravity currents.

**Pipe Assemblies**

The oldest of the pipe units in use represents a most graphic demonstration of the difference between laminar and turbulent flow.
It consists of a 15-foot length of 3/4-inch brass pipe with bell inlet, together with a 6-inch approach pipe, a transparent outlet hood, weighing and storage tanks, and a 1-horsepower centrifugal pump to form a closed circuit for the flow of oil. The oil is of the commercial mineral variety, having a viscosity some 10 times that of water, permitting Reynolds numbers from 100 to 8,000 to be obtained. The unit is so well streamlined that laminar flow prevails through the entire Reynolds-number range, unless an initial disturbance is introduced in the form of a removable rod just ahead of the bell. The turbulent jet is of the usual rough form, but the laminar jet is almost glass-like in appearance. With the disturbance rod in place, the flow remains laminar until the lower critical Reynolds number is reached, and then abruptly becomes unstable. A dozen piezometers with leads to a manifold and open-tube manometer permit measurement of the gradient of piezometric head, and a Pitot-tube housing near the end of the pipe will enable velocity traverses to be made.

A unit just completed continues the measurements of surface resistance to Reynolds numbers as high as about 200,000 through the flow of air in 1/4-inch and 2-inch pipes of both drawn brass and galvanized iron. The flow is produced by a 10-horsepower centrifugal fan, and measured by 3 calibrated Venturi meters of different sizes arranged in parallel. Each pipe is provided with 4 piezometers at regular intervals, and the two large pipes terminate in Pitot-tube housings for measurement of the velocity distribution. As in the case of the oil unit, the experiment includes evaluation of the velocity distribution and resistance characteristics as functions of the Reynolds number and as well of the relative roughness.

The third unit, also just installed, utilizes water for the demonstration of form losses at various section changes. Two parallel systems of 2-inch brass pipe contain in series an inlet, an enlargement, a contraction, a constriction, and an elbow, and then each branches into two lines, one of which ends in a submerged outlet and the other of which passes through a valve to a free outlet. The one system consists entirely of fittings of the abrupt commercial type, and the other entirely of streamlined fittings. Measurement of flow is made by means of triangular weirs, and measurement of pressure through some 44 piezometer connections leading to a central manifold and mercury gage of the zero-displacement type. The experiment includes preparation of a plot of the lines of total and
piezometric head for both systems, and evaluation of loss coefficients for all fittings and discharge coefficients for those which can serve as flow meters.

Water Tunnel

In 1941 a unit was constructed for the demonstration and measurement of two-dimensional flow around and between various boundary forms at conditions both above and below the cavitation limit. After seeing a great deal of service (and being reproduced by two other laboratories), this unit has been entirely rebuilt, and is again in constant use. A 25-horsepower centrifugal pump located in the basement provides velocities as high as 35 feet per second through a test section 18 inches long, 6 inches high, and $\frac{3}{4}$-inch wide. Pressure loads on the system may be varied from +30 to —30 feet of water by means of either a vacuum pump or a combination of leads to high- and low-level tanks. The test section is provided with $\frac{1}{2}$-inch lucite windows, between which can be mounted either constrictions of the Venturi type or bodies such as cylinders or foils, the rear lucite panel being provided with some 20 piezometers suitably arranged. A differential mercury manometer indicates the rate of flow in terms of the change in pressure head at the rounded inlet to the test section, and a manifold and compound Bourdon gage permit determination of the pressure intensity at each piezometer. Tests include evaluation of the pressure distribution along the boundary under study for various values of the cavitation parameter.

Air Tunnel

Completion of a portable air tunnel of the open-throat type now gives the laboratory the last of three planned units for the study of form effects. This tunnel is of $\frac{1}{4}$-inch plate aluminum, with a free jet some 15 inches in diameter and having a maximum velocity of about 100 feet per second. A 24-inch axial-flow fan powered by a 2-horsepower Varidrive motor permits control of the speed over a 5-fold range. Longitudinal rails at the test section are provided for the support of measuring instruments and bodies under study. Possible experiments include the determination of the pressure distribution and drag of elementary forms, buildings, vehicles, and bridge sections.
**Water and Air Jets**

Two distinct units, the one utilizing air and the other water for purposes of convenience, have been designed for the study of free and submerged jets in any fluid. The water-jet unit consists of a horizontal 4-inch pipe with suitable approach and controls, at the end of which may be secured an orifice or nozzle of any desired form. A movable gage with two-way motion is arranged for determination of the liquid trajectory, piezometers along the pipe and outlet permit investigation of the dynamics of the accelerated flow, and a deflector plate and dynamometer are provided to illustrate the force characteristics of the free jet. The air-jet unit consists of a low table in the middle of which interchangeable nozzles with vertical axis and varying from \( \frac{1}{4} \) to 2 inches in diameter may be mounted, a 2-horsepower centrifugal fan below the table, and vertical rails with traversing mechanism above. Measurements consist of velocity (and possibly turbulence) distribution at successive cross sections of the zone of diffusion, with subsequent determination of the similarity of the flow pattern and the flux of volume, momentum, and energy.

**Graduate Instruction**

Just as all graduate students in the Department of Mechanics and Hydraulics must complete an intermediate course in the mechanics of fluids prior to optional advanced study, so must all graduates complete an intermediate laboratory course prior to optional advanced laboratory investigation. This course is basically similar to the one taken by undergraduates, in that the same equip-
ment is used and the same procedure followed. However, whereas the undergraduates perform only 7 selected experiments, the graduates become familiar in the intermediate laboratory course with all the instructional equipment available. The optional advanced course then includes various special uses of the basic units, together with application of such equipment as the electrical analogy, the hotwire anemometer, the larger water and air tunnels, and the sediment flumes. Tests are also made on certain of the models or temporary equipment in current use for specific projects.

Since the majority of the graduate students in this department conduct experimental investigations for the master’s or doctor’s degree, such routine laboratory courses serve as the background training for independent handling of research equipment. The latter equipment is provided in part by the Department of Mechanics and Hydraulics and in part by the Iowa Institute, depending upon the nature of the project. Sometimes thesis subjects represent distinct problems brought to the University by students on leave from other universities or from organizations dealing with fluid motion. More frequently, topics agreed upon by students and their advisers form individual parts of a series of related projects of particular interest to the adviser. Finally, students employed on a part- or full-time basis by the Institute for the conduct of contract research often find it possible to extend some portion of the research as a thesis subject, both the thesis and the project thereby

Graduate degrees granted from 1922 to 1949

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<thead>
<tr>
<th>Country</th>
<th>M.S.</th>
<th>Ph.D.</th>
</tr>
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<td>Germany</td>
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<td>1</td>
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<tr>
<td>Hawaii</td>
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<td>Hungary</td>
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<tr>
<td>Iraq</td>
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<td>1</td>
</tr>
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<td>Peru</td>
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</tr>
<tr>
<td>Total</td>
<td>168</td>
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</tbody>
</table>
increasing in scope or completeness. Unless entirely new apparatus must be purchased or constructed for these studies, that used is made available from the general research facilities owned by the Department or the Institute and described in the following pages.

During the three decades since the first master's degrees were granted in 1922, nearly 200 graduate students have taken advantage of the opportunities for advanced study in hydraulic engineering offered by the University. As indicated by the accompanying table, graduate degrees have been received by students from twelve foreign countries. In addition, representatives from eight other countries have attended formal classes or taken special instruction for limited periods. Some 60 percent of these men have either held graduate assistantships or been employed by the Institute.

Research Facilities

River Channels

The two large channels beneath the main laboratory permit, through utilization of river water under gravity flow, a wide variety of large-scale tests to be made which would otherwise require prohibitively expensive pumping equipment. Approximately a 10-foot drop in head is available between the pool above the dam and the river below. One of the channels is 10 feet wide, 10 feet deep, and extends a distance of 300 feet from the headgate at the dam to the downstream end of the laboratory. The other channel is 16 feet wide, 13 feet deep, and 100 feet long, and lies wholly within the building; it is supplied in part by a 4-foot steel pipe leading from the dam and in part by diversion from the smaller channel. Hinged tailgates at the downstream ends, used in conjunction with remote-control adjustment of the headgates, provide the necessary flow regulation. Discharge rates as great as 250 cubic feet per second may be obtained.

Water supplied by the 4-foot pipe is metered through a side-contraction Venturi, and discharge in the channels by means of weirs, current meters, or Pitot tubes. A carriage is mounted on rails over each channel, so that measuring equipment can be moved to any desired position. Steam heat through the channel makes winter operation possible. These channels have served such varied purposes as full-scale studies of culverts, embankments, and fish ladders; investigations of stationary ship models in flowing water; and the detailed measurement of the diffusion of fire streams.
Flumes

In order to permit visual study of flow conditions below the water surface, the first of the Institute's glass-walled flumes was constructed in 1935 with Department of Agriculture funds. It has since been entirely rebuilt, and continues to find almost constant use. The flume itself is 2½ feet wide, 3 feet deep, and 22 feet long, and has four 5-foot panels of ½-inch glass on each side. The head tank contains stilling racks and a gear-driven sluice gate at the flume entrance, and a geared tailgate is located at the downstream end. Stainless-steel rails support a gage carriage with secondary lateral movement. Rates of flow up to 7 cubic feet per second are measured by means of 6-inch and 10-inch elbow meters in the supply pipes. The flume is permanently installed near the center of the first floor of the main laboratory.

A recent addition to the equipment of the annex is a glass-walled flume constructed with funds of the Office of Naval Research and designed for the primary purpose of studying the mechanics of sediment scour. This unit is 1½ feet wide, 3 feet deep, and 15 feet long, and has three 5-foot panels of ⅛-inch plate glass on each side. The head tank, which may be changed in elevation relative to the flume, is provided with a nozzle-like gate for producing horizontal jets of flume width and variable thickness. Stainless-steel rails support a gage carriage with longitudinal movement to any position. Rates of flow up to 6 cubic feet per second are measured by means of a diaphragm orifice in the 8-inch supply line.

Now under construction with funds provided by the Office of Naval Research is a recirculating flume designed for the study of sediment transportation and also located in the annex. The flume proper has a width of 3 feet, a depth of 1½ feet, and a length of 90 feet. All wall sections are of plate glass. By means of interconnected cams, the slope may be varied about an axis at the midsection between the limits of plus and minus 1%. Flow is produced by two 8-inch axial-flow pumps arranged in parallel and having a total capacity of 10 cubic feet per second; the rate of flow is controlled by variable-speed pump drives. Velocities in the return pipes are sufficiently high to carry the sediment at all flows.

Mention has already been made of the small glass-walled flume used primarily for student instruction. This unit is so convenient to operate that it has also served for many a graduate investigation, and hence deserves mention again at this point. In addition, some
80 feet of steel flume of trapezoidal and rectangular section, used previously for sediment studies, is available for such temporary installations as the side-channel-weir study now being conducted under the J. Waldo Smith Fellowship of the American Society of Civil Engineers.

Water Tunnels

Following completion of the small water tunnel already described under instructional equipment, the Institute constructed at very moderate cost a larger tunnel for fundamental research. The tunnel proper is a closed circuit in the form of a vertical rectangle with vaned turns at each corner. The circular cross section varies gradually in diameter from somewhat over 1 foot just beyond the test section to 3 feet just before the test section, the axial-flow pump in the lower portion of the circuit having a 2-foot diameter. Two interchangeable glass-walled test sections are of the open-throat and closed-throat type, with cross-sectional areas of 1 square foot. For want of direct current, the pump was originally driven by a gasoline engine with remote control clutch and throttle; an electric-motor drive will eventually be installed. Through use of an auxiliary system consisting of a small vacuum pump, tank, and circulating pump, the pressure head at the test section may be varied from 30 to 30 feet of water at velocities of flow from 8 to 35 feet per second. Fundamental tests conducted with this facility have included cavitation studies on several systematic series of head forms, gate slots, and jets.
Now under construction with funds provided by the Office of Naval Research is a second tunnel of somewhat larger capacity and considerably more refined design. Although the cross-sectional area at the test section is again 1 square foot, the axis of the circuit is some 30 percent greater in length and the diameters of the pump and approach sections are accordingly 2.5 feet and 4 feet respectively. All interior surfaces of the tunnel are of stainless steel. Three interchangeable test sections are planned, the initial one having a cross section 6 inches by 24 inches for tests on two-dimensional forms.

Air Tunnels

In 1943 the Institute constructed the first of its low-velocity air tunnels for wartime investigations under the Office of Scientific Research and Development. This tunnel has since been in almost constant use, with as many as four distinct projects being conducted simultaneously in day and night shifts. The tunnel proper has a width of 6 feet, a height of 4 feet, and a length of 20 feet, and is so constructed of removable hardboard panels as to be readily adaptable to various requirements. Because of the original necessity of contaminating the air stream with either gas or heat, thus making recirculation unfeasible, the tunnel draws fresh air from the four north windows of the laboratory and exhausts on the east and west sides. Flow is produced by means of a centrifugal fan at the down-stream end, powered by a 7½ horsepower variable-speed motor. Air speeds from 1 to 25 feet per second may be obtained. In view of the new tunnel now nearing completion, this older tunnel will eventually be rebuilt as a recirculating unit of smaller cross section and higher air speed, for use in graduate research.

The new tunnel, located in the annex and constructed through funds provided by the Office of Naval Research, has a test section with a length of 30 feet and a cross section in the form of a 5-foot octagon. The entire front of the test section is of plate glass for ease in observation. Flow is produced by means of a standard airplane propeller with shortened blades, hydraulic transmission of power from the 20-horsepower electric motor to the propeller permitting accurate control of speed. Air velocities at the test section reach a maximum of 100 feet per second.

The original tunnel continues to be used for studies of pressure distribution and turbulence, often in close correlation with the
water tunnel. The new tunnel is intended initially for studies of boundary-layer development on surfaces of controlled roughness in connection with the underwater resistance of ship hulls. Air is used in such investigations because of the greater economy and convenience of operation in comparison with water and the relative difficulty—at least for the time being—of measuring turbulence in water.

**Sedimentation Equipment**

In addition to the several permanent flumes designed for the study of sediment scour and transportation, special facilities are constructed for specific investigations as they arise. Among these may be mentioned the Loup River project, which involved the determination of transport characteristics for flow over fine silt; the Rio Paraiba project, dealing with the diversion of bed load from the intake of a Brazilian pumping installation; and the current project on bridge-pier scour sponsored by the Iowa State Highway Commission and the Federal Public Roads Administration. The latter is being conducted in two parallel channels each 5 feet wide, 2 feet deep, and 40 feet long, in the laboratory annex.

The conduct of such tests requires extensive equipment for both the preparation of the sediment and the analysis of samples. The Institute has at hand a considerable quantity of quartz sands in various grades, and an air-tunnel separator for the quantity preparation of bed materials of any desired characteristics. Apparatus for sample analysis includes standard screens, filters, drying ovens, balances, bottom-withdrawal tubes, and special units for precise measurement of the velocity of fall and for the rapid analysis of suspended materials by the stratification process.

**Plumbing Units**

Past and present contracts with the National Association of Master Plumbers and other agencies in this field have led to the assembly of equipment for both demonstration and investigation of various plumbing arrangements encountered in building construction. These include a transparent model of the plumbing system of a schematic dwelling, and a unit to illustrate the dangers and prevention of water pollution through back siphonage. Equipment is also at hand for the study of stack requirements, water hammer, vacuum breakers, and the performance of standard and
new devices. At the present time the plumbing investigations are being conducted in the Testing Materials Laboratory of the Engineering College.

**Instrumentation**

The Institute has at hand a wide assortment of devices for the measurement of depth, velocity, pressure, and discharge, some of which are commercial products but most of which have been constructed in the laboratory shops for specific purposes. A variety of adjustable mounts for point and hook gages and other instruments permit either screw or rack-and-pinion displacement over short or long distances, with verniers reading to 0.001 inch for the former and to 0.001 foot for the latter. Pressure gages include the Bourdon type with dials from 4 to 10 inches in diameter for negative as well as positive values; manometer banks, both standard and precision-reading; direct-reading differential water manometers; and zero-displacement differential manometers accurate to 0.001 foot of mercury and 0.001 inch of alcohol. Velocity meters include both cup and screw current meters; Prandtl-type Pitot tubes; stagnation tubes; differential-pressure direction vanes; three-component Pitot tubes; and sensitive midget anemometers for air flow. Discharge meters comprise a considerable assortment of orifice, nozzle, Venturi, and elbow meters, weir tanks, and small weighing tanks. The two large weighing tanks described under basic equipment permit the accurate calibration of all such measuring equipment.

Within the past five years the Institute has developed a well-equipped electronics section, with the result that a considerable portion of its instrumentation for fundamental research involves present-day electrical methods. Noteworthy developments in this connection have been the constant-temperature hot-wire anemometer for the measurement of turbulence in air; the electronic Pitot tube for measurement of turbulence in water; and electrical-analogy equipment for the study of irrotational flow in three dimensions. This section also services the various devices used for the study of sound and cavitation and for high-speed photography.

Equipment for visual and photographic observation of flow phenomena includes a number of high-intensity light sources, single-flash units, and stroboscopic lamps. The Institute possesses both still and moving-picture cameras, editors, and projectors, including a device for studying film records frame by frame in the analysis.
of turbulence. A considerable part of the photographic work of the Institute, such as the preparation of films for instructional purposes and the illustration of thesis investigations, is handled by the photographic service of the University.

**Estimated Value of Plant and Facilities**

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<th>Buildings and Appurtenances</th>
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<tr>
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<tr>
<td>Gage house and cableway (1921)</td>
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<td>North wing and penstock (1923)</td>
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<td>Piping</td>
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<td>Air tunnel</td>
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<td>Pipe assemblies</td>
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<td>Scour channels</td>
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<td>Tanks and scales</td>
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### Shops and Stock

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**Total** $340,000
REVIEW OF INSTITUTE RESEARCH

HYDROLOGY

In order to provide useful hydrologic data for small watersheds, measurements of rainfall, runoff, and ground-water levels have been recorded since 1924 for the upper branch of Ralston Creek. The records, obtained by graduate assistants under the direction of Professors Nagler, Lane, and Howe, represent those of longest duration for a region of small drainage area (3 square miles) in the United States, and are in frequent demand by various agencies. A similar project on nearby Rapid Creek was started in 1941. The U. S. Weather Bureau has provided recording rain gages and publishes rainfall data for the two basins in monthly "Climatological Summaries." Standard gaging stations maintained by the U. S. Geological Survey provide continuous records of runoff. The Institute has also operated a Class "A" evaporation station in cooperation with the Weather Bureau since 1936. The unique data furnished in these studies have been the basis for investigation of various hydrologic phenomena as described in theses (see abstracts in following section) by Revell, Albertson, Carstens, Moorman, and Smith. Studies have been made of ground-water flow, infiltration rates, and time of concentration of runoff.

SEDIMENT

One of the most comprehensive projects ever conducted at the Institute was a cooperative investigation of the methods used in the measurement and analysis of the sediment load of streams, involving the joint efforts of the Tennessee Valley Authority, Corps of Engineers, Department of Agriculture, Geological Survey, Bureau of Reclamation, Indian Service, and the Institute, under the direction of Professor Lane. The project included an extensive survey of the literature, the development of improved samplers and techniques of sample analysis, and the preparation of a series of reports covering each aspect of the investigation. Seven of the proposed nine reports were published by the Iowa City Sub-Office of the St.
Paul District, Corps of Engineers, and are listed in the section on Engineer Corps Reports later in this Bulletin.

Under Professors Lane and Kalinske a long-term program of analytical and experimental studies was carried out, involving the interrelationship of flow characteristics and sediment characteristics. Particular attention was given to prediction of the suspended load of streams through analysis of the turbulence and bed-sediment properties. A special study was made of the transport function of a particular section of the Loup River in connection with power development. Publications on this subject are listed under Reprints 13, 19, 21, 28, 33, 35, 38, and 58 (see list at end of bulletin) and graduate theses by Pien, Hsia, and Lei.

A rather extended series of graduate theses on the subject of fall-velocity characteristics and their use in size-frequency determinations has been supervised by Professors Rouse and McNown. These have dealt with the behavior of sediment in upward flow, the effect of particle size, shape, and proximity upon settling rates, the prediction of size from bulk fall-velocity determinations, and the development of equipment for rapid size-frequency measurement. Reference is made to theses by DeLapp, Lee, McPherson, Engez, Malaika, and Skidmore, and to Reprint 47.

The Institute recently completed a study of bed-load movement through a portion of the Rio Paraiba, a Brazilian stream on which a pumping plant is being constructed as part of a hydroelectric project. The purpose of the investigation was to determine the best means to divert the bed material from the pump intakes through use of groins and training walls, together with planned gate operation. The experiments were conducted by Mr. Laursen on a 1:75 concrete model of the river section under contract with the Canadian and General Finance Co., Ltd.

**Open-Channel Flow**

A continuing project of the Institute, partially supported by The Engineering Foundation through the Committee on Hydraulic Research, Hydraulics Division, American Society of Civil Engineers, dealt with the design of open-channel expansions in supercritical flow. Work on this project is described in part in the abstracts of theses by Bhoota and Hsu, and in full in the paper “Design of Channel Expansions for Supercritical Flow,” presented by Messrs.
Rouse, Bhoota, and Hsu at the 1948 Annual Meeting of the A.S.C.E. and thereafter submitted to the Society for publication.

Turbulence in open channels was investigated under the direction of Professor Kalinske as a part of his fundamental study of turbulence and sediment transportation. Current-meter measurements made in the Mississippi River by the Corps of Engineers were analyzed statistically, as were small-scale measurements made in the laboratory by means of motion pictures of dye streaks and immiscible droplets, to provide information on the intensity and scale of turbulence pattern. Analyses of the data may be found in the thesis by Pien and Reprints 20, 24, 26, 27, 37, 42, 43, and 59.

Two investigations of open-channel waves have been made in an enclosed flume containing a mechanical wave generator and means of varying the relative velocities of the water and the air above. These investigations included an evaluation of the effect of wind on the generation and breaking of waves, and the design of closed conduits flowing partly full. A similar investigation of internal waves was conducted in collaboration with the Oceanographic Section of the U. S. Radio and Sound Laboratory in 1942. The stability of internal waves and the effects upon them of breaking surface waves were studied qualitatively in connection with problems of submarine detection.

Miscellaneous projects dealing with open-channel flow have included the design of stilling basins, the relationship of the laminar-turbulent and the tranquil-rapid categories, the hydraulic jump, and the characteristics of flow over side weirs. These have been supervised by various members of the Institute staff, and are described in the thesis abstracts of Dubrow and Goodrum, Behera and Qureshy, Thorssen, Forster and Skrinde, Yen, Lyon, Montaña, Moreno-Gomez, and Feldt, and in Reprints 25, 48, and 68.

**Pipe Flow**

Since the accumulation of air at high points in pipe lines may often be a serious problem, the possibilities of removing the air by flowing water were studied under Professor Kalinske in a project sponsored for two successive years by the J. Waldo Smith Fellowship Committee of the American Society of Civil Engineers. The most important factor in the process of air removal was found to be the formation of a hydraulic jump at the downstream end of the pocket. Criteria for determining the effectiveness of the jump
in removing air are presented in theses by Bliss and Robertson and in Reprints 40 and 56.

In an investigation of the characteristics of flow at sudden and gradual pipe expansions, Professor Kalinske determined the characteristics of the induced turbulence and the conversion of kinetic to potential energy. The loss of energy was found to be considerably greater than the increase in turbulence energy, indicating that a major portion of the loss in mechanical energy is converted to heat energy directly in regions of intense shear. The results of this study, which received the 1947 Karl Emil Hilgard Prize of the A.S.C.E., are presented in Reprint 69.

A fundamental investigation of both converging and diverging flow in branching pipe lines was started by Professor McNown in 1945 with the sponsorship of The Engineering Foundation and the Hydraulic Research Committee, Hydraulics Division, A.S.C.E. The changes in pressure occurring at the junction for lateral and main conduit flow were determined experimentally for a single lateral with diameters $\frac{1}{4}$, $\frac{1}{3}$, and 1 times that of the main conduit for the entire range of lateral-to-main-pipe discharge ratios. The results are verified by approximate analyses based on modified energy equations. Theses by Barton, Niaz, and Escobar contain the details of the investigation.

PLUMBING

Prior to the war the National Association of Master Plumbers sponsored research work at the Institute on many phases of building plumbing, particularly in connection with venting requirements and the prevention of water pollution. The results of the studies, conducted under the supervision of Dean Dawson and Professor Kalinske, were published in Technical Bulletins 1-3 of the N. A. M. P. and in numerous articles in trade journals. Extensive work was done during the war years on the testing and certification of traps for the removal of grease from plumbing systems in army cantonments, and on the improvement of such units. Numerous devices such as vacuum breakers, valves, traps, and hydrants were tested from time to time on short-term contract with commercial firms. Reference is made to Reprints 14, 39, 52, and 54.

FREE AND SUBMERGED JETS

Near the end of the war the Institute undertook under contract
with the Bureau of Ships the improvement of fire streams from fixed and portable fire monitors. Since the concentration and throw of the streams as compared with the characteristics of their ideal trajectories depend essentially upon the initial turbulence of the flow, monitors and nozzles were developed which reduced the turbulence to a practical minimum. Comparative measurements were made of concentration and throw for both existing and improved monitors, and the latter were then completely evaluated over the working range of base pressure and inclination. The results of the initial phases of the investigation were summarized in Reprint 67, and a final report is in preparation.

An investigation of submerged jets was begun in connection with the development of burners for the FIDO project and continued thereafter under the sponsorship of the Bureau of Ships and the Office of Naval Research. This study included both two- and three-dimensional flow conditions, originally restricted to jets emerging into a relatively large body of fluid, but more recently extended to the case of pipe expansions, submerged sluice gates, and propeller slip streams. A paper by Albertson, Dai, Jensen, and Rouse in the December 1948 issue of the A.S.C.E. Proceedings summarizes the original study of the mean pattern of motion, and theses by Baines and Liu cover additional aspects.

AIR-TUNNEL INVESTIGATIONS

Requests during World War II for the investigation of unusual fluid-mechanics phenomena led to the construction of the low-velocity air tunnel described as a part of the Institute facilities (see Reprint 65). Perhaps the most significant study was related to the removal of fog from airfield runways by raising the temperature of the air above the runway. Three methods were investigated: (1) free convection of heat from a row of burners upwind from the runway, (2) forced convection of heated air issuing vertically from a horizontal slot also some distance upwind from the runways, and (3) creation of a large eddy over the runways by means of baffles or air jets upwind from the runways, the heat being supplied to the eddy by a row of burners along the downwind side.

Systematic information on the performance of the first method of fog dispersal known as FIDO was obtained, including the relation of the local temperature increase to the wind velocity and rate of heat release. The low efficiency of this method, which resulted
from the fact that free convection alone does not produce the most effective thermal pattern, led to an investigation of the other types. In the latter a large eddy of the desired proportions was maintained over the runways, and heating of this relatively stable mass of air was found to require only 25-35% as much heat energy. An efficient type of burner adapted to the requirements of fog dispersal was developed as a part of the investigation. Six reports and one motion picture submitted to the N.D.R.C. between 1943 and 1945 describe these investigations, and Reprint 62 contains a detailed analysis of the first method.

At the request of the Chemical Warfare Service an air-tunnel investigation of the diffusion of smoke and gas in urban districts was undertaken under N.D.R.C. auspices. Preliminary tests involved correlation studies on schematic building forms at various scales and air speeds to validate the dimensionless parameters used in the analysis. Systematic measurements on various arrangements of schematic buildings provided the steady-state distribution of gas concentration, and indicated that the gas was rapidly carried into the air above by the eddies produced in the air flow past the structures. Specific studies were made for typical Japanese villages. Agreement between steady-state diffusion and that following a gas-bomb burst was established by a comparison of air-tunnel and field data, the latter being obtained at the Dugway Proving Ground. Four reports and a motion picture were submitted to the N.D.R.C. on various aspects of this study.

At the request of the Meteorological Section of the Army Air Forces, the air-tunnel was also used to determine whether measurements of wind currents over models of terrain would yield useful data on meteorological phenomena. The problems of large-scale turbulence over mountainous terrain were investigated using standard air-tunnel techniques. For less irregular terrain, small-scale measurements were found to introduce experimental errors, and the effect of a distortion of vertical scale was investigated on idealized shapes. Semi-ellipsoids, parallelopipeds, and cones of various proportions were tested in addition to two- and three-dimensional idealized mountain forms with sinusoidal profile. Although no simple method of estimating the effect of scale distortion was found, reliable qualitative indications were obtained. Two reports were submitted to the N.D.R.C. and two to the Weather Service of the Army Air Forces describing these exploratory investigations.
In addition to the foregoing investigations for the solution of specific problems, a fundamental study of the effect of screens and perforated plates on flow in closed conduits was conducted. The energy loss as reflected by the drop in pressure across the screen, the characteristics and variation of the resulting turbulence, and the effect of screens on the velocity distribution of the mean flow were investigated. The geometry of the screens was varied over a wide range using perforated plates and lattices of square bars, the open area varying from 25% to 75% of the total area. Turbulence characteristics were determined by means of hot-wire anemometry and both gas and heat diffusion. Systematic results on the drop in pressure as a function of the area ratio were obtained and substantiated by approximate analyses. The scale, intensity, and eddy diffusivity of the induced turbulence were determined, as well as the variation of these quantities with distance downstream from the screen. Finally, the effect of screens on irregularities in the velocity distribution of the approaching flow were found to agree reasonably well with approximate analyses, providing that the proportion of open area was not less than 50%. Two reports concerning these studies were submitted to the David Taylor Model Basin of the Bureau of Ships and a final report is being prepared for the Office of Naval Research.

Cavitation Studies

Since completion of the Institute water tunnel in the spring of 1944, continuous research on pressure distribution and cavitation has been conducted for various branches of the Navy. Bulletin 32 contains a complete description of the facilities, the preliminary tests on tunnel characteristics, and a detailed summary of the investigation of the flow with cavitation past a variety of head forms at zero angle of yaw. Basic information concerning the effect of cavitation on the pressure distribution and the geometry of the vapor pocket was sought for head forms of widely varied geometry. Series of rounded, conical, and ellipsoidal head forms ranging from elongated to blunt and concave profiles were investigated as well as several modified forms. Approximate analyses of the longer forms were used to verify the results and to provide a reliable means for both interpolation of intermediate profile forms and extrapolation to longer forms than those tested. A modified ellipsoidal profile with a partially blunt nose was found to be less likely to
produce cavitation than other forms of the same ratio of maximum diameter to length of curved portion. Cavitation for the shorter forms, which invariably occurred initially along the boundary of the zone of separation, was observed to take place well before the pressure along the profile boundary had been reduced to the vapor pressure. In addition to Reprint 66 and Bulletin 32, seven reports have been submitted to the N.D.R.C., thirteen to the Bureau of Ships, and one to the Office of Naval Research on various phases of this study.

In a subsequent investigation, several representative profiles were tested with axes inclined at small angles to the direction of the approaching flow (see thesis by Lamb). Pressure distributions for inclined flow with and without cavitation were determined for long, intermediate, and blunt forms, the asymmetric geometry of the pocket forms being noted also. The pressure distribution for cavitation-free flow past the longer form was also determined analytically, remarkably good agreement being found between the two results.

The relationship between pressure distribution and cavitation has also been investigated for two-dimensional flow past a slot or discontinuity in the boundary (see thesis by Abul-Fetouh). Rectangular slots with various geometrical proportions and various superelevations of the downstream edge were investigated for flow without cavitation and with various degrees of cavitation; the limiting case of zero slot dimensions, representing a simple boundary discontinuity such as a joint or flaw in a conduit boundary, was also studied. The tendency toward cavitation was found to be directly affected by the relative magnitudes of the superelevation and the boundary-layer thickness. Because of the relative simplicity of large scale measurements, a more thorough investigation of boundary-layer effects was conducted in the low-velocity air tunnel. The formation of a long cylindrical vortex within the slot was found to affect to a considerable degree the pattern of flow in the vicinity of the slot.

**Potential-Flow Determinations**

For a number of instances in which the pattern of flow is essentially irrotational, reliable results have been obtained between theory and electrical analogy. Both methods have been used to determine the flow pattern past various projectile forms, through
boundary transitions, for free jets, and for seepage through porous media. The exact methods of hydrodynamics have been used where applicable, the approximate methods of von Kármán and Southwell serving in other instances. Both two-dimensional and axisymmetric flow patterns have been evaluated.

The electrical analogy was adapted to axisymmetric flow by duplicating only a small segment of the flow on a slightly inclined table. The boundary form could then be closely approximated without double curvature, the intersection of the level surface of the electrolyte and the table representing the axis of revolution of the boundary and flow pattern. Flow around submerged bodies was simulated in a large electrolyte bath. The agreement among three different types of results — namely, experimental, analytical, and electrical — has been proven satisfactory in a number of instances. Theses concerning electrical analogy have been presented by LeClerc and Hassan, in addition to one report to the Taylor Model Basin and one to the Office of Naval Research. A description of the electrical analogy for axisymmetric flow has been published in Reprint 76, and a part of the theoretical studies were summarized in Bulletin 32 and Reprint 66.

**INVESTIGATIONS OF SHIP-MODEL TESTING**

Studies of various phases of ship-model testing were conducted in the river channels of the Hydraulics Laboratory to provide information for the design of the large circulating model basin at the David Taylor Model Basin. Ship models, friction planes, and spheres of various sizes were tested to provide information on the effect of model-to-channel cross-sectional area ratio and of the degree of turbulence in the water on the drag of the model and the distribution of velocity and pressure. Corrections for surface slope were found to be essential, and the effect of turbulence was evaluated by means of screens upstream from the model. The possibility of duplicating towing-tank results in a circulating channel was concluded to be very good. The details of this investigation were presented in six reports to the David Taylor Model Basin.
ABSTRACTS OF GRADUATE THESES

Cavitation

Cavitation at Sluice-Gate Slots. Abdel-IIadi Abul-Fetouh. M. S. Thesis, August 1947; Professor Rouse, adviser. Flow characteristics in the vicinity of a sluice-gate slot were investigated for various slot widths, depths, and superelevations of the downstream edge. Results were presented as dimensionless curves of pressure distribution versus the cavitation index for systematic variation of the boundary geometry.

The Effect of Angles of Yaw on Pressure Distribution Around Various Head Forms. Charles A. Lamb. M. S. Thesis, August 1948; Professor McNown, adviser. The effects of small angles of yaw on the pressure distribution around blunt, hemispherical, and 2:1 ellipsoidal head forms were studied both experimentally and theoretically. Close agreement was found between theoretical curves and measured pressure distributions for the 2:1 ellipsoidal head at a 6-degree angle of yaw. Pressure distributions about the hemispherical and ellipsoidal heads were qualitatively similar, but the blunt head produced pressure variations of a different nature owing to modification of the separation pattern. The experimental studies were made both with and without cavitation.

Electrical Analogy

Use of the Three-Dimensional Electrical Analogy in the Design of Conduit Transitions. Mohamed M. Hassan. Ph. D. Dissertation, August 1948; Professor Rouse, adviser. A systematic family of boundary contractions was constructed according to elementary mathematical functions and the flow characteristics of each successive form were determined by means of the three-dimensional electrical analogy. Comparison between boundary curves composed either of two cubical or two circular arcs, tangent respectively to the entrance and exit sections with a common point of tangency at some intermediate location, indicated the general superiority of the cubical-arc transition. Interpolation diagrams, developed as part
of the study, may be used to select cavitation-free or separation-
free contractions for the practical range of diameter and length 
ratios. (See Reprint 77.)

**Deflection of a Liquid Jet by a Perpendicular Boundary. Andre 
LeClerc.** M. S. Thesis, August 1948; Professor Rouse, adviser. The 
shape of the free surface and the internal flow pattern of a vertical 
jet deflected by a horizontal boundary were determined through 
application of the electrical-analogy and relaxation methods, re­
spectively. Results are given in dimensionless form, showing free­
surface profile, flow pattern, and velocity and pressure distribution 
along the plate and the centerline of the jet.

**EVAPORATION**

**The Effect of Freeboard on Evaporation from a Class “A” 
Evaporation Pan. Russell W. Revell.** M. S. Thesis, February 
1941; Professor Howe, adviser. The effect of freeboard was studied 
through use of three standard land evaporation pans. The water 
level was maintained at constant elevations in two of the pans and 
allowed to vary according to standard Weather Bureau procedure 
in the third. Wind velocities and water and air temperatures were 
observed in the vicinity at frequent intervals. Results indicated 
that the pan with a 3-inch freeboard evaporated less water at low 
wind velocities and more at high velocities than did the pan with 
the 2-inch freeboard and were explained in terms of the scale of 
turbulence caused by the pan rim.

**Analysis of Evaporation as a Boundary-Layer Phenomenon. 
Maurice L. Albertson.** Ph.D. Dissertation, January 1948; Pro­
fessor Rouse, adviser. The effect of different types of boundary 
layer and the extent of their development upon the rate of evapora­
tion from porous surfaces was studied in a low-velocity air tunnel. 
It was shown experimentally that an evaporation layer forms over 
a smooth evaporating surface in a manner similar to the formation 
of the boundary layer over a smooth body. Following a discussion 
of the principles of diffusion and a review of boundary-layer the­
ory, evaporation-layer equations were developed and adapted for 
application to field conditions. (See Staff Publications.)

**HIGH-VELOCITY FLOW**

**The Spreading of a Water Jet on a Flat Floor. Enver Murat­
zade.** M. S. Thesis, August 1939; Professor Lane, adviser. This
thesis was the first of a series studying the spreading of a jet of water at supercritical velocities on a level floor. The object was to obtain data for use in the design of spillway chutes at the entrance to stilling pools. Data were obtained on the expansion of flow from rectangular outlets of various width-depth ratios.

**The Flow of Water in Transition Sections of Rectangular Channels at Supercritical Velocities.** Warren E. Wilson. Ph.D. Dissertation, August 1940; Professor Lane, adviser. This investigation was a continuation of the work of Muratzade, attacking the problem from the standpoint of wave analysis. Expansion of the jet was guided through use of reverse-curve transitions. The application of the wave theory to the flow patterns is brought out and the process by which such conditions can be analyzed is outlined. The existence of underpressures along the sides of the channel is discussed.

**Characteristics of Supercritical Flow at an Abrupt Open-Channel Enlargement.** Baboobhai V. Bhoota. Ph.D. Dissertation, December 1942; Professor Rouse, adviser. This study applied the method of gravity-wave analysis to the boundary condition investigated by Muratzade. Surface-contour maps for a wide range of Froude numbers and width-depth ratios were reduced to a single generalized diagram. Tests were made in this investigation for three different breadth-depth ratios of the section of initially uniform channel flow — the ratios, respectively, being 2, 4, and 8 — and for Froude numbers \( F^2 = \frac{V^2}{gd} \), varying in steps of \( \sqrt{3} \), from 1 to 27. Measurements were made of surface profile, pressure distribution along the floor and walls, and stream-line configuration.

**Characteristics of Supercritical Flow at a Gradual Open-Channel Enlargement.** En-Yun Hsu. M.S. Thesis, February 1946; Professor Rouse, adviser. The experimental work of Bhoota was extended for channel expansions with curved divergent walls for different Froude numbers and width-depth ratios, and checked by the methods of characteristic-curve analysis. The results are expressed as a generalized channel-transition shape in terms of the Froude number and the width-depth ratio.

**Hydraulic Jump**

**The Effect of Certain Fluid Properties Upon the Profile of the Hydraulic Jump.** Morgan D. Dubrow and John C. Goodrum. M.S.
Thesis, June 1940; Professor Posey, adviser. The effect of surface tension and viscosity upon the profile of the hydraulic jump was investigated experimentally. Tap water and solutions of Aerosol were used in a 6-inch flume, and water, mixtures of water and glycerine, and kerosene in a 2-inch flume. No well-defined trends were noted, but the profile of the jump seemed to become steeper as the viscosity increased.

**A Length Criterion for the Hydraulic Jump. Bhubaneshwar Behera and Asrar Ahmad Qureshy.** M. S. Thesis, February 1947; Professor Posey, adviser. The length of jump was determined as the distance from the toe to the section where a cylinder placed on the floor of the flume would just topple. A series of 16 different cylinders of different sizes, shapes, and specific gravities were used.

**Control of the Hydraulic Jump by Sills. John W. Forster and Raymond R. Skrinde.** M. S. Thesis, February 1947; Professor Rouse, adviser. A combined analytical and experimental investigation was made of the formation and means of control of the hydraulic jump in a horizontal rectangular channel by use of vertical non-aerated baffles and abrupt rises in the channel bottom. Graphical relations were developed from which sill dimensions for preliminary design purposes may be selected or the behavior of existing sills predicted. (See *Proc. A.S.C.E.*, Vol. 75, No. 4, p. 469, April, 1949.)

**HYDROLOGY**

**Studies on Runoff from River Bottom Lands. Marvin O. Kruse.** M. S. Thesis, June 1940; Professors Lane and Howe, advisers. A study of actual field data on six drainage districts along the Illinois and Mississippi Rivers gave relations between seepage into the districts and river stages outside the levees.

**Analysis of Discharge-Recession Curves for Three Iowa Streams. Julian R. Fleming.** M. S. Thesis, August 1941; Mr. B. S. Barnes, adviser. An analysis of the discharge hydrograph of Rapid Creek, by breaking it down into three components. Study of the records for Rapid Creek revealed that each of the component flows plotted on semi-logarithmic paper as straight lines and the slopes remained practically constant for all hydrographs studied. Studies extended to Skunk River Basin (13 times larger) and Wapsipinicon River Basin (100 times larger) were found to apply equally well.
Ground-Water Flow in Rapid Creek Watershed. Maurice L. Albertson. M. S. Thesis, July 1942; Professor Howe, adviser. A comparison study was made between low flows in Rapid Creek (25-square mile area) and ground-water elevations in certain unpumped wells located within the basin. Data for the years 1941 and 1942, while not in agreement, showed a consistent logarithmic relation between low flow and ground-water elevation in each year. Relations also were developed for predicting low flows providing no precipitation occurs.

Synthesis of the Runoff Hydrograph on Ralston Creek. Marion R. Carstens. M. S. Thesis, June 1947; Professor Howe, adviser. A procedure for producing a synthetic hydrograph was developed and results were compared with particular occurrences on Ralston Creek. Procedure was rather complicated, maximum discharges not checking closely in every case, but total discharges by synthetic method agreed well with observed figures.

A Comparison of Maximum Runoff Formulas with Actual Measurements on Certain Watersheds in Iowa. Fu-Huan Fang. M. S. Thesis, June 1947; Professor Doty, adviser. A compilation was made of various empirical formulas in general use for the estimation of the maximum rate of runoff from small and intermediate sized watersheds, followed by a brief analysis of their suitability in application to certain watersheds in Iowa and a comparison of their application with measured figures.

A Study of Infiltration on Rapid Creek Watershed. Robert W. Moorman. M. S. Thesis, August 1947; Professor Howe, adviser. A 5-year rainfall record at four rain gages on the Rapid Creek watershed (25 square miles) and the corresponding runoff record at a gaging station near the mouth were analyzed to determine the relation between length of storm and average infiltration rate during the storm. Antecedent soil-moisture conditions were assumed to be reflected by the flow preceding the storm. Variation in Horton's "i" index" was found to be between 1.4 and 0.19 inches per hour for storms varying in length from $\frac{1}{2}$ to 6 hours.

A Study of Concentration Time on Ralston Creek Watershed. Robert L. Smith. M. S. Thesis, August 1948; Professor Howe, adviser. The intensity and amount of rainfall and the initial moisture index as determined from antecedent rainfall records were investigated as a means of evaluating the time of concentration on small
watersheds. The correlation of these factors was studied graphically as a function of time and a consistent relation discovered for the Ralston Creek watershed.

**Miscellaneous**

**Hydraulics of Culverts.** Arthur R. Luecker. M. S. Thesis, February 1939; Professor Mavis, adviser. This thesis contains an analysis of hydraulic tests performed on concrete, clay, and corrugated-metal culverts by Messrs. Yarnell, Nagler, and Woodward, and on creosoted wood culverts by Mavis. Entrance-loss coefficients from these and other reports were summarized and tabulated in terms of the ratio of radius of rounding to pipe diameter. Tests were conducted on a model culvert 3½ inches in diameter and 51 inches long and additional data obtained on the effects of rounded and square entrance.

**Chinese River Control During the 16th Century.** Fa-Yao Wong. M. S. Thesis, June 1939; Professor Mavis, adviser. An analytical summary of a collection of reports by Pan Chi-Hsun is presented. Pan was in charge of flood control on the Yellow River from 1565 to 1592 A.D. He is considered to have been one of the most capable Chinese experts in flood control and inland waterways since the first project was undertaken in China in 2297 B.C. Interesting early concepts of methods for the control of floods and sediment are included.

**Experiments on Waves in Rectangular Channels.** Victor A. Koelzer. M. S. Thesis, June 1939; Professor Mavis, adviser. Waves were produced in a rectangular channel and hydrographs at three stations were recorded. Experimental wave velocities were found to check the formula for the solitary wave. An interesting phenomenon, worthy of further research in connection with flood routing, was the gradual rise in the water surface after the wave had passed.

**Design of Outlet Works of the Han River Flood Control Reservoir.** Hsuan Kuo. M. S. Thesis, August 1939; Professor Lane, adviser. A design is presented in this thesis for the outlet works of a retarding basin on the Han River in China which had been proposed to control the floods of this river for the protection of the city of Hankow and adjacent communities.

**Design of a Dam on the Seyhan River, Turkey.** Orhan Akyur-ek. M. S. Thesis, June 1940; Professor Lane, adviser. Design of a
masonry dam consisting of overflowing and non-overflowing sections was examined, taking into account earthquake effects. This dam forms a part of a proposed irrigation enterprise for the plains of the Seyhan River in Turkey.

**Practical Hydraulics in Highway Engineering.** Carl F. Izzard. M. S. Thesis, June 1940; Dean Dawson, adviser. An analytical study was made of all available experimental data on the flow of water through box culverts and adjacent channels. Hydraulic principles were applied to the practical design of highway culverts. The advantages of rounded over square-cornered entrances were demonstrated and general design procedures recommended.

**Reinforcement of Concrete Flume Corners.** Orvill Kofoid. M. S. Thesis, June 1940; Professor Posey, adviser. Arrangements for reinforcing flume corners subject to tensile stresses at the inside of the corners were critically examined and a new design developed. Comparisons with the best design used in standard practice indicated a greater ultimate strength and toughness for the new design.

**The Measurement of Velocity of Flowing Water by Electrical Methods.** Marion C. Boyer. M. S. Thesis, August 1947; Professor Rouse, adviser. Studies were made of the adaptation of electromagnetic or electrokinetic principles as a means of measuring the velocity and turbulence of flowing water. The electromagnetic principle was that of voltage generation in a conductor (water) passing through a magnetic field. The electrokinetic principle was that variation in electrical potential at a liquid-solid interface caused by movement of the water. Electronic devices were developed to magnify the indication.

**A Study of the Characteristics of Gravity Waves at a Liquid Interface.** Chia-Shuuen Yih. M. S. Thesis, February 1947; Professor Rouse, adviser. A combined analytical and experimental study was made of the motion following removal of a barrier between salt and fresh water. A generalized relationship was presented for density differences ranging from 0.05 to 6 percent.

**Vortex over Outlet.** Hsieh-Ching Hsu. M. S. Thesis, June 1947; Professor Posey, adviser. Experiments were conducted in a circular, 6-foot tank with a 4-inch circular sharp-edged orifice at the center of the horizontal bottom, the depth of water being constant and the direction of inflow variable. The strength of the vortex formed
depended upon the ratio of tangential and radial inflow velocity components. With the strongest vortices tested, the discharge coefficient was 25 percent of that for wholly radial flow.

**A Constant-Temperature Hot-Wire Anemometer for the Measurement of Turbulence in Air.** Philip G. Hubbard. M. S. Thesis, February 1949; Professor Rouse, adviser. The development and operating procedures are described for a hot-wire anemometer which depends for its operation on constant wire temperature rather than constant current through the wire. The device offers a simplification in the technique of measuring turbulence in air and materially reduces the time for collection and computation of data. (See Reprint 76.)

**Model Studies**

**Hydraulic Characteristics of a Navigation Lock with Floor Culverts.** Miles M. Dawson. M. S. Thesis, June 1939; Professor Mavis, adviser. An analysis was made of experimental data secured on a lock model built by the U. S. Engineer Department, which indicated that filling and emptying cannot be satisfactorily accomplished by the same culvert system and that the port area in the downstream half of the lock should be less than in the upstream half.

**Comparison of Model and Prototype Performance of Two Miami Conservancy District Retarding Basin Stilling Pools.** John D. Lee. M. S. Thesis, May 1942; Professor Lane, adviser. Operation of prototype and model (1:36) of Germantown and Englewood stilling pools of the Miami Conservancy District was compared. Good correlation between data collected in the field and on the model was reported, except for viscous effects. Splashing was higher and turbulence greater relatively in the model.

**Measurements of Velocity Distribution Around a Stationary Ship Model in Flowing Water.** Wallis S. Hamilton. Ph.D. Dissertation, December 1943; Professor Rouse, adviser. This investigation was made both to demonstrate the practicability of open-channel tests of ship models to gain further understanding of the factors which determine the magnitude of skin friction in curvilinear flow. Specially designed equipment for determining the detailed flow pattern consisted of a three-component Pitot tube with directional traversing mechanism. The study indicated the far greater
convenience of continuous measurement in flowing water, and per-
mitted an approximate evaluation of the effect of hull form on sur-
face resistance. (See Civil Eng., Vol. 16, No. 6, pp. 265-267, June,
1946.)

**Roller-Type Stilling Action.** Harold W. Feldt. M. S. Thesis, August 1945; Professor Posey, adviser. Tests were conducted on the performance of a stilling basin with horizontal apron and stepped sill in a 1-foot glass-walled flume; the primary variables were ratios of head, length of horizontal apron, height of sill, and depth of tailwater to height of dam. Results were shown by 33 photographs and 6 charts covering the range of variables for which stilling action was judged satisfactory. Most attention was given to roller-type action which occurred when tailwater depths were too great for formation of the hydraulic jump.

**A Study of Pressure Distribution on a Series of Two-Dimensional Roof Forms.** George A. Austin, Jr. M. S. Thesis, June 1947; Professor Howe, adviser. Pressure distributions around a series of roof forms were studied in a small air tunnel having a 2x24x36-inch test section. Due to the small width and to the fact that corrections of observed pressures for acceleration at the model section and for tunnel resistance were not made, results were purely qualitative. However, negative pressures were observed at the eaves and on both windward and lee roofs for models having flat roofs and slopes of 1:2 and 1:4 and three different wall heights.

**Pressure Distribution on Models of Three-Dimensional Buildings Exposed to Moving Air.** Ning Chien, Yin Feng, Hung-Ju Wang. M. S. Thesis, June 1948; Professor Howe, adviser. Building models constructed of 1/4-inch lucite plates with suitable piezometer connections, and length-width ratios of 1, 2, and 4; height-width ratios of 1/2, 1, and 3/2; and roof angles of 0°, 15°, and 30°, were tested in a low-velocity air tunnel with approaching wind directions of 0°, 45°, and 90°. Contour maps of pressure distribution, prepared from the test results, show that positive pressures occurred on the windward walls only, while severe negative pressures were found near the upwind roof corner with a quartering wind. Recommendations supplementing the A.S.C.E. structural code were made on the basis of the analysis.

**An Investigation of the Aerodynamic Stability of Bridge Sections.** Elmo G. Peterson. M. S. Thesis, August 1948; Professor
Rouse, adviser. Tests of typical deck and girder sections for sus-
pension bridges were made in low-velocity air tunnel. In each test
the deck was 1 foot wide by 2 feet long; two sets of plate girders
were used, one 1.8 inches by 2 feet and the other 3.6 inches by 2
feet. Pressure-distribution, lift, and moment graphs were prepared
for various angles of incidence and the vertical and torsional sta-
bility determined. Stabilizing effects of slots of different widths cut
in the deck alongside the girders were investigated.

A Model Study of Tainter-Gate Operation. Donald E. Metzler.
M. S. Thesis, August 1948; Professor Rouse, adviser. The discharge
coefficient and forces on a scale-model Tainter gate were determined
over the complete range of operation for both submerged and free-
flow conditions. A systematic experimental procedure was outlined
and a simplified method of plotting the data was developed through
the use of dimensional analysis. The model was a 1:13.9 repro-
duction of one of several Tainter gates to be installed in the diver-
sion dam of the Santa Cecilia pumping plant of the Sao Paulo
Tramway, Light and Power Co., Ltd., Sao Paulo, Brazil.

Diffusion of Flow from a Submerged Sluice Gate. Hsin-Kuan
Liu. M. S. Thesis, February 1949; Professor Rouse, adviser. The
mean flow pattern of discharge under a submerged sluice gate into
tailwater depths of finite magnitude and over a limited range of
Froude numbers was studied. Expansion length, velocity distribu-
tion in the vertical, velocity distribution along the bottom, coeffi-
cients of contraction, and water-surface profiles were the principal
features investigated. Results were presented in dimensionless form.

Open-Channel Flow

A Comparison of Lacey’s Stable Channel Relations with the
Conditions in the St. Clair and Lower Mississippi Rivers. Chung-
Teh Li. M. S. Thesis, June 1940; Professor Lane, adviser. For the
purpose of this thesis two river channels were selected which were
known to be relatively stable. An attempt was made to compare
their cross sections with those which would be indicated for those
conditions by Lacey’s formulas for irrigation canals in India. Nei-
ther of the sections showed close agreement with Lacey’s theories.

Determination of Best Proportions for Canal Bend. Chen-Hsing
Yen. Ph.D. Dissertation, February 1941; Professor Howe, adviser.
The effects of widening, narrowing, or deepening a bend of 5-foot radius in a rectangular channel 11 inches wide and 10 inches deep were investigated. The cross-sectional area was kept constant for a given discharge and head losses for various conditions were compared. An 11-percent reduction in head loss was observed when the channel width was decreased 30 percent at the midpoint of the bend; a reduction in head loss of about 10 percent resulted when the channel was widened 15 percent by moving the inside wall of the bend away from the center of the channel. (See Reprint 48.)

An Experimental Study of the Flow of Water Through Transitions in Rectangular Open Channels. George B. Lyon. M. S. Thesis, February 1942; Professor Posey, adviser. Observations were made of flow through a single narrowing transition from a rectangular channel 1 foot wide to $\frac{1}{2}$-foot wide, with flat bottom throughout, for three conditions of bottom slope. The walls of the transition were planes intersecting the walls of the flume at an angle of approximately 14°. Flow conditions for four regimes were observed. Flow from deeper than critical to shallower than critical, impossible by the elementary theory unless the transition has a throat, was clearly demonstrated to occur over a fairly wide range.

A Study of Possible Extensions of the Huai River Flood-Control Plan. Pao-Fu Chu. M. S. Thesis, July 1942; Professor Lane, adviser. Consideration of further controlling floods on the Huai River by flushing the bed of Old Yellow River and reclaiming Hungtze Lake led to recommendation of step-by-step procedure for development within the limited funds available for the project.

A Study of Stream Meanders. Daniel Escobar-E. M. S. Thesis, April 1944; Professor Posey, adviser. The relations between the variables which are considered to be basic in the meander phenomenon were studied by use of data collected on mountain streams in Colorado, a creek and river in Iowa, and in directive energy studies at the Waterways Experiment Station, Vicksburg, Mississippi. Tentative conclusions relative to slope, flow in erodible material, time rate of change of meander pattern, and geometry of the pattern were reached.

Experimental Study of the Free Overfall as a Function of the Froude Number. Jaime M. Montaña. M. S. Thesis, April 1945; Professor Posey, adviser. A study was made of the surface profile of flow approaching a free fall in an open channel at velocities.
higher than the critical. Profiles were observed for Froude numbers ranging from 2 to 20 in a channel 0.4 foot deep, 1 foot wide and 8 feet long. Empirical formulas to fit the data were developed and comparison made with the work of Rouse and Woodward.

**Unsteady Flow Problems from Massau's Line of Attack.** Pin-Nam Lin. M. S. Thesis, June 1947; Professor Posey, adviser. The theoretical basis of the method of characteristics, first applied to the study of general problems of unsteady flow in open channels by Junius Massau in 1895-1900, was examined. It was shown that the equations of the characteristics can be derived in several different ways, and that the general equations of steady flow can be obtained from the equations of the characteristics. A graphical trial-and-error solution of a specific problem was included. (See Staff Publications.)

**An Experimental Study of Backwater Curves.** Hsu-Hua Hu. M. S. Thesis, February 1947; Professor Posey, adviser. The purpose of this investigation was to make an experimental study of backwater curves with steady flow in uniform flumes. Curves of the types M1, M2, H2, and S1 were developed experimentally and compared with theoretical curves developed through use of the Manning equation. The comparison for the M1 and M2 curves was good if the Manning n was taken as 0.015; for the H2 curve n had to be taken as 0.023; the S1 curve could not be closely approximated unless n were taken nearly equal to zero.

**Pipe Flow**

**Correlation of Experimental Data and Rational Equations on Boundary Roughness and Resistance.** Frederick L. Hotes. M. S. Thesis, August 1941; Professor Rouse, adviser. An analysis was made of field data and the equations of Kutter, Manning, and Bazin in the light of the Kármán-Prandtl-Nikuradse relations for surface resistance and a rational formula for evaluation of the Chezy C was derived.

**Entrainment of Air in Pipes by Flowing Water.** James M. Robertson. Ph.D. Dissertation (J. Waldo Smith Fellowship), August 1941; Professor Kalinske, adviser. A study was made of air entrainment by a hydraulic jump in a 6-inch pipe for various slopes, depths, and velocities of flow. The air demand, expressed as a fraction of the water discharge, was determined as a function of the
Froude number of the jump. This study was concerned with the movement of air in a pipe line by the hydraulic jump, the dragging effect of high velocities, and the entrainment at the end of an air pocket. The relations of slope of pipe, depth of flow, and velocity of flow with the amount of air moved were determined. (See Reprint 40.)

The Removal of Air from Pipe Lines by Flowing Water. Percy H. Bliss. M. S. Thesis (J. Waldo Smith Fellowship), May 1942; Professor Kalinske, adviser. Investigation was made of the collection of air at the summits of pipe lines of different sizes and slopes and its removal by entrainment. The data were analyzed with a view toward presenting relationships between the various hydraulic factors which would be of assistance in determining the need for air-release valves in pipe-line design. (See Reprint 56.)

Hydraulics of Vertical Drain and Overflow Pipes. William M. Wachter. M. S. Thesis, August 1941; Professor Kalinske, adviser. An investigation was made of the hydraulic and pneumatic conditions which obtain when water and air flow into the top of a vertical overflow or drain pipe which is not flowing full, as into drains and soil lines in building plumbing. The discharge was found to vary with the square of the head above the top of the pipe and the square root of the diameter for a given head, and to be independent of the pipe length. The ratio of amount of air drawn into the water discharge was found to be a maximum at relatively low heads.

A Study of Diverging Flow in Pipe Lines. James R. Barton. M. S. Thesis, August 1946; Professor McNown, adviser. This was the first in a series of studies of manifold flow, in which characteristics of outflow were investigated for a single lateral at right angles to a pipe line. The pressure rise in the main pipe and the pressure drop in the lateral were determined in the vicinity of the branch point for lateral flows ranging from zero to the entire discharge and for various sizes of lateral pipe. The experimental data were compared with a modified energy equation, systematic discrepancies between the two being explained rationally from considerations of the velocity distribution of the approaching flow.

A Study of Converging Flow in Pipe Lines. Sadiq M. Niaz. M. S. Thesis, June 1947; Professor McNown, adviser. In the second of the series of studies of manifold flow the characteristics of inflow were studied for a single lateral at right angles to a pipe line.
The pressure drops of the lateral and main-pipe flow were measured for the entire range of relative discharges and for various sizes of lateral pipe. Comparisons between the experimental data and energy equations, modified by head-loss terms, indicated general agreement, which was particularly good for large lateral discharges. Results for the three sizes of lateral yielded in dimensional form a single curve for the lateral flow.

Studies of Manifold Flow. Julio Escobar. M. S. Thesis, August 1948; Professor McNown, adviser. This was the third in the series of studies of manifold flow, in which the multiple-port manifold was investigated with special attention to spacing, the pattern of diverging flow being determined. The study was for the purpose of explaining or interpreting qualitatively the energy changes and the head losses which occur in the region of the lateral.

Sedimentation

Sediment Behavior in Upward Flow. Warren DeLapp. M. S. Thesis, June 1940; Professor Rouse, adviser. An experimental and analytical study was made of variations in sediment concentration throughout suspensions produced by the upward motion of water through a column of sediment. A generalized relationship was obtained between the concentration, the ratio of fall velocity and flow velocity, and the vertical gradient of piezometric head.

Investigation of Turbulence and Suspended Material Transportation in Open Channels. Chung-Ling Pien. Ph.D. Dissertation, June 1941; Professor Kalinske, adviser. The purposes of this project were to study the characteristics of turbulence in open channels that are important in the transportation of suspended material; to measure the concentration of suspended material; to compare the data with theoretical relations; and to study the relations between suspended and bed material. Qualitative determinations were made of the diffusive power of turbulence, the turbulence diffusion coefficient, sediment concentration near the bed, and the general behavior of the bed. (See Reprints 42 and 43.)

A Study of the Transportation of Fine Sediments by Flowing Water. Chen-Huan Hsia. M. S. Thesis, July 1943; Professor Kalinske, adviser. An investigation was made of the transportation of suspended sediment of fine sizes and high concentrations, and the experimental data were compared with present theoretical devel-
opments relating to suspended-sediment movement. Special attention was given to the relation between bed composition and the quantity of material in suspension. (See Bulletin 29.)

A Study of a Method of Computing Sediment Deposits in Retarding Basins. Kai Lei. M. S. Thesis, February 1946; Professor Lane, adviser. An investigation was undertaken by mathematical means of the rate of sediment deposition in a retarding basin. The study was based on design data for the Kuan Ting detention basin on the Yung Ting Ho River in north China.

A Modification of Stokes' Law to Account for Boundary Influence. Hsin-Min Lee. M. S. Thesis, February 1947; Professor McNown, adviser. From measurements of the terminal velocities of spheres falling along the axes of vertical cylindrical tubes filled with various liquids, a correction factor to the Stokes equation for resistance was obtained in terms of the ratio of the diameter of the particle to the diameter of the cylinder. An approximate theoretical expression was developed and found to agree with the experimental results. The final result was an extension of Ladenburg's formula for motion with negligible inertial effects.

Boundary Influence on the Fall Velocity of Spheres at Reynolds Numbers Beyond the Stokes Range. Murray B. McPherson. M. S. Thesis, August 1947; Professor McNown, adviser. Experimental techniques and equipment were developed which permitted the extension of the work of Lee to spheres having a maximum Reynolds number of 200 and sphere-to-cylinder diameter ratios from zero to 1/6. Thermostatic control of the fluid temperature and stroboscopically lighted photographs increased the accuracy of measurement. The effect of the diameter ratio in altering the coefficient of drag was found to decrease as the Reynolds number increased from 0.1 to 10. The empirical drag function currently in general use was found to be as much as 10 percent too high because of the boundary influences neglected in earlier experiments.

An Extension of the Study of Boundary Influence on the Fall Velocity of Spheres. Selahattin M. Engez. M. S. Thesis, January 1948; Professor McNown, adviser. The equipment and techniques developed by McPherson were utilized to extend considerably the results of previous experimenters on the effects of a coaxial cylindrical body on the fall velocity of spheres. The coefficient of drag was determined for sphere-to-cylinder diameter ratios from
zero to 0.98 and for Reynolds numbers of the spheres from 0 to 1,000. Analytical results for small diameter ratios were verified by experiment, as was a functional trend derived for diameter ratios nearly equal to unity. For a given Reynolds number inertial effects were shown to decrease with increasing diameter ratio.

**Development of a Stratified-Suspension Technique for Size-Frequency Analysis.** Herrol J. Skidmore. Ph.D. Dissertation, August 1948; Professor Rouse, adviser. An experimental apparatus was developed for rapid size-frequency analysis based on stratification of a sediment sample. The apparatus consisted of a vertical tube containing a pervious piston on an axial shaft. Piezometer openings in the top of the tube and in the shaft immediately above the filter piston permitted differential pressures to be measured. A sediment sample was introduced into the top of the tube with the piston at its highest position. The piston was then lowered, leaving the sediment in an increasingly stratified suspension. Differential pressures in the suspension were recorded against time by means of a modified Wahlen gage, the results being converted directly into grams in suspension versus fall velocity. Turbulence and concentration effects, for samples of the weights tested, appeared to be negligible. Comparison of the results with those obtained by bottom-withdrawal analyses of corresponding samples indicated the same relative precision of measurement. The time required to make a test with the experimental apparatus varied from 6 to 8 minutes as compared to many hours for presently accepted methods.

**Effect of Shape of Particles on Their Settling Velocity.** Jamil Malaiaka. Ph.D. Dissertation, February 1949; Professor McNown, adviser. An experimental and theoretical investigation was made on the effect of particle shape on settling velocity. A number of representative axisymmetric shapes were used within a Reynolds-number range from $10^{-4}$ to $10^{-3}$. The resistance of spheroidal particles moving within the Stokes range was determined theoretically. Three significant conclusions were reached: (1) All shapes followed a resistance law in the viscous zone parallel to Stokes' law for the sphere; (2) a combination of analytical and experimental results permitted development of a semi-empirical equation, combining three characteristic factors of particle shape for determination of settling velocity; (3) particles having similar positions and ratios of their principal axes showed comparable dynamic behavior re-
gardless of shape, so that the theoretical results can be applied to a variety of shapes with good approximation.

**Turbulence**

**Distribution of Velocity in Turbulent Jets of Air.** YAU-BEN DAI. M. S. Thesis, February 1947; Professor Rouse, adviser. The velocity distribution throughout a free jet of air was determined as a function of the jet diameter, the jet velocity, and point locations in the field. Generalized curves for both longitudinal and radial directions of flow were developed by utilization of dimensionless parameters. (See Staff Publications.)

**Investigations in the Diffusion of Submerged Jets.** W. DOUGLAS BAINES. M. S. Thesis, August 1948; Professor Rouse, adviser. Several points concerning the diffusion of submerged jets, which had not previously been dealt with, were investigated: first, a mathematical analysis using boundary-layer equations was developed; second, a series of measurements of mean velocity and turbulence were conducted in air to show the effect of the Reynolds number on the flow pattern.

**Free Convection Due to a Point Source of Heat.** CHIA-SHUEN YIH. Ph.D. Dissertation, August 1948; Professor Rouse, adviser. For a heat source of constant strength, located in the boundary plane of a semi-infinite fluid originally isothermal and at rest, the velocity and temperature in the surrounding field were shown to be specific functions of position, source strength, initial temperature, and the physical properties of the fluid. The velocity and temperature relationships for laminar flow were derived mathematically; those for critical and turbulent were determined experimentally.

**Weirs**

**Effect of Aeration Rates upon Discharge over a Sharp-Crested Weir.** CLAUD C. LOMAX, JR. M. S. Thesis, February 1942; Professor Howe, adviser. A sharp-crested rectangular weir 1.7 feet high and 2.5 long was equipped with aeration ports containing orifices to measure the flow of air to the underside of the nappe. Empirical relations between the change in head and the negative pressure under the nappe, and between the quantity of air needed for complete aeration and the quantity of water flowing, were developed. (See Staff Publications.)
Effect of Vacuum on a Free Nappe. Leroy A. Thorssen. M. S. Thesis, June 1945; Professor Lane, adviser. A study was made of the shape of a free-falling nappe from a vertical, sharp-crested weir when pressures less than atmospheric occurred under the nappe, together with determinations of variation in the coefficient of discharge. Investigation of the increase in spillway discharge with negative pressures was included.

A Study of Flow over Lateral Spillways. Hector Moreno-Gomez. M. S. Thesis, August 1948; Professor McNown, adviser. The loss in total head and the discharge coefficient of a lateral spillway was determined for the limiting condition of total discharge over the weir to the outflow channel. The head loss and the discharge coefficient were evaluated as functions of the Froude number.
SYNOPSIS OF
ENGINEER CORPS REPORTS

Prepared under the direction of the District Engineer, Corps of Engineers, St. Paul, Minnesota, by the Sub-Office, Hydraulics Laboratory, Iowa City, Iowa

Laboratory Tests on Hydraulic Model of Lock and Dam No. 22, Mississippi River, Hannibal, Missouri. (Final Report No. 33), 77 pp., May, 1939. Tests on hydraulic models of Mississippi River Dam No. 22 were made to obtain data for stilling basin and Tainter gate hoisting machinery design and for gate operation. A total of 157 tests were made on 19 models. A gate sill with 6-ft. drop in 15.5 ft., and a stilling basin 40 ft. long with a single row of 7 baffle piers 3 ft. high, 17 ft. from the end of the apron, and a solid end sill 5 ft. high were found to be satisfactory.

Laboratory Tests on Hydraulic Model of Filling and Emptying System of the General Joe Wheeler Lock, Tennessee River, near Florence, Alabama. (Final report No. 34), 84 pp., July, 1939. Tests were made on a model of the General Joe Wheeler Lock to determine operating time, hydraulic system coefficients, and flow distribution. Limited, comparable data, obtained at the prototype, are presented to show the degree of similarity between model and prototype. The model structure, tests, and analyses are described, and illustrated with photographs and drawings.

Permeability Tests on St. Peter Sandstone Specimens. (Final Report No. 35), 49 pp., July, 1939. Permeability tests were made on four specimens of St. Peter sandstone obtained from the Ford sand mine near the Twin City Dam at four different elevations comparable to the foundation elevation of the proposed lower locks at St. Anthony Falls, Mississippi River, Minneapolis, Minnesota. The results indicate the variation in percolation rates in sandstone at the four elevations, in each of three mutually normal directions, and in samples having fracture planes of different magnitudes. In many tests, gradients were gradually increased until failure of the sandstone obtained. Permeability tests were made also on sand obtained by crushing the sandstone. The data are presented in this work.

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report in graphical and tabular form. Comments based on observations during the tests are also presented. Difficulties encountered in evolving a test technique and the conditions that led to the adopted testing methods are explained.

**Laboratory Tests on Hydraulic Models of Roller Gate Stilling Basins.** (Final Report No. 36), 279 pp., August, 1939. This report covers comprehensive tests on models of non-submergible and submergible roller gates to determine shapes and dimensions of stilling basins adequate to protect Mississippi River dams operated under emergency conditions required in the discharge of ice from the pools. Water pressures on the roller gates and sills were also observed in the model for the purpose of determining water loads and chain pulls on prototype gates under various conditions of operation.

**Laboratory Tests on Hydraulic Models of Submergible Tainter Gates.** (Final Report No. 37), 271 pp., October, 1939. Part I — Stilling Basin Studies and Determination of Water Loads on the Submergible Tainter Gate. Tests made on models of submergible Tainter gates to determine the hydraulic characteristics of a truss-type and a drum-type gate when operated in various submerged positions are discussed in this report. Models were built to scale ratios of 1:28.87 and 1:4, model: prototype. The design of the proposed stilling basin was checked and discharge coefficients were determined for flow over the gates. Water pressures on the downstream faces of the submerged gates, and loads on the hoisting chains were determined. Aeration of the nappe, vibration tendencies of the gate, and the effect of extending the end shields above the water surface were also studied.

Part II — Tainter Gate Discharge Coefficients. The discharge capacities of several Tainter gate models were determined for gate openings ranging from 2 to 18 ft., under variable upper pool and lower pool water surface elevations. The effect on discharge capacity was noted for the following variations in the models: Recessed and non-recessed gate piers; angle theta varying from 22°-50’ to 70°-33’; variations in the shape of the gate sill; stilling basins with and without baffle piers; various lengths of apron; and gate radii of 30 and 40 ft. Two nomographs were developed for empirical discharge coefficients, one for a Tainter gate with recessed gate piers and submergible gate sill and the other for a Tainter gate on an ogee spillway.
Laboratory Tests on Hydraulic Model of Lower Approach to Proposed Landward Lock, Lock and Dam No. 2, Mississippi River, Hastings, Minnesota. (Final Report No. 38), 104 pp., December, 1939. A model of the Mississippi River in the vicinity of Lock and Dam No. 2, Hastings, Minnesota, in which a problem of navigation in the lower approach to a proposed new lock was studied, is the subject of this report. A number of approach channel schemes excavated in the existing right bank were studied to determine their effects on current conditions and on sedimentation in the navigation channel. The tests indicated that the most satisfactory arrangement was one in which the excavation was carried from the existing right bank of the river to a line prolonged from the right wall of the new lock, with a 500-ft. guard wall constructed as an extension of the river wall of the existing lock, and the left river bank straightened so as to approximately parallel the right bank.

Laboratory Tests on Hydraulic Model to Determine Roller Gate Coefficients for upper Mississippi River Navigation Dams. (Report No. 39 — Appendix to Final Report No. 13; see last paragraph on page 77, Bulletin 19), 72 pp., January, 1940. The tests described in this appendix were made on a model of the type of submergible roller gate installed in Mississippi River navigation dams 11, 12, 13, 14, 17, 18, and 21. The results of these tests are presented by a set of discharge curves for the range of conditions which will be encountered at these dams. Similar curves are included also to present in more usable form calibration data for other types of roller and Tainter gates in the Rock Island District.

Laboratory Tests on Hydraulic Model of Lock and Dam No. 11, Mississippi River, Dubuque, Iowa. (Final Report No. 40), 111 pp., April, 1940. Part One of this report describes model tests made to indicate the best combination of gates and overflow spillway sections to be included in Dam No. 11, and the most suitable modifications of the piers and approach of the highway bridge immediately downstream. Part Two describes tests made on a hydraulic model of the structure to indicate the most desirable distribution of flow through the gates of the dam as constructed, with the objectives of reducing scour in the river bed which might endanger the stability of the structures and of avoiding the deposition of material in the navigation channel.

Laboratory Tests on Hydraulic Model of Diversion Channel
and Stilling Basin, Dry Run Flood Control Project, Decorah, Iowa. (Final Report No. 43), 37 pp., October, 1940. The Dry Run diversion channel is a proposed project for flood protection at Decorah, Winneshiek County, Iowa. Tests on a model of the diversion channel were made to observe the performance of the channel as designed, and to develop a stilling basin for the outlet. A stilling basin 75 ft. long, 130 ft. wide, with a solid end sill 9 ft. high, was found to be satisfactory. This report is the preliminary presentation of the test data and the conclusions drawn from them. It contains the information essential to an understanding of the prototype problem, describes the model arrangement, gives the procedure of the tests, and conclusions with recommendations on hydraulic features of the design.

Laboratory Tests on Hydraulic Model to Determine Navigation Conditions in Approaches to St. Anthony Falls Locks, Mississippi River, Minneapolis, Minnesota. (Final Report No. 44), 143 pp., November, 1940. The St. Anthony Falls Navigation Project requires the construction of a new dam, consisting of three submergible Tainter gates; two locks, one with a lift of 50 ft. at St. Anthony Falls and the other with a lift of 25 ft. at the new dam; guide fences; a dredged navigation channel; and alterations to certain existing bridges. A hydraulic model of this project was built and tested to determine the navigation conditions in the Mississippi River and the lock approaches, to study the operation of the proposed locks and dam, and to develop any corrective measures found necessary. In general, the project was found to be entirely feasible. Possibly the most valuable result obtained from the model was the successful development of a training wall in the middle pool to eliminate dangerous cross currents in the navigation channel and lock approaches.

Laboratory Tests to Determine Discharge Coefficients for Obstructions to Super-Flood Flows. (Final Report No. 45), 55 pp., December, 1940. This report describes a model study conducted for the purpose of determining coefficients of obstruction for bridges subject to floods which would result under the most critical combination of heavy storm run-off and saturated ground conditions that could occur on any watershed in the Rock Island District. Chapter II describes the basic model and accessories, Chapter III the testing procedure in the general studies, including the computation methods and results obtained from the bridge coefficient studies, and
Chapter IV describes a series of tests in which existing conditions in the vicinity of the junction of the Des Moines and Raccoon Rivers at Des Moines, Iowa, were approximately simulated. The water surface profile of the Des Moines River, the bridge coefficients determined for this set-up, and the backwater effect of the Scott Street bridge and dam are included.

**Laboratory Tests on Weep Holes.** (Final Report No. 41), 82 pp., May, 1940. This report on experimental studies of four sizes of vertical, cylindrical weep holes filled with two gradations of river gravel. Although individual test results varied considerably in certain cases, it was concluded that the maximum safe hydraulic gradient could be computed from a theoretical equation involving portion of voids in and specific gravity of filler.

Appendix A of the report presents results of experiments on conical weep holes. The best weep hole shape was one diverging in the direction of flow, that is, a frustum of a cone with the large end up.

**A Study of Methods Used in Measurement and Analysis of Sediment Loads in Streams.** Field Practice and Equipment Used in Sampling Suspended Sediment. (Report No. 1), 175 pp., August, 1940. This report is a review of field procedure and equipment used in the past in sampling suspended sediment loads of streams. The methods followed in locating sampling points across a stream and in selecting the depths of observations in a vertical are discussed in detail, and the advantages and disadvantages of the various methods are presented. Consideration is given also to the frequency with which samples should be taken.

The devices used in the past for sampling suspended sediment are described and 65 forms are illustrated. The samplers have been classified according to their mode of action, and the advantages and objectionable features of each class are given. The requirements of a sampler which would meet all field conditions satisfactorily are set forth.

**Model Study of the Effect of Pool No. 5, Mississippi River, on Hydraulic Conditions Near Minneiska, Minnesota.** (Final Report No. 42), 63 pp., September, 1940. This report presents the results of a model study made to determine the effect of the backwater pool of Lock and Dam No. 5 near Minneiska, Minnesota, on bridges near the mouth of the Whitewater River, a small tributary which
enters the Mississippi about 4.5 miles upstream from Lock and Dam No. 5, and especially its effect on the hydraulic capacity of bridge L-90 of the Chicago, Milwaukee, St. Paul, and Pacific Railroad.

The results indicated that the raising of Pool No. 5 will not affect the silting action of Whitewater River floods or necessitate any bridge changes at the mouth of the Whitewater River.

A Study of Methods Used in Measurement and Analysis of Sediment in Loads in Streams. Equipment Used for Sampling Bed-Load and Bed Material. (Report No. 2), 57 pp., September, 1940. The available literature concerning bed-load and bed material samplers has been reviewed and, in this report, the samplers are classified according to their type of construction and principle of operation. The samplers are described and illustrated by photographs and drawings. Bed-load samplers of the basket, pan, and pressure-difference types, and bed material samplers of the drag bucket, vertical and grab bucket types, are included. The results of calibrations of bed-load samplers performed by Shamov, Einstein, Ehrenberger, and the Swiss Federal Authority for Water Utilization are presented.

The various field conditions encountered in bed-load sampling are discussed, and the type of sampler suitable for each case is indicated.

Prototype Lock Hydraulic Tests to Verify Model Experiments. (Final Report No. 46), 411 pp., October, 1941. This report covers a series of tests made on the filling and emptying systems of navigation locks in the Tennessee and Ohio Rivers, to compare different types of hydraulic systems and to compare the performance of model and prototype lock hydraulic systems for which model test data were available. Test data, usually in the form of time graphs, are presented for three locks with model studies and for six locks without model studies.

In order to obtain the prototype test data, an instrument was developed which was capable of measuring high and rapidly changing velocities and of transmitting these measurements to heights greater than that of the barometric head. In the comparison of a prototype lock with its model, an attempt was made to point out any difference in the geometric similarity of the two structures and in the operation conditions occurring during tests. The properties of the lock chamber stage record and the characteristics of port and culvert flow form the bases of the comparisons.
A Study of Methods Used in Measurement and Analysis of Sediment Loads in Streams. Analytical Study of Methods of Sampling Suspended Sediment. (Report No. 3), 82 pp., November, 1941. In this report is presented an analysis of some of the sampling methods commonly used in determining the magnitude of suspended sediment loads in streams. A study of the various sampling methods has been made to determine their inherent errors when used in a stream where the sediment concentration and velocity vary between the surface and the bed of the stream. The analysis is based upon the assumption that the samples collected represent the true average value of the sediment concentration at every point of observation and that the sediment distribution conforms to the turbulence theory.

A method is presented also whereby the mean sediment concentration at a vertical in a stream can be determined from the concentration and size composition observed at any given point in the vertical.

A Study of Methods Used in Measurement and Analysis of Sediment Loads in Streams. Methods of Analyzing Sediment Samples. (Report No. 4), 203 pp., November, 1941. A discussion of methods used in determining particle size, particularly with reference to suspended sediment, occupies the major portion of this report. Various methods used in analyzing sediment samples for total solids concentration are also discussed. Applicable standard procedures of the American Society for Testing Materials are indicated. An extensive bibliography pertaining to suspended sediment analysis is given, classified by subjects as well as by authors, in alphabetical order.

A Study of Methods Used in Measurement and Analysis of Sediment Loads in Streams. Laboratory Investigation of Suspended Sediment Samplers. (Report No. 5), 99 pp., December, 1941. This report presents the results of experimental studies of suspended sediment samplers. Various forms of simple intake tubes and typical suspended sediment sampler intakes were tested to evaluate errors in the sediment concentration of samples due to adverse sampler entrance conditions, deposition of sediment with flow through a horizontal cylinder, and loss of sediment in transferring the samples to other containers.

Tests were made with five representative slow filling samplers to
determine their filling characteristics under various conditions of stream velocity, sampling depth, and sampler operation.

A Study of Methods Used in Measurement and Analysis of Sediment Loads in Streams. A Study of New Methods for Size Analysis of Suspended Sediment Samples. (Report No. 7), 102 pp., June, 1943. In Report No. 4 of this series it was concluded that none of the present methods of analyzing suspended sediment can be applied satisfactorily to all conditions of particle size and concentration which are encountered in flowing streams. The present study was undertaken in an attempt to supply this deficiency. The bottom withdrawal tube developed in the course of this study appears to meet the need.

The report includes a review of the range of conditions for which the present methods of size analysis are suitable. The various devices investigated and the method of computing the size analysis of sediments on the basis of a uniform dispersion of particles are described. The modification of this method for application to data obtained with the bottom withdrawal tube is explained. A description of the tests made to determine the accuracy and range of applicability of the apparatus is also included.

A Study of Methods Used in Measurement and Analysis of Sediment Loads in Streams. Density of Sediments Deposited in Reservoirs. (Report No. 9), 60 pp., November, 1943. In order to determine the rate at which reservoirs will fill with sediment it is often necessary to estimate the weight per unit volume of the deposited sediment, because the quantity of sediment carried by a stream is usually expressed in terms of weight rather than volume. A thorough study of this subject has never been undertaken and consequently the estimated densities used cover a wide and indiscriminate range of values. All available data have been compiled in this report. The results and conclusions drawn from an analysis of the data are summarized in a form applicable to the needs of organizations or individuals interested in reservoir design.

Laboratory Tests on Hydraulic Model of Navigation Conditions in Upstream Approach to Lock No. 10, Mississippi River, Guttenberg, Iowa. (Final Report No. 47), 90 pp., December, 1943. A scale model of Lock and Dam No. 10, together with a portion of the Mississippi River extending upstream and downstream from the dam, was tested to determine what corrective features would
effectively and economically eliminate currents, hazardous to navigation, existing in the upstream approach channel to the lock. Various corrective measures were studied. The best results were obtained by extending the upper guide wall 400 feet upstream, constructing a deflecting dike from the right bank to channel marker No. 1, excavating along the left bank of the navigable channel, and removing wing dams Nos. 14 and 53 in the channel about 5,000 feet upstream from Lock and Dam No. 10.

Laboratory Tests on Hydraulic Model of Filling and Emptying System for the MacArthur Lock, St. Marys River, Sault Ste. Marie, Michigan. (Final Report No. 48), 114 pp., February, 1944. Tests were made on a model of the MacArthur Lock in order to check the hydraulic features of the design and develop corrective features where indicated. Particular importance was placed on the time required for lock operation and forces acting upon a boat in lockage. Upon construction of the MacArthur Lock studies were made correlating results obtained from the model and the full-size hydraulic system.

Laboratory Tests on Hydraulic Models of Filling and Emptying Systems for New Lock No. 2, Mississippi River, Hastings, Minnesota. (Final Report No. 49), 19 pp., February, 1944. Scale-model investigations of two general types of navigation lock hydraulics systems, the stub culvert, and the side culvert and ports, are treated in this report. The models were tested with lifts varying from 12 to 75 feet to determine their lockage characteristics such as operating time, rate of rise or fall, surge, and hawser pull exerted by a barge tow, and to compare the functioning of each type of system. The prototype, models, instruments, and methods of testing are described and illustrated by drawings and photographs. The results of over 200 tests are analyzed and pertinent test data are given in tabular form.

Hydraulic Model Study of Navigation Conditions in Upstream Approach to Lock No. 6, Mississippi River, Trempealeau, Wisconsin. (Final Report No. 50), 132 pp., December, 1944. A hydraulic model of Lock and Dam No. 6, including upstream and downstream reaches of the river of sufficient length to develop prototype flow conditions, was built and tested to determine corrective features that could be economically employed to effectively eliminate existing currents hazardous to navigation in the upstream
approach to the lock, and to arrest excessive scour in the vicinity of the upstream end of the river lock wall. As a supplementary consideration, the study was extended to investigate the characteristics of a cellular guard which would not eliminate the hazardous cross currents but would create an area of comparatively still water in which river craft could maneuver in approaching the lock. The model tests indicated that the conditions could be satisfactorily rectified by one of the following combinations of corrective structures: three or four submerged weirs in the upstream lock bay and a 400-foot upper guide wall extension, or two submerged weirs in the upstream lock bay and a 400-foot upper guide wall extension, or two submerged weirs in the upstream lock bay in conjunction with a 280-foot cellular guard wall and at least a 140-foot upper guide wall extension.

Laboratory Tests on Hydraulic Models of a Submergible Tainter Lock Gate for St. Anthony Falls Lower Lock, Mississippi River, Minneapolis, Minnesota. (Final Report No. 51), 107 pp., August, 1945. Model tests on the proposed hydraulic system for the lower lock at St. Anthony Falls are covered in this report. The hydraulic system consists of a submergible Tainter gate, as the upper lock gate, for filling, and a stub culvert system at the downstream end of the lock for emptying.

The report, dealing primarily with tests on the Tainter gate used in filling the lock, covers studies of gate profiles, gate operation schedules and disturbances set up in the lock chamber by the overflowing nappe. Other phases of the filling operation which are covered include tests on stilling bay arrangements for dissipation of the energy of the nappe, and tests on different sizes and displacements of tows. Tests were made in two undistorted models, a general model simulating the complete hydraulic system and a sectional model simulating only the upper lock gate and sill.

Laboratory Tests on Models of Lock Hydraulic Systems. (Final Report No. 52), 156 pp., June, 1946. Extensive hydraulic model tests on the sidewall filling and emptying system for a navigation lock are described in this report. Certain features of the hydraulic system were isolated and studied in special model arrangements, while the entire hydraulic system was tested in a composite model simulating all essential features of the prototype lock structure. Special studies were made of the distribution of flow in a lock cham-
ber manifold; the effects on surge and rate of filling due to various shapes of ports, port spacing, and port to culvert area ratios; and the differences in minimum culvert pressures and air entrainment due to culvert Tainter valve position with the skin plate either upstream or downstream.

A Study of Methods Used in Measurement and Analysis of Sediment Loads in Streams. Measurement of the Sediment Discharge of Streams. (Report No. 8), 92 pp., March, 1948. The purpose of this report is to clarify the principles of sediment transportation and to summarize the practices most commonly used in carrying out fluvial sediment investigations. The report deals with the necessity for studying sediment load problems and presents a history of early sediment measurements. Types of sediment are described and an explanation based on the turbulence concept is given for the vertical distribution of suspended sediment. The general principles involved in suspended sediment measurements are treated as well as the practical aspects of selecting sampling points and of determining the frequency of sampling. The principal types of suspended sediment samplers are described, their advantages and disadvantages are discussed, and details are given regarding sampler designs which were developed after a thorough study of existing sampling equipment. Descriptions are also given of methods used in the measurement of material moving on or near the beds of streams and of the equipment used to obtain samples of the bed material.

Laboratory Tests on Hydraulic Models of Lock and Dam No. 4, Mississippi River. (Final Report No. 53), 205 pp., April, 1948. Hydraulic characteristics of Lock and Dam No. 4, Mississippi River, investigated in a river model and in large scale sectional models of the movable dam are discussed in this report. The river model included all of the main features of the lock and dam structures and about 4.7 miles of river channel. The sectional models, tested in a glass-walled flume, included different stilling basin designs for a Tainter gate, a roller gate, and a vertical lift gate. With a 3,000-foot spillway in the earth dike, backwater was sufficiently reduced and flow distribution throughout the river model, in general, approximated that for the natural channel. The stilling basins adopted for the Tainter and roller gates permitted discharges of 2,375 c.f.s. and 5,000 c.f.s. per gate, respectively.
STA F F PUBLICATIONS NOT AVAILABLE AS REPRINTS


“Photographic Technique for Recording Direction of Surface Currents in Models,”’ by C. J. Posey; Civil Eng., Vol. 9, p. 619, October 1939.


“Conversion of Units and Dimensions,”’ by J. W. Howe and C. J. Posey; Civil Eng., Vol. 10, p. 528, August 1940.


Trend in Rainfall Record Confirmed," by L. C. Crawford; Civil Eng., Vol. 11, No. 1, p. 45, January 1941.


Discussion by C. J. Posey of "Surges in Panama Canal Reproduced in Mod-


"Rocky Mountain Hydraulic Laboratory," by C. J. Posey; The Iowa Transit, Vol. 50, No. 8, p. 8, May 1946.


STUDIES IN ENGINEERING


REPRINTS


   "Predicting Stages for the Lower Mississippi," by E. W. Lane; Civil Eng., Vol. 7, No. 2, pp. 122-125, February 1937.


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8. Two Papers on the Hydraulic Jump. Price $0.10.

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55. "Quarter-Wavelength Insulators," by L. A. Ware; *Communications*, Vol. 24, pp. 51-52, November 1944.


76. "Application of a D-C Negative-Feedback Amplifier to Compensate for the Thermal Lag of a Hot-Wire Anemometer," by Philip G. Hubbard; *Pro-

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