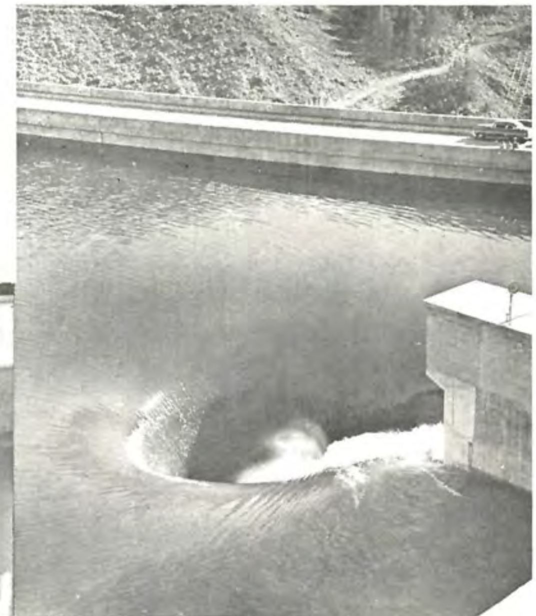
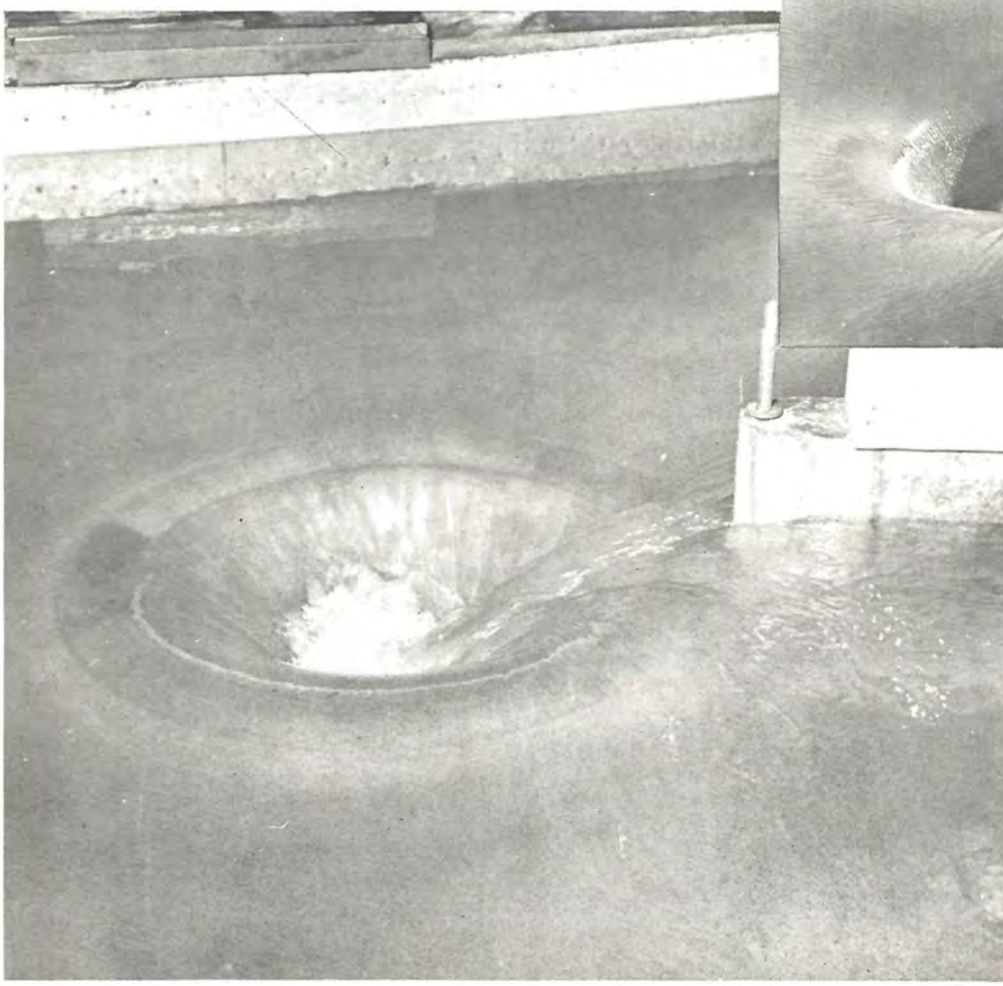
HYDRAULIC LABORATORY





BUREAU OF RECLAMATION

DENVER COLORADO

THE HYDRAULIC LABORATORY

This pamphlet contains a collection of technical articles published periodically to acquaint Bureau of Reclamation employees with the functions, work, and test facilities of the Hydraulic Laboratory Branch of the Division of Engineering Laboratories, Office of the Assistant Commissioner and Chief Engineer, Denver Federal Center, near Denver, Colorado. The articles describe typical and diversified problems studied in the laboratory. Future articles will describe other work phases and test facilities.

The Hydraulic Laboratory Branch conducts hydraulic laboratory investigations of structures such as dams, spillways, outlets, canals, intakes, siphons, drops, and chutes, and hydraulic equipment including gates, valves, turbines, and pumps to obtain information for planning, design, construction, operation, and maintenance of such structures and equipment; conducts field investigations and performance tests of hydraulic structures and equipment; performs laboratory and field studies of sedimentation, seepage, and salinity problems; studies methods and develops equipment for water measurement; designs and constructs special electronic apparatus for precise measurements in hydraulic and seismic investigations; provides technical advice and assistance internationally on hydraulic problems; and constructs topographic and relief models and displays.

The Hydraulic Laboratory includes approximately 53,000 square feet of a factory-type building which was converted for use by the Division of Engineering Laboratories and occupied in 1946.

Water for testing is stored in large channels below the floor level. Water is circulated from the channels to the models through a 12-inch supply line contained in a small channel located at the perimeter and below the floor of the main part of the laboratory space.

The primary water supply system contains one 8-inch and three 12-inch horizontal centrifugal pumps placed in pits at the ends of the storage channels. The pumps can be operated singly or in parallel with a maximum delivery of 36 cfs. Two 12-inch pumps can be operated in series with a shutoff head of 200 feet and will deliver 5 cfs at 150 feet of head. Hydraulic valves operated from either of two control boards at opposite ends of the laboratory regulate and control test flows. Seven 8-inch and six 6-inch portable vertical pumps supplement the fixed-pump system. Rates of flow are measured by Venturi or combination orifice-Venturi meters. The test flows are returned to the storage channels for recirculation. Special testing facilities include a glass-walled flume 4 feet wide, 8 feet high, and 80 feet long; a volumetric calibration tank of 678 cubic feet capacity; a 10-inch centrifugal air blower having a capacity of 3,000 cfs at 4 inches of water for air testing; an apparatus for feeding sediment to a movable bed model at constant rates; fluid polariscopes; electrical analog apparatus; and many specialized measuring devices with electronic instrumentation.

When heads and flow quantities needed are higher than those of the main laboratory, tests are made using facilities provided in the Colorado-Big Thompson flow system near Estes Park, Colorado. An 18-inch outlet at Estes Powerplant provides about 100 cfs of water at a head of 500 feet, while an 18-inch outlet at Mount Olympus Dam supplies about 50 cfs at a 40-foot head.

L A B O R A T O R Y   F A C T S

No. 15
June 1, 1956

HYDRAULIC MODELS AND TESTING

The need for hydraulic models and hydraulic testing was probably first expressed by Galileo some 300 years ago when he said: "I have met with fewer difficulties in discoveries relating to the movement of heavenly bodies, notwithstanding their astonishing distances away, than in investigating the motion of flowing water taking place before my very eyes."

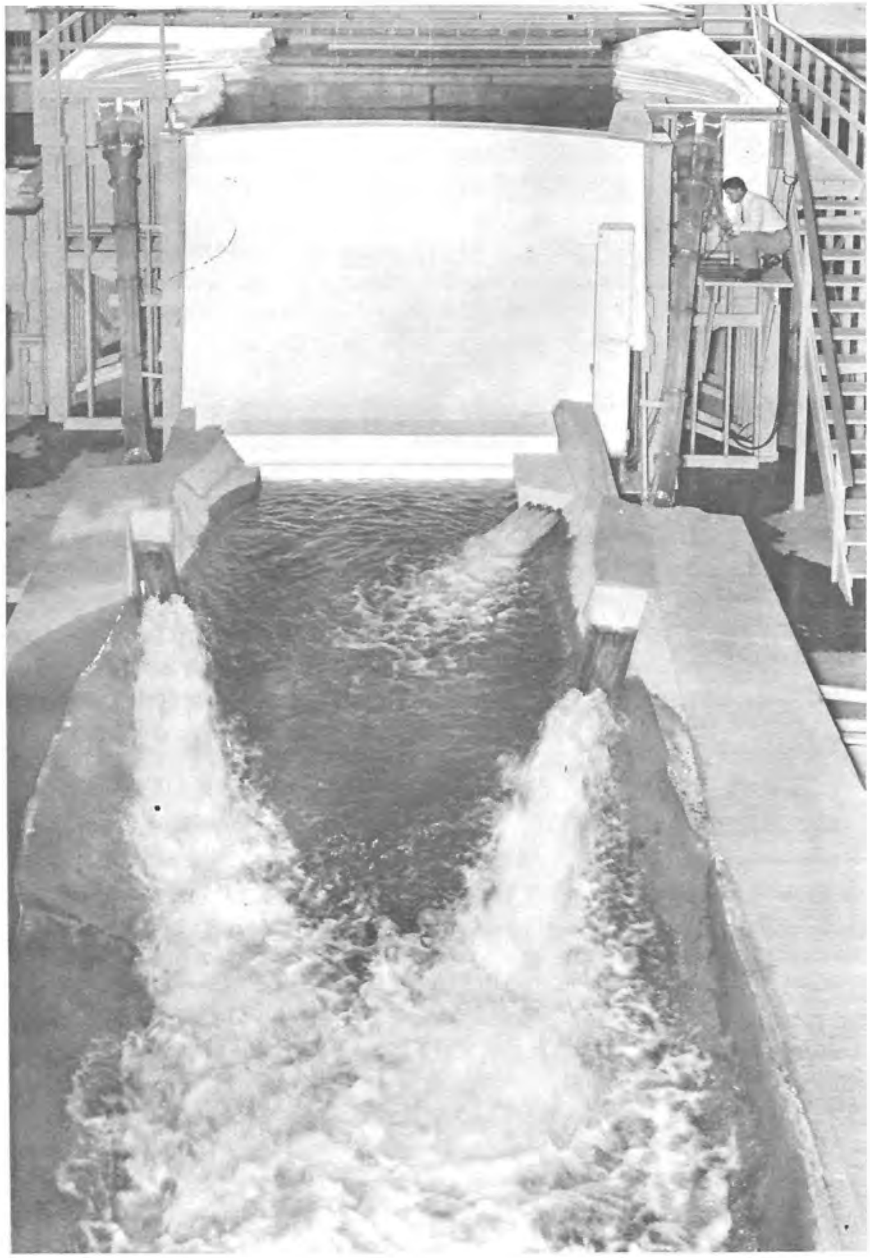
Many hydraulic problems are impossible to solve without the aid of models or hydraulic testing. Most methods and equations used in hydraulic work are empirical in nature and have been developed from experience. When new situations arise, when old limits are exceeded, or when new demands are placed on a usual hydraulic structure, the established equations are inadequate and new coefficients, equations, or methods must be developed. Thus, problems received in the laboratory are those that have never been solved or are familiar problems in which the components have been rearranged sufficiently to make the usual solution doubtful or impossible.

Test projects may be concerned with either civil or mechanical engineering problems and are conducted both in the laboratory and in the field. Civil engineering studies include spillways and outlet works for dams; chutes, drops, checks, siphons, measuring and other devices for irrigation distribution systems; diversion works; sediment problems of all descriptions; and other open channel flow-way problems. Mechanical engineering studies include gates, valves, piping systems, penstocks, pumps and other closed conduit problems.

Requests for testing are initiated by the designers of a project. Preliminary designs are submitted to the laboratory along with a request, stated in general terms, to investigate the problem. The laboratory engineers estimate the cost of the study, often pointing out certain difficulties that may be encountered. Close liaison throughout the tests is then maintained between designer and laboratory engineer to obtain the best structure, hydraulically and structurally, at the least cost.

The laboratory studies may cost as little as $500, where existing facilities may be used to solve a simple problem in a few days, to $25,000 or more where extensive construction work is required and the testing period may be a year or longer. Benefits of the studies are often twofold; first, the test program insures that the structure will operate as intended, and secondly, improved performance is often obtained with a smaller and less costly structure. In addition, operating data or procedures are obtained for the project to clarify the operation and maintenance procedures.

Model studies are conducted according to mathematically and experimentally proved rules of hydraulic similitude, so that results of model tests, properly interpreted, may be applied to the corresponding field structure. Field tests of model tested structures are often made to extend the range of useful knowledge which may be obtained from a model in the laboratory. In certain design problems, as a result of extensive laboratory and field tests, the laboratory has been able to generalize design procedures and rules so that structures may be constructed to operate properly without the need for individual tests.



1 to 63.5 scale model of Glen Canyon Dam used to study spillway entrance channel shape and extent, flow and pressure conditions in spillway tunnel, and flow distribution and erosion conditions in downstream river channel. Both spillways and outlets discharging full capacity. (H-1273-68)

L A B O R A T O R Y   F A C T S

No. 19
July 13, 1956

FIELD HYDRAULIC STUDIES

Hydraulic studies are not confined to the laboratory. Although many accurate predictions can be made from hydraulic models, field studies are often desirable and sometimes essential to obtain certain data. Hydraulic investigations in the field can be generally summarized into four groups.

Investigation of operating structures may be required when unforeseen difficulties arise. As an example, excessive vibration or cavitation may develop, requiring on-site measurements of flow characteristics to establish remedial procedures.

Performance tests of hydraulic structures and machinery are necessary in many instances to determine the operating characteristics. These tests are conducted to ascertain whether design criteria have been met, to establish compliance with specifications, to acquire data for future designs, and to determine whether additions or changes are necessary in the structure or machine.

Design data of some types can be obtained accurately only by field studies. For example, air entrainment in a high-velocity jet of water cannot aptly be duplicated in a laboratory model. Also, measurements of discharge and head loss to determine the roughness coefficient of a conduit are best made on the prototype.

Model-prototype conformance studies are needed for verification of results of model investigations where laws governing the relationship between the model and its prototype are still unknown. Studies of this nature have developed where turbulence effects and cavitation and air demand downstream of gates and valves in closed conduits are problems.

The results of field studies are invariably of value in subsequent structure design. Some hydraulic problems may be wholly or partially solved by studies of field structures in operation at little if any more cost than for model studies. Field studies also have an advantage in yielding quick results directly from undistorted prototypes. The rapidly increasing number of newly built hydraulic structures throughout the United States affords a diversified field of opportunity for useful observations and investigations, and the Hydraulic Laboratory maintains careful watch over the work of others in this field.

Spillway of Grand Coulee Dam releasing about 500,000 cfs; about 50 percent of design capacity. (H-740-30)

1 to 60 scale model of Grand Coulee Dam, Spillway and Powerplants used mainly to study flow conditions as related to protection of downstream river banks and channel. Spillway releasing flow representing 500,000 cfs or 50 percent of capacity. Model is located on the shore of Lake Roosevelt upstream from the left abutment of the dam. (H-843-181)

THE HYDRAULIC JUMP

Those of you who have been on a tour of the Hydraulic Laboratory have heard the term "hydraulic jump." The hydraulic jump is an abrupt rise in water surface which may occur in an open channel when water flowing at high velocity is retarded. In the controlled form it is commonly seen below a spillway where the water sliding down the slope has a higher velocity than the tail water into which the flow discharges.

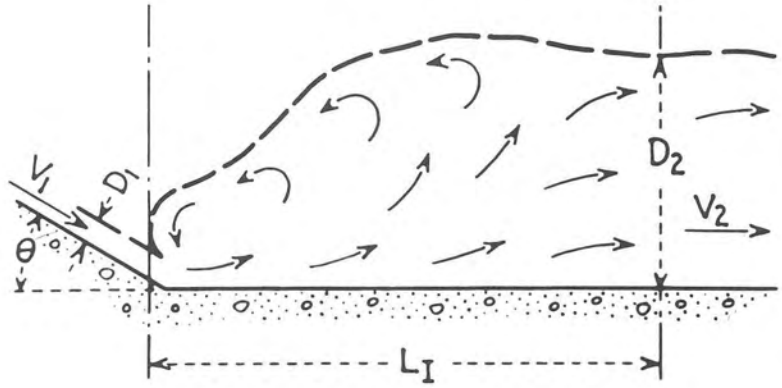
Jumps may also be seen in ditches or streams where submerged rocks or obstructions produce conditions favorable to a jump. The conversion of high-velocity low-depth flow to low-velocity high-depth flow is accomplished in the body of the jump; the process produces turbulence which consumes energy. Thus the flow in passing through a jump reduces the energy in the outflowing water and thereby reduces the ability of the flow to damage a stream bottom or banks.

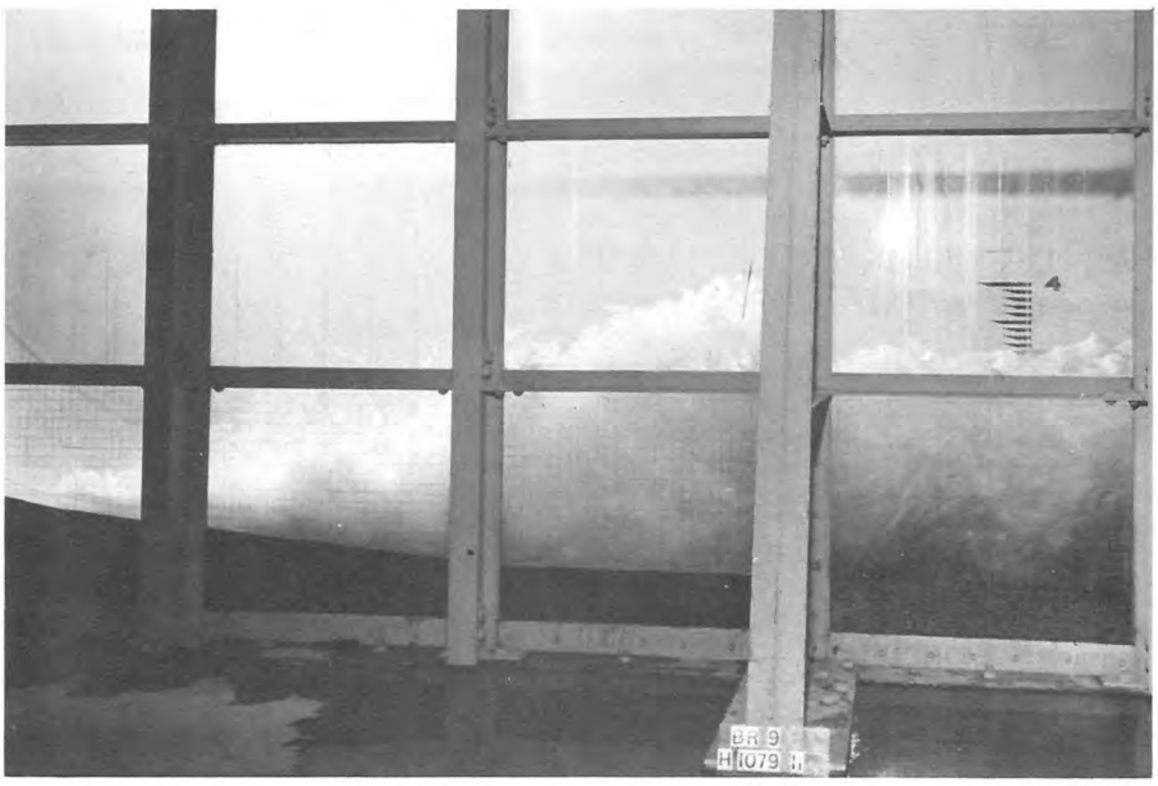
Sufficient research has been accomplished to make it possible to predict the occurrence of a jump and to provide the proper dimensions for the structure or stilling basin used to contain the jump.

If the velocity and depth of the incoming flow are known, the outgoing depth may be computed from proved equations. The energy losses in the jump, the length of jump, and the water surface profile may also be computed for any type of jump.

Hydraulic jumps occur in many forms both on horizontal and sloping floors. When the ratio of the incoming depth to the outgoing depth is small, the jump is poorly developed and energy losses may be only a few percent. When the incoming flow has high velocity and the ratio of incoming to outgoing depth is large, the jump is stable and energy losses may run as high as 85 percent, although surface waves may be a problem. Jumps in the middle range provide best performance and stability.

It is possible to predict with good accuracy the size and general arrangement of stilling basin necessary to contain the hydraulic jump under all conditions, and to predict the effectiveness of the jump in accomplishing energy dissipation. Several types of stilling basins will be discussed in future issues.





Flow lines for hydraulic jump on horizontal floor and side view of hydraulic jump in a 4-foot wide glass-sided flume. (H-1079-11)

HYDRAULIC JUMP STILLING BASIN

The hydraulic jump (Laboratory Facts No. 24) has been the subject of a sufficient number of research projects to make it possible to design a stilling basin on paper which will contain the jump and provide quiet flow in the downstream channel. Since the length of a hydraulic jump may be as great as 6.5 times the downstream depth in the jump, large structures such as Shasta Dam would require a basin well over 500 feet long. This is too costly a structure, and various means are used to reduce the basin length.

Hydraulic model tests provide a very effective method for determining the minimum structure consistent with satisfactory performance. After the general shape and dimensions of the basin have been determined using the general design rules, a model is constructed to a suitable length scale, usually between 1:20 and 1:60. The scale is dependent on water requirements, space limitations, and on the importance of certain minimum dimensions of the structure. The test program includes modifying each variable component in the basin and evaluating it in terms of the others. General appearance, water surface roughness, scour in the riverbed downstream, pressures on component parts, and other factors are used to evaluate the effectiveness of each arrangement.

Appurtenances such as chute blocks, baffle piers, and end sills are used to hasten the formation of turbulence in the basin and reduce the length required for energy dissipation. Chute blocks are rectangular teeth fitted to the basin floor at the upstream end so that about 50 percent of the flow passes between and 50 percent over their smooth tops. Thus the chute blocks separate the flow to form two layers of turbulence. The baffle piers are a single row of vertical-faced blocks which intercept the flow and create additional energy dissipating eddy patterns. The baffle piers, taller than the chute blocks, are located at the upstream one-third point on the apron (or basin floor) and occupy a total of about 50 percent of the basin width. The end sill is a solid, triangular-in-section deflector at the end of the basin used to direct the remaining bottom currents upward and away from the river bottom. When baffle piers are not used, dentils may be added to the end sill, resulting in a dentated sill. This, in effect, moves the baffle piers downstream where they are less effective but are also subject to less damage by high velocity flow.

Hydraulic model tests will often make it possible to reduce the basin length to less than 50 percent of the jump length with entirely satisfactory performance.

L A B O R A T O R Y   F A C T S

No. 39
March 8, 1957

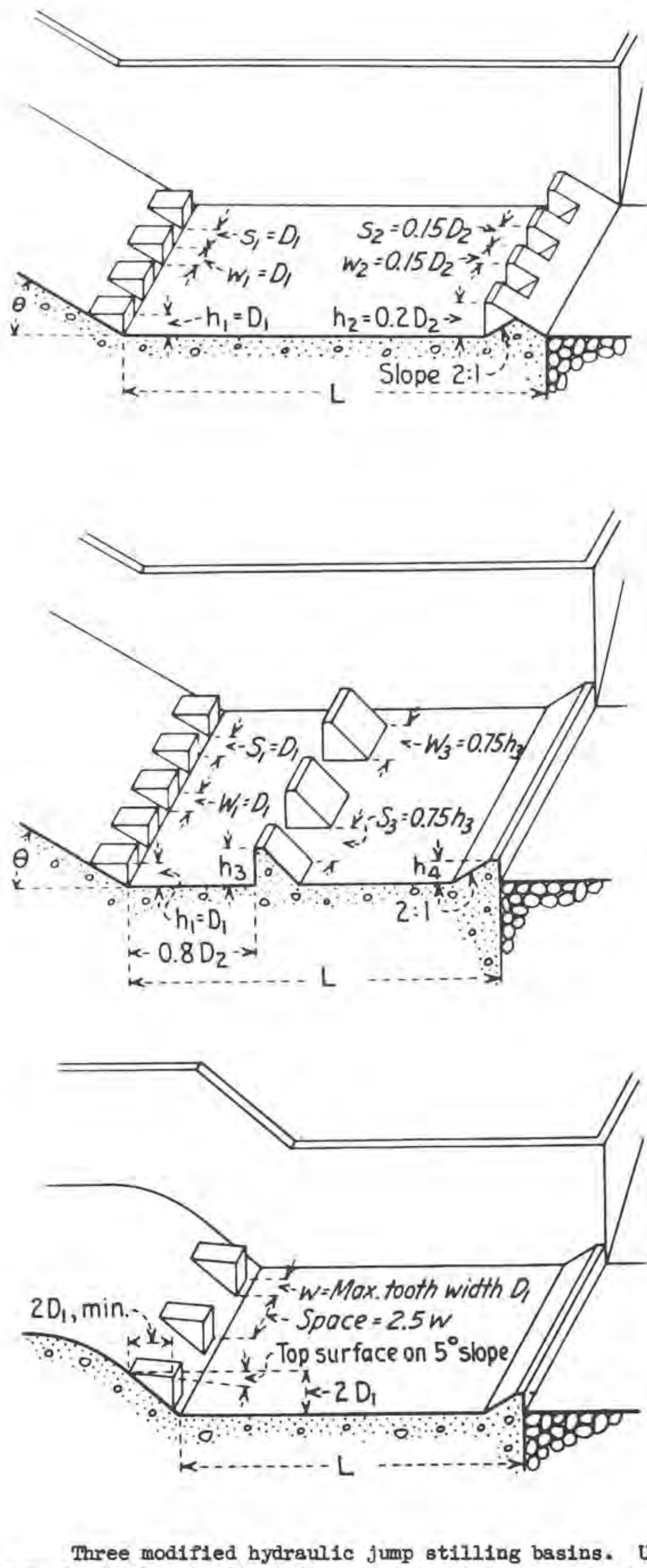
HYDRAULIC JUMP STILLING BASINS

Most of the stilling basins tested in the Hydraulic Laboratory employ the hydraulic jump principle to obtain energy dissipation sufficient to prevent undermining of the discharge structure. If the stilling basin is made sufficiently long to contain the entire hydraulic jump (Laboratory Facts No. 24), the basin becomes a costly structure. Laboratory tests have shown that by adding chute blocks, baffle piers and an end sill to the basin, the jump length may be reduced about one-half. Thus, the basin length and cost may be reduced accordingly.

The function of the chute blocks, which are placed in the upstream end of the basin, is to divide the incoming flow into separate small jets arranged in two layers, one group along the basin floor and the other above the basin floor. The baffle piers, placed farther downstream, act as impact surfaces which intercept these jets, turning some of the flow upwards and allowing the remainder to pass on downstream. The end sill tends to direct all flow away from the channel bottom to prevent erosion and undermining. All three appurtenances also induce fine grain turbulence which dissipates energy by converting it to heat.

On low dams, or where the velocity entering the jump is 50 to 60 feet per second or less, baffle piers may be used without question. On higher dams, or where the entrance velocity is above 60 feet per second, baffle piers must be used with caution since cavitation may occur to produce damage to the piers and other parts of the basin. Baffle piers are seldom used for velocities above 100 feet per second unless the piers have been model tested and streamlined to prevent cavitation pressures. The chute blocks are often omitted with high velocity entrance flow for the same reasons. Thus the end sill is the only appurtenance used in the basin of a high dam. Hydraulic model tests of high dam stilling basins are important since the reduction in length usually recommended as a result of model tests represents a saving in construction costs. For example, the Shasta Dam stilling basin was constructed 308.6 feet long whereas the length of the hydraulic jump was 469 feet. Satisfactory stilling basin performance was therefore obtained in a basin only 66 percent as long as the hydraulic jump.

Design procedures and rules have been generalized in the laboratory as a result of hundreds of tests on stilling basins. The standard procedures devised make it possible to design a stilling basin which will perform properly and is economical to construct. Since the generalized procedures contain factors of safety which may not be necessary on a particular basin, it may still be desirable to model test the basin to obtain the optimum in performance and the minimum in cost.



Three modified hydraulic jump stilling basins. Upper basin is for high velocity inflows and is 33 percent shorter than jump length; center basin is for medium velocity inflows and is 50 percent shorter than jump length; lower basin is mainly for low velocity inflows, is equal to jump length and gives minimum wave action.

L A B O R A T O R Y   F A C T S

No. 43
April 19, 1957

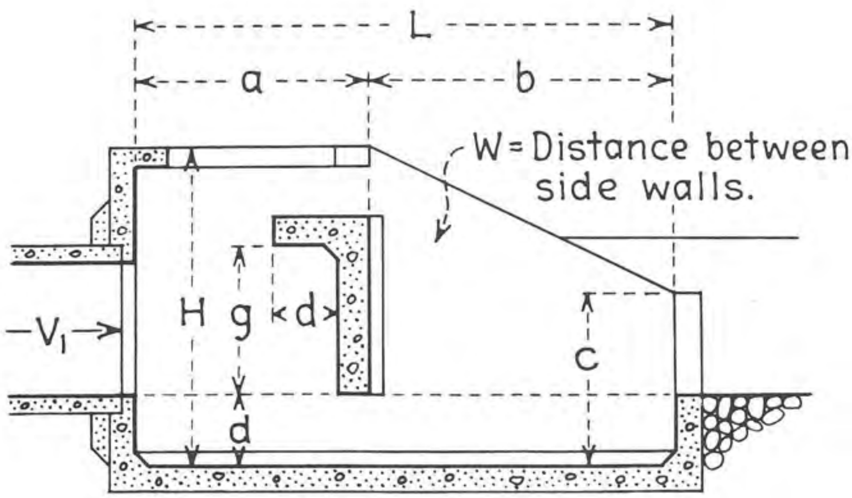
IMPACT STILLING BASIN

When a hydraulic jump stilling basin (Laboratory Facts No. 39) cannot be constructed for reasons such as (a) the tail water depth is not sufficient for the formation of a jump, (b) foundation conditions are not suitable for a jump basin, or (c) large discharges must be released quickly before sufficient tail water can be formed, impact basins are sometimes used.

Various types of impact basins have been developed in the laboratory for specific installations but only one type has been generalized for use without individual model tests. For this stilling structure the flow enters the basin from a pipe 12 to 72 inches in diameter flowing full or partly full. The flow is directed against the vertical face of a baffle having a short cover extending upstream. The cover prevents the flow from spilling out of the structure but does not form a closed roof to pressurize the basin. Vertical eddies induced by the baffle create energy consuming turbulence within the basin. The flow passes beneath the baffle in leaving the basin and passes over an end sill before entering the discharge channel. No tail water is required for satisfactory operation although a smoother water surface is obtained with normal downstream depths. With ordinary tail water depths the energy loss in the basin is greater than in a hydraulic jump basin of comparable size.

Hundreds of model tests were required to provide a set of standard impact basins to handle maximum discharges ranging between 20 and 340 second-feet with velocities up to 35 feet per second. A table, listing the minimum dimension for each part of nine different sized basins, was devised in the Hydraulic Laboratory to aid the structural designers in providing impact basins on small field structures without the need for individual model tests. Basins range in size from 5 by 7 by 3 feet deep to 16 by 22 by 12 feet deep. Intermediate sizes between those shown in the table may be interpolated. The designer may choose an upper or lower limit of maximum discharge so that the basin will provide optimum performance or acceptable performance at minimum cost.

Field reports of these structures, designed and built according to the table dimensions, have been analyzed in the Hydraulic Laboratory and the structures have been found to be satisfactory or have exceeded the performance claimed for them. These basins have been found particularly useful on canal and irrigation systems where many basins are often required on a single project. Much economy is gained through the use of the standardized designs.



Impact stilling basin for dissipating energy in flow from conduits. (H-1036-31)

L A B O R A T O R Y F A C T S

No. 36
December 28, 1956

CLOSED CONDUIT FLOW

Closed conduit flow is defined in hydraulics as flow in a completely filled pipe or conduit system where no free water surface exists. This type of flow occurs most commonly at appreciable positive pressures but may take place at near-atmospheric or subatmospheric pressures.

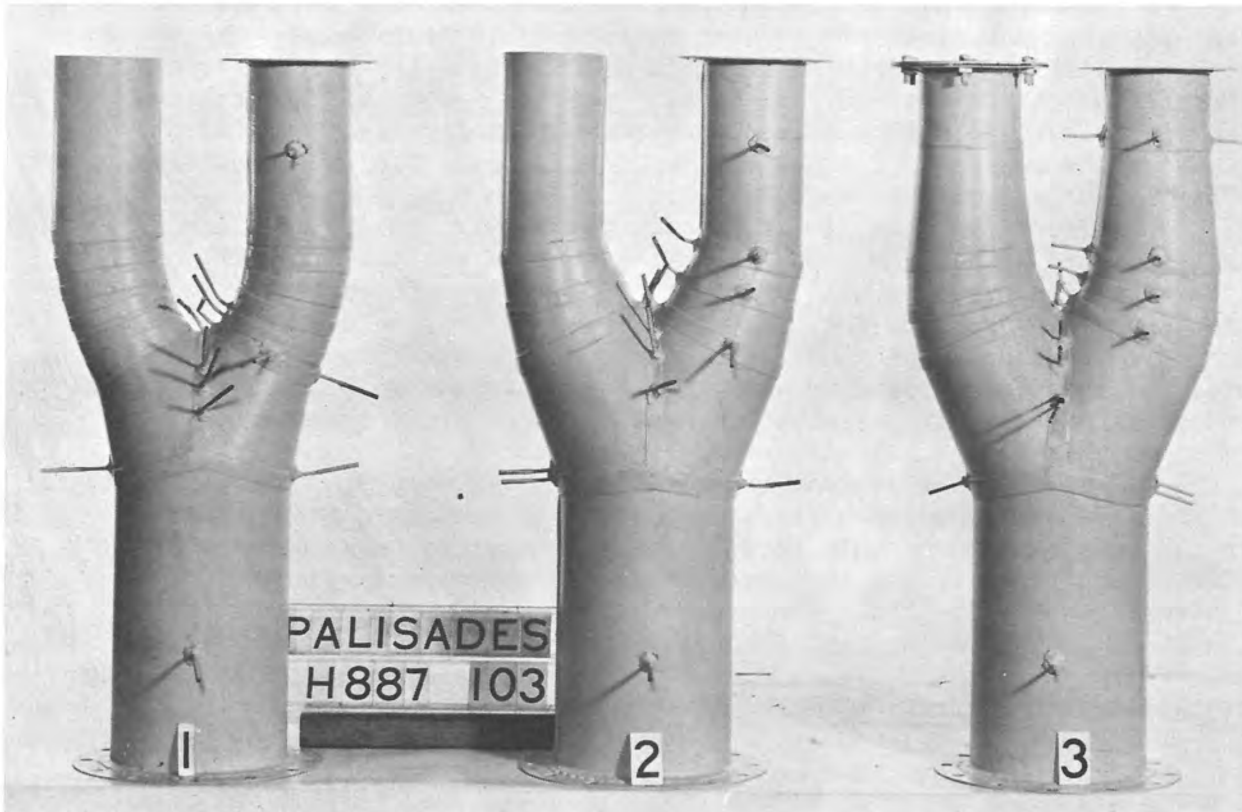
Investigations made in the Hydraulic Laboratory on problems of closed conduit flow have concerned a wide variety of hydraulic facilities, systems, equipment, and devices ranging from large outlets and penstocks to small fluid passages of machines and their controls. Tests have been conducted on conduit entrances, bends, branches, exits, gates, valves, gate seals, meters, siphons, nozzles, culverts, pumps, turbines, draft tubes, energy dissipators, small fluid passages in hydraulic controls, etc.

Usually the efficiency and capacity of the flow systems are of primary importance, but other factors such as velocity distribution, pressure distribution, cavitation tendencies, hydraulic forces like downpull, torque or thrust, vibration, turbulence, and fluctuating pressures may undergo close scrutiny.

An interesting factor in hydraulic testing of closed conduit systems is that although two systems may be designed to perform completely different functions, they consist of the same basic components and involve the same problems of investigation and design. For example, a power penstock would be designed to minimize hydraulic losses while an energy absorber such as used in a turbine bypass would be designed to include a maximum of hydraulic losses. Both systems require attention to elements like entrance shape, bend losses, expansion losses, wall friction, pressure distribution, and velocity distribution.

The Hydraulic Laboratory is equipped with pumps, meters, and supply lines of sufficient range and capacity to permit the testing of many types and sizes of hydraulic models. However, there are occasions when the facilities are not sufficient as to head and/or quantity of flow. An 18-inch high-head outlet at the Estes Powerplant and an 18-inch low-head high-capacity outlet at Mount Olympus Dam are used for these special cases. Many closed conduit problems can be solved by using air as a test fluid (see Laboratory Facts No. 28).

In some cases tests are conducted on field structures in which facilities have been installed during construction. These studies are conducted usually as extensions to laboratory studies to establish particular hydraulic relationships but may be conducted to procure data which cannot be obtained directly from the model. Friction coefficients for large conduits are an example of data which cannot be evaluated from model studies.



1:32 scale models used to study pressure distribution and loss coefficients for two-way Y-branches of outlet works piping system of Palisades Dam. The No. 3 branch with 5° 48' 13" converging passages was superior to other designs. (H-887-103)

STUDIES OF OUTLET CONDUITS

Under normal conditions, the outlet works at a dam regulates the flow from the reservoir to meet water demands downstream. The outlet works consists of one or more conduits which have a trashrack, streamlined entrances, control devices, and exits. Outlets are usually placed near the river level to make good use of reservoir storage and to permit emptying the reservoir for inspection and repairs. They must function properly for a range of heads from a few feet to hundreds of feet.

The high velocities accompanying the high heads make it imperative to streamline flow boundaries so that regions of severe subatmospheric pressure will not be formed. Where substantial irregularities exist in the flow surface, local areas of extremely low pressures may form when the high capacity gate or valve is opened. These low pressure areas may reach the vapor pressure of water and cause cavitation-erosion. Streamlining of flow passages is therefore thoroughly investigated in hydraulic model studies.

Because the rapid change from potential energy (reservoir head) to kinetic head (flow velocity in the conduit) occurs in the conduit entrance, the shape of this portion of the outlet is very important. Standard entrance shapes have been developed for circular, square, and rectangular conduits, but gate grooves and the relative position of the trashrack to the outlet may affect the pressure distribution in the entrance. Thus, the entrance shape is thoroughly investigated by placing piezometer taps in regions where low pressures may occur.

The pressure conditions associated with abrupt changes in boundary alinement and short-radius curvatures are normally investigated. Careful attention is given to the gate slots and transitions. Adequate aeration downstream from the control is essential to prevent cavitation and vibration, particularly if the control is used for regulation.

The exit of the outlet is also investigated when the conduit terminates on the downstream face of the dam. The flow is directed downward by means of a vertical bend which places the exit at an elevation lower than the entrance. Regions of low pressures may be found on the inside of the bend or immediately downstream from the intersection of the conduit and the face of the dam. The conduit often terminates in the spillway chute, necessitating proper flow conditions when a spillway and outlets are operating simultaneously or singly. To prevent the spillway flow from impinging on the outlet trough, a deflector is placed upstream from the outlet exit to lift the flow trajectory sufficiently to clear the trough. The size and shape of the deflector may be determined from the model studies.

General data collected over the years have standardized the design of portions of the outlet conduit. Cavitation-free entrance shapes, gate slots, and transitions have been developed for the more common outlet shapes operating at conventional heads. However, with the tendency toward higher operating heads and the departure from conventional designs to meet unusual operating or design conditions, the hydraulic model continues to play an important part in resolving outlet design problems.

Model of typical river outlet used for concrete dams. A gate or valve controls the flow into the horseshoe tunnel and water is deflected downward along face of dam by vertical bend at end of conduit. (H-471-14)

LABORATORY FACTS

No. 77
September 12, 1958

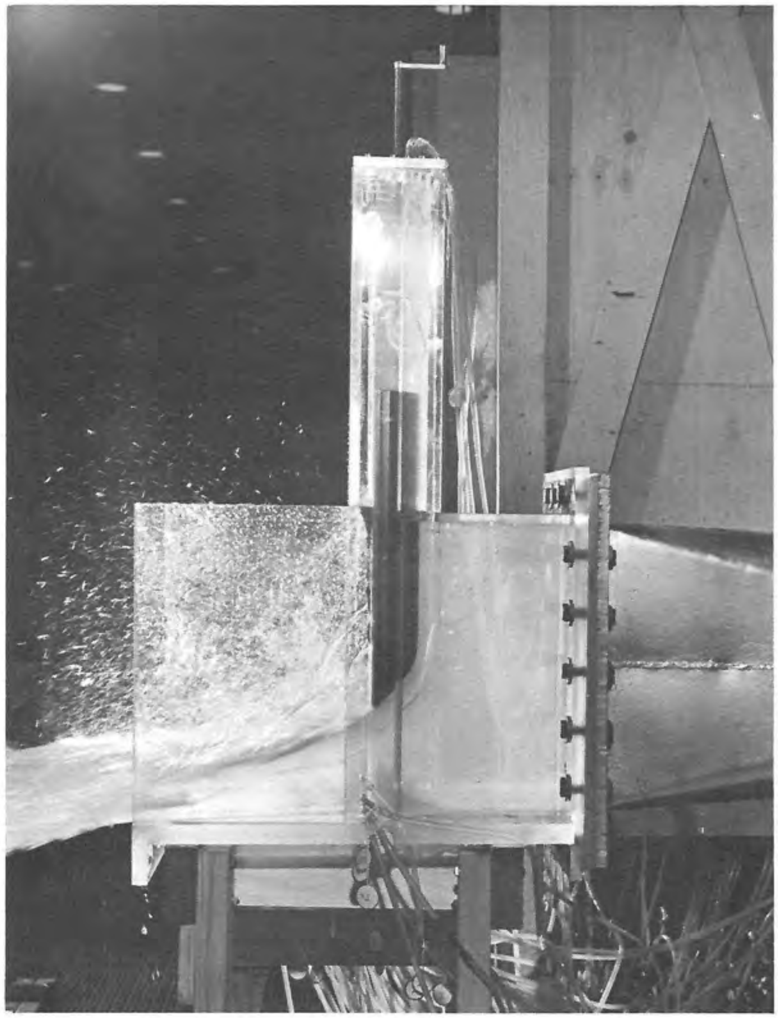
STUDIES OF CONTROLS FOR CLOSED CONDUIT FLOWS

Controls for closed conduit systems (see Laboratory Facts No. 36) include all devices used to restrict, regulate, or stop the flow in a conduit by obstructing the passageway. The controls presently used with medium to high heads in large conduits fall into four general classification groups. The first includes designs where plungers move away from, or toward, a seat ring to open and close the passageway. Needle, tube, and hollow-jet valves are typical examples. The second uses some form of leaf that moves across the passageway to open or close it. Slide gates, gate valves, and top-seal radial gates are examples. The third uses rotating elements within the passageways to control the flow. Plug, ball, and butterfly valves are examples. The fourth consists of controls for preventing return or backflow in a conduit. Swing-check and ball-check valves lie in this classification group.

The Hydraulic Laboratory has worked closely with the Design groups, to develop better operating, less expensive, more dependable control devices. The controls in common use a number of years ago were often large, heavy, inefficient, and subject to extensive damage and vibration due to cavitation. Some failed while in service and others were so badly damaged that expensive repairs and alterations were required. This need for revision initiated studies to determine the causes of the trouble and the necessary remedial measures. Models offered the best means for making these studies because known relationships of pressure, velocity, and discharge exist between the model and the prototype when the two are geometrically similar.

Many studies have been made, and are still being made, to develop more economical, efficient, and dependable controls suitable for use in a wide variety of installations. These studies have covered problems such as cavitation, vibration, hydraulic forces on needles, and leaves, torque on rotating elements, actuating devices, jet stability, gate seals, coefficient and discharge capacity curves, pressures within the controls and bounding surfaces downstream, the adaptability of designs to unusual installations, including submerged operation, and air requirements.

The development and testing program has led to a family of very good control devices and a knowledge of the good points and the limitations of each member. As the need and opportunites arise, further studies will be made to improve these devices and to find new and better controls for future structures.



Transparent model used to study the flow action through a high-pressure slide gate and pressure intensities on flow surfaces of the gate leaf and slot. (H-1320-7)

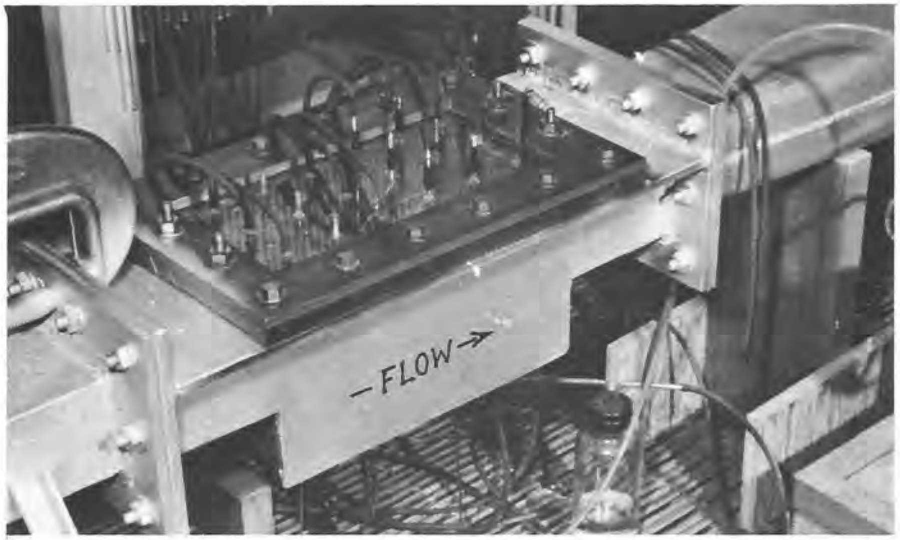
TESTING FOR CAVITATION

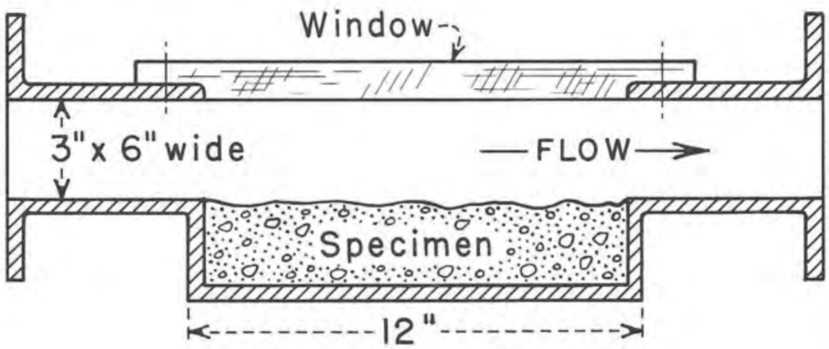
Cavitation occurs in hydraulic structures when the pressures in local or general areas are reduced to the vapor pressure of the flowing fluid. This pressure is about 0.5 psi, absolute, for water at a temperature of 56° F. Cavitation consists of the formation, transportation and collapse of vapor bubbles or cavities which form as a result of "boiling" while the fluid is subjected to its vapor pressure. The collapse of the cavities, or implosion, occurs when they move out of the vapor pressure zone into a region of higher pressure and takes place with such violence that extremely high unit forces are produced. When the implosions occur at a surface, these forces are sufficient to produce the disintegration known as cavitation-erosion.

Cavitation in hydraulic structures and hydraulic equipment may be induced in many ways but those most frequently encountered are: (a) boundary surfaces that curve too rapidly away from the normal paths of high velocity fluid streams, (b) irregularities or discontinuities in boundary surfaces exposed to high velocity flow, (c) excessive elevation differences between parts of a system not controlled properly to eliminate siphon action, (d) poorly streamlined shapes subjected to high velocity flow, and (e) flow passages that expand too rapidly in the direction of flow.

The elimination of the causes of cavitation is the first and most logical step in designing a cavitation-free structure. However, it is difficult in many cases to analytically predict what pressure conditions will exist. Fortunately these conditions can usually be detected by constructing and testing a scale model of the feature or structure in question. When the scaled values of the model pressures indicate the pressures on the full-size structure to be equal to or less than vapor pressure, cavitation with possible damage will occur on the full-size structure. On the other hand, when these scaled values indicate pressures above the vapor pressure, cavitation is not expected to occur. Because of pressure fluctuations, it is not advisable to permit values near the vapor pressure, and in most cases pressures equal to or greater than atmospheric are sought. Where it is impracticable to obtain pressures of this magnitude, values as low as a half-atmosphere may sometimes be used. In other cases it is not practicable to entirely eliminate the existence of vapor pressure at all conditions of operation. In these cases model studies are extremely useful in establishing the conditions under which vapor pressure will occur so that operation of the structure may be confined to noncritical ranges. In many structures air may be admitted to raise the pressures to a safe value in zones where vapor pressure would exist otherwise. This treatment is not always practicable since it may be difficult to introduce the air into the proper area, or because the air may interfere with downstream equipment or result in undesirable turbulence. Sudden flow passage enlargements in regions of low pressure have also proven effective in eliminating cavitation damage. This treatment in effect moves the flow boundary far enough away from the cavitation action to prevent damage.

Testing for cavitation is therefore always directed toward one or more of these four corrective measures: (1) maintaining all pressures above the vapor pressure of the fluid by selecting the proper boundary shapes, (2) limiting operation of the structure to noncritical ranges, (3) admitting air to low pressure zones, and (4) discharging high velocity jets into sudden enlargements. All four methods have been used successfully by the Hydraulic Laboratory to eliminate cavitation and/or cavitation damage.





Apparatus for determining cavitation potential of roughened concrete surfaces. The pressure-velocity relationships for incipient cavitation at irregularities in the surfaces are obtained permitting determinations of possibility of cavitation of comparable surfaces under field conditions. (H-1090-5)

LABORATORY FACTS

No. 28
September 21, 1956

TESTING OF HYDRAULIC STRUCTURES USING AIR AS A FLUID

The technique of using air flowing at low velocity to obtain solutions to hydraulic problems is a rather recent development. Although the use of air for this purpose is limited mainly to closed-conduit flow, it offers a quick inexpensive approach to many problems relating to hydraulic equipment such as large gates and valves and flow passages of unusual shape. This method of testing is particularly useful in qualitative or comparative tests but may also be used to obtain quantitative answers.

In many cases air testing cannot be substituted for water testing because the discharge of air into the atmosphere represents a submerged condition in hydraulics and this condition may not be representative. Also, air does not become discontinuous as does water when its vapor pressure is reached, and thus cavitation tendencies can only be indicated.

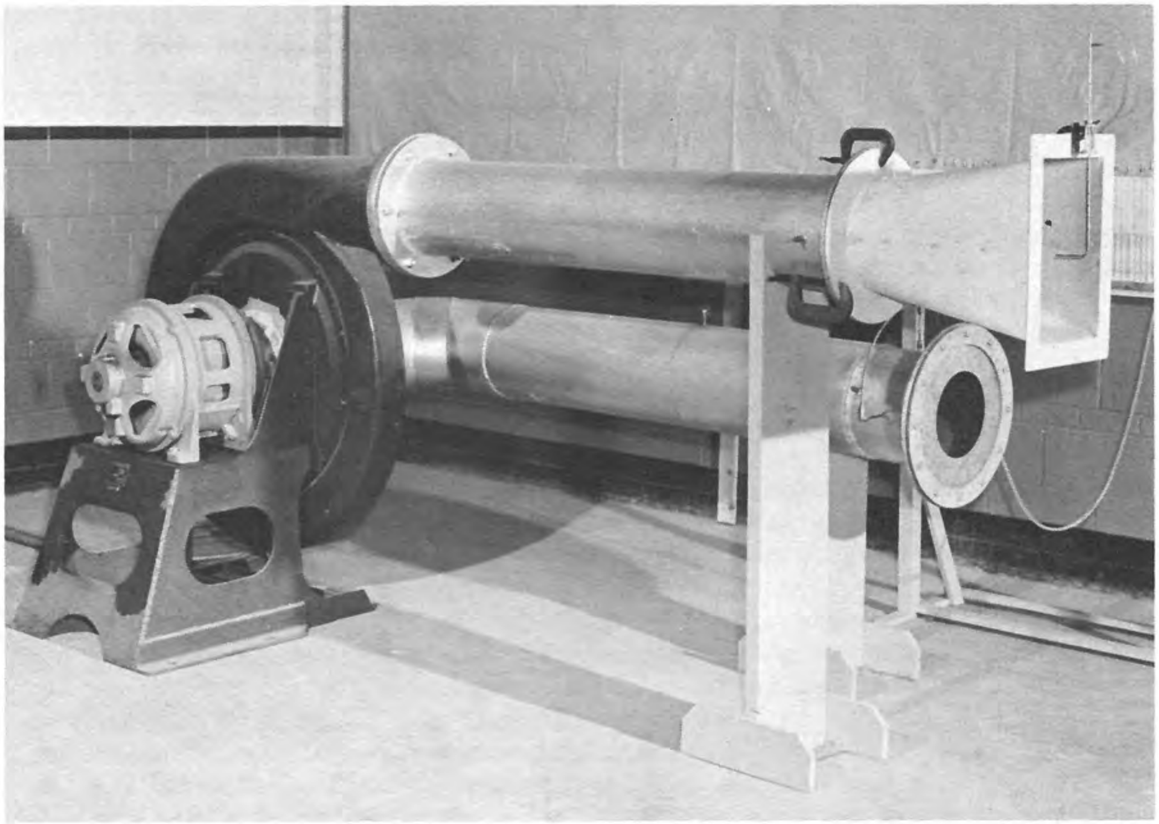
In cases where it is feasible to test with air, there are many advantages. An air model or test structure can be constructed and tested more rapidly than one using water and with an equal degree of accuracy. A minimum of test equipment is required, and there is usually no problem of storing and disposing of the fluid as there is in the case of water. An exception to this arises when smoke having objectionable properties is used for observing the flow direction. Low-cost, lightweight material can be used for most test structures, and changes in design can be represented and tested readily. Modeling clay, moulding plaster, or wood are excellent materials for shaping boundary surfaces in cut-and-try experiments.

In making model tests with air, it is usually best to keep the velocity of the air within the test structure below 300 feet per second (1/4 sonic speed). When this is done, the effects of compressibility can be neglected and computations can be made using hydraulic formulae.

Proper representation of controlling factors such as approach conditions and turbulence is very important because results are likely to be in error and of little or no value when these factors are represented incorrectly. The Hydraulic Laboratory is equipped with a 10-inch centrifugal blower and suitable instrumentation which is used specifically for air testing.

Air testing has been used successfully to study pressure distributions on flow surfaces of valves, gates, piers, louvers, gate grooves, pipe branches, and special conduit entrance shapes. From these data determinations were made of cavitation tendencies of the designs, thrust forces on closure elements of valves, hydraulic downpull forces on gate leaf shapes, head loss coefficients for flow systems, capacities of flow systems, and discharge coefficients of valves and orifices. Also, air has been used in conjunction with smoke to study the flow lines between the louvers in fish screens and to assist in developing deflectors that reduced the hydraulic losses through the louvers.

The use of air flowing at low velocity for testing hydraulic equipment has gained popularity in recent years due to its low cost, convenience, and dependability, and it is anticipated that expanded use will be made of it in the future.



Study of velocity distribution and pressure measurements in an outlet transition model attached to the discharge of a 10-inch centrifugal air blower. Orifice on blower inlet is used to measure flow quantity. (H-1308-7)

LABORATORY FACTS

No. 64
February 14, 1958

SIPHON SPILLWAY STUDIES

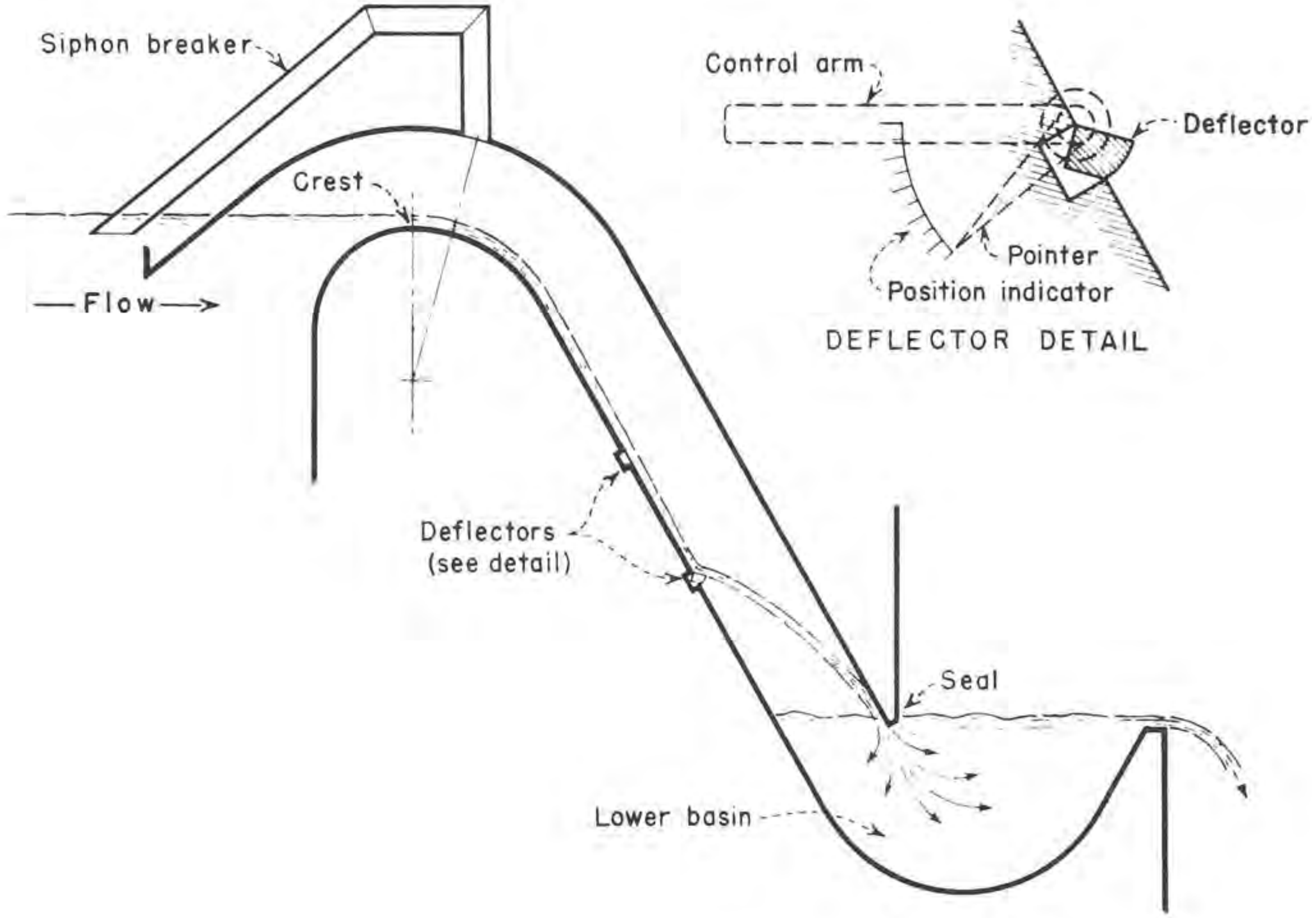
Siphon spillways have been used for many years by the Bureau for the protection of such facilities as canals, inverted siphons, and powerplants. They are placed along canals to discharge excess storm waters which enter through drainage inlets, thus preventing encroachment on the freeboard and overtopping the banks. Occasionally, a siphon is used upstream of a canal gate structure to handle any rapid rise in the water level caused by purposely or accidentally closing the gate. The siphon spillway serves a similar function when installed upstream of a powerplant penstock or an inverted siphon barrel.

The advantage of a siphon spillway over a simple overflow crest is the much shorter crest length needed for a given discharge because of the siphon action employed. Most Bureau siphons have a rectangular flow passage, or barrel, either 2 by 4 feet or 3-1/2 by 5 feet, the shorter dimension being the height of the barrel. They are built in both single and multibarrel units. The crest may be of concrete and fixed in elevation, or it may be of curved steel plate, adjustable in elevation as required for proper operation. Every siphon is provided with a means to break the siphon action, or prime, when the water surface in the forebay has dropped to a safe level. The more common siphon breaker is merely a pipe which allows the rapid entrance of air at the high point of the barrel. The inlet end of the pipe is so positioned that air may enter it when the canal water surface has dropped to the siphon crest elevation or just below it.

The Hydraulic Laboratory is conducting a program of research on siphon spillways to study operational characteristics of our standard design and to investigate new designs. This work was started because of the unpredictable behavior of prototype units, some of which operated satisfactorily and some did not. At present, a new design suggested by siphons of France and Italy is being tested, in addition to our standard design.

To be most effective, a siphon spillway must prime quickly at a head which is a small percentage of the barrel height. In order to prime quickly, the turbulence of the water near the exit of the siphon must function to pump air as rapidly as possible from the structure. Any delay in this process allows the forebay water level to rise above that otherwise necessary for priming. It is also desirable to design a siphon which can operate over a high percentage of its discharge range at a partial prime. The suggested design being tested is more consistent in regard to priming qualities, and it is able, therefore, to reach the primed state at lower heads and discharges. Some improvement in the range of discharges for which it will operate at a partial prime has been noted. Principal disadvantage of the new design is a lower coefficient of discharge.

Laboratory research will continue as time permits. On the agenda for future work will be attempts to improve the coefficient of discharge, to further reduce priming heads, and to increase the range of discharges at partial prime. Work will continue on a device to automatically proportion air and water in the barrel during the partial prime type of operation.



Improved low head siphon spillway design. Deflector in lower surface of flow passage directs small flows to the seal where air is entrained and carried outside through the lower basin. This feature gives rapid priming at small heads.

L A B O R A T O R Y   F A C T S

No. 51
August 2, 1957

MEASURING IRRIGATION WATER

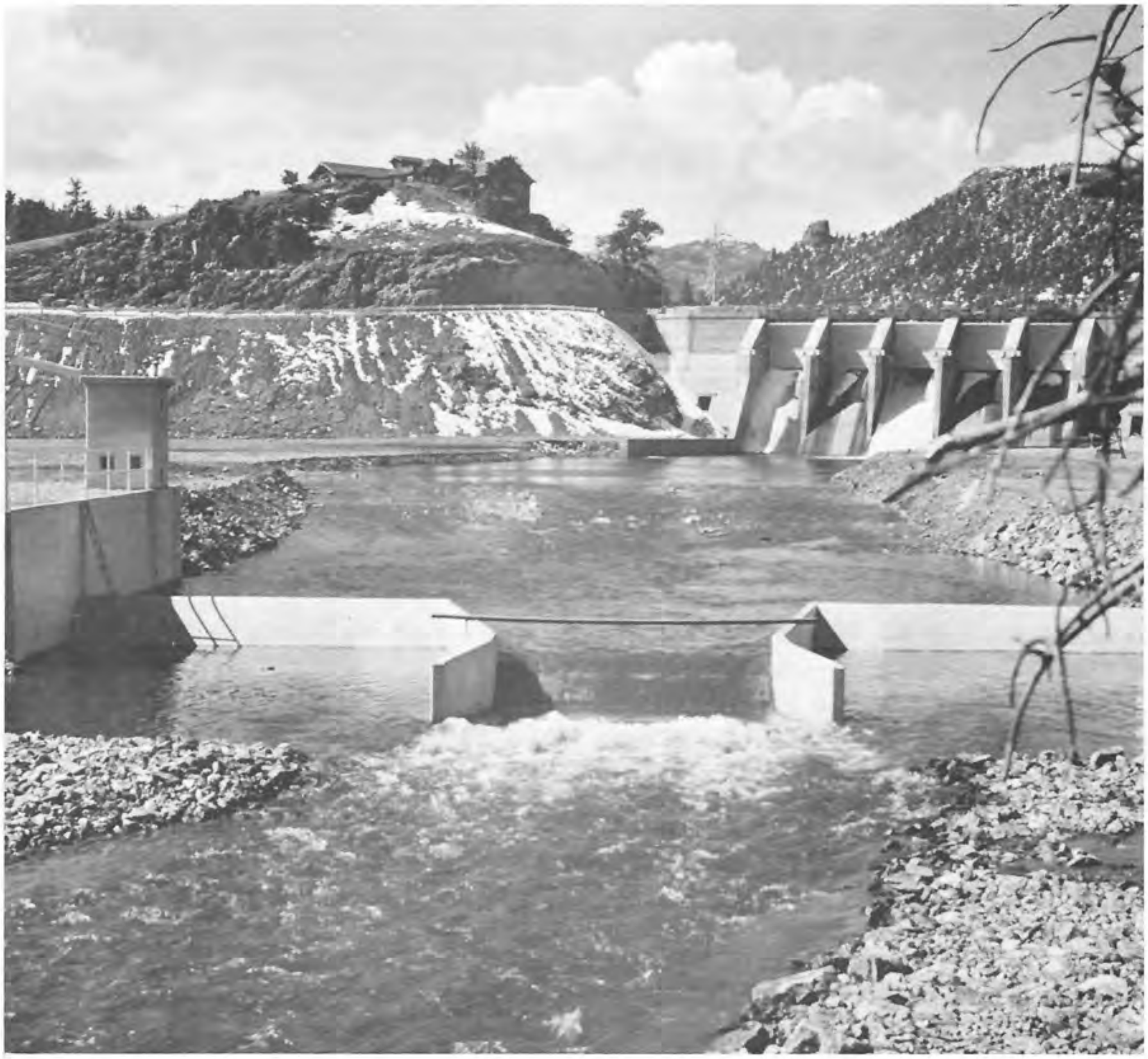
Adequate control and accurate measurement of water throughout an irrigation system from storage to farm delivery are necessary (1) for successful business management, (2) to meet legal obligations of water priorities, (3) for water conservation, (4) to insure an equitable distribution of water to land areas served, and (5) to establish and maintain a cordial relationship among owners, operators, and water users.

In an ideal arrangement, flow should be measured at storage outlets, canal headworks, at strategic locations in canals and laterals, and at points of delivery to the consumers. These measurements are made by either primary or secondary devices. A primary device is one considered a standard by water measurement authorities and for which there are accepted rating curves. A secondary device is dependent on a primary device for calibration, thus, the accuracy is dependent upon that of the primary device.

The generally used primary devices at the reservoir, canal headworks, and in the canal and laterals are current meters, critical depth flumes, weirs, venturi meters in outlet tubes, or others. Considerable advancement has been made toward the utilization of outlet controls as primary devices in the measurement of releases from storage reservoirs to downstream river channels. Models of the control gates and valves have been successfully calibrated in the Hydraulic Laboratory and the results transferred to the prototype to permit their use as measuring devices in the field. Reduced costs can be effected in an irrigation system by thus omitting separate measuring devices. Calibration curves for the primary devices used in other parts of the system, such as flumes, weirs, and meters are often established in the laboratory with recommendations for installation of the devices in the field.

Certain secondary devices at the farm turnout combine measuring and closure features, for example, meter gates, Denver screw lift gates, and constant head orifice turnouts. Other secondary devices used in the laterals, not incorporating the closure feature, are small Parshall flumes, weirs, and propeller-type meters. Calibration curves and operating characteristics of these devices are established or checked in the laboratory for use in the irrigation system.

Although many measuring methods are available, a careful study is required to determine the device most suitable for installation at a particular site. For these studies by the designers and operators of the irrigation systems, the laboratory serves as a source of information because of the use of these devices in the laboratory and experience gained from field observations.



15-foot Parshall Flume for measuring flow in rivers below Olympus Dam near Estes Park, Colorado. Gagehouse at left contains instruments for continuous recording of head in flume. (H-983-9)
6

No. 11

LABORATORY FACTS April 20, 1956

SEDIMENT PROBLEMS

In general, sediment may be defined as any fragmental material transported by, suspended in, or deposited by water or air. The chief concern of the Bureau is with material transported by water. The ability of flowing water to keep in suspension and to transport solid fragmental particles, of a specific gravity greater than that of water, is the phenomenon which brought sediment engineering into being. Many theories have been developed and are employed as tools by the sediment engineer. It is found, however, that many of these tools are empirical and are inadequate for many of the problems faced in the design, construction, and maintenance of Bureau projects. In sediment problems where present theory and experience do not adequately cover the requirements, the Sediment Investigations Unit of the Hydraulic Laboratory is called upon to help in their solution.

Assistance to our designers and the Division of Project Investigations is most often given by hydraulic model studies. One type of problem for which a number of model studies have been made involves sediment control at canal headworks. It is of course important to keep sediment in canal waters to a minimum, because the sediment settles to the bottom at the low canal velocities. To maintain the capacity of the canal, this sediment must be frequently removed from the canal if it is not prevented from entering at the headworks.

Various sediment controlling devices have been tested, including: curved guide walls, vortex tubes, and short tunnels. Model studies being conducted at present include rehabilitating the existing canal headworks and making channel improvements in the Middle Rio Grande. The channelization studies of the Middle Rio Grande are being conducted to help determine the most economical method of placing revetment and jetties to stabilize the banks of the river during medium size floods and create a self-cleaning channel for normal flows.

Various other services are provided. Aid is given in developing field testing programs and in conducting field tests. An example is the soil erosion-tractive force studies now underway. Tractive force is the shearing force acting on the canal bottom and sides in the direction of flow due to the weight of water and the slope of the canal. In two regions various sites on canals have been chosen in cooperation with field personnel, and studies to determine factors of canal stability are in progress. The method by which the tractive force acting on the canal boundary will be determined was developed through a research program conducted in the Hydraulic Laboratory. Under closely controlled laboratory conditions, tests were made to verify the fact that the tractive force acting on the boundary of a channel can be determined from the velocity distribution of the flow in the channel.

The science of sediment engineering is a young and growing science. While much research and investigations remain to be done, the tools already available have been advanced to a point where they can be applied effectively.

Movable bed hydraulic model study of Woodston Diversion Dam near Stockton, Kansas. The curved guide walls of the intake induced secondary spiral currents that caused the coarse bed material to move to the inside of the curve away from the canal intake and into the sluiceway. (H-1305-48)

No. 56
October 11, 1957

TRACTIVE FORCE STUDIES IN THE LABORATORY

Although the excavating of channels in earth and conducting water through them goes beyond the beginning of recorded history, there are some phases of this practice which have not yet been satisfactorily developed. One concerns the stability of channel banks and bed. Laboratory investigations are performed to determine limiting tractive forces permitted in the design of stable channels.

The tractive force τ exerted on the bottom of an infinitely wide channel by flowing water is equal to wds, where τ is the shear on the boundary in pounds per square foot, w is the weight of water in pounds per cubic foot, d is the depth of water in feet, and s is the slope of the hydraulic energy gradient. For a regular channel, the average tractive force over the entire boundary is $\tau_a = wrs$, where r is the hydraulic radius of the section.

Knowledge of the resistance of various materials to erosion is important in designing canals in earth materials. The limiting tractive force, or boundary shear, of the materials can be readily determined by testing them in flumes and channels in the laboratory. The Prandtl-von Karman velocity distribution equation is used to determine the boundary shear or tractive force.

Velocity distributions are measured, usually with Pitot tubes, and then plotted on a semilogrithmic graph showing point velocities compared to relative depth. Because of the steep velocity gradient near the boundary, velocities are measured at points as near the boundary as possible without causing disturbance to the movable boundary material or to the flow pattern around the Pitot tube. The static pressure is measured, and the difference between the static head and the dynamic head gives velocity head from which the point velocity is determined.

Using the Prandtl-von Karman velocity distribution equation as a basis, the following equation was developed to determine the tractive force at a point on the open channel boundary.

$$\tau_o = C(V_2 - V_1)^2$$

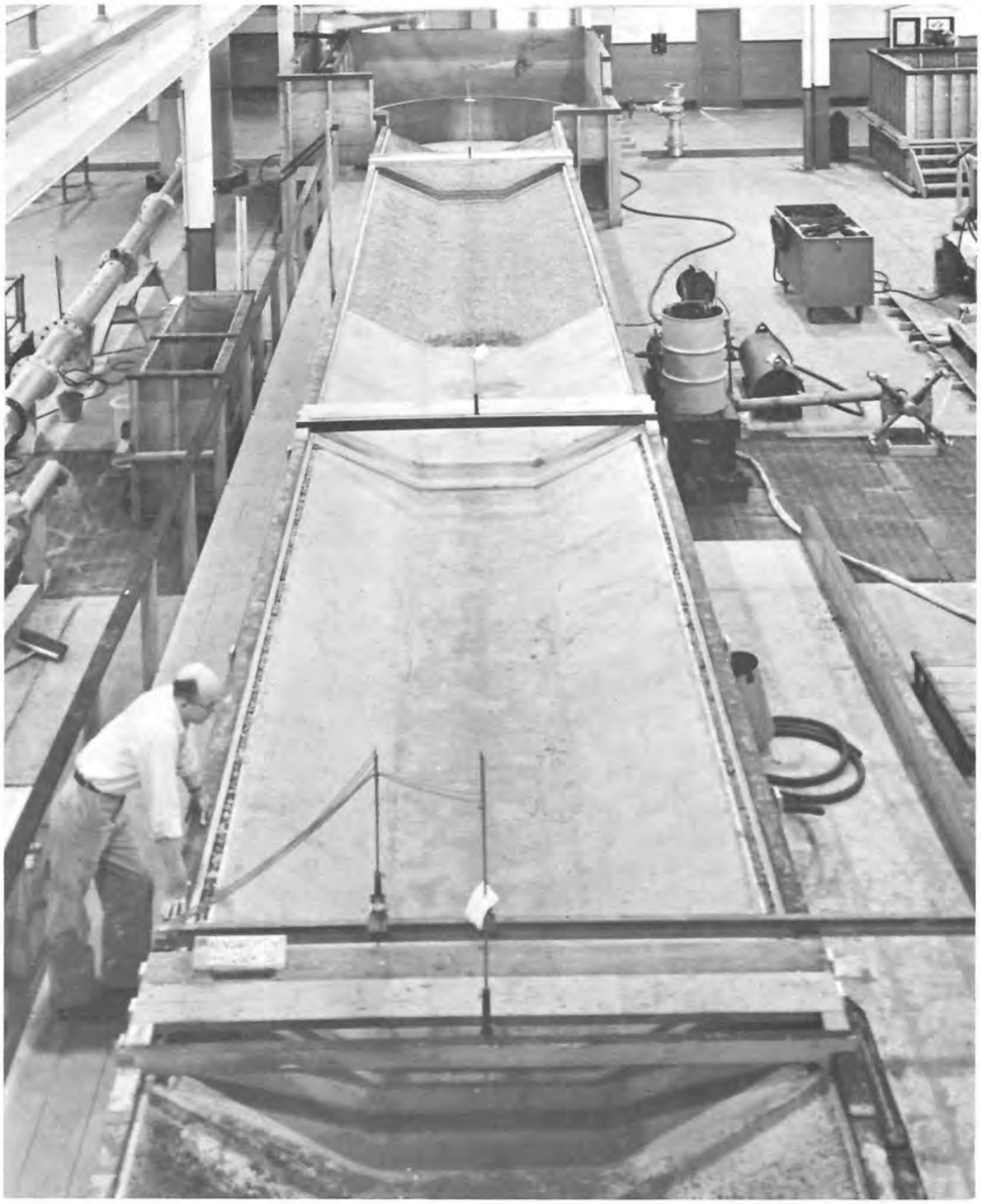
where C is a constant equal to $\dfrac{\rho}{(5.75 \log \frac{Y_2}{Y_1})^2}$ and ρ is the density of the water, V_2 and V_1 are point velocities in feet per second at perpendicular distances Y_2 and Y_1 from the boundaries.

Inserting the values of velocities picked from the velocity distribution plotted on semilogrithmic paper into the above equation, the boundary shear or tractive force is determined at various points around the perimeter.

The average tractive force for a channel cross section is determined from the area plotted from the tractive force distribution. This average tractive force can be checked by measuring the hydraulic slope and the hydraulic radius of the channel, and applying these values in the equation

$$\tau_a = wrs$$

Tractive force studies in the field will be described in later Laboratory Facts.



Fine dune sand shaped to a trapezoidal canal section in place in a testing flume 8 feet wide, 2 feet deep, and 70 feet long. Critical shear values for this and other materials are obtained by making velocity distribution and hydraulic grade measurements with water flowing over the material. (H-1105-5)

L A B O R A T O R Y   F A C T S

No. 60
November 15, 1957

TRACTIVE FORCE STUDIES IN THE FIELD

Permissible velocities in unlined and earth lined canals have usually been determined in the past on the basis of standard soil mechanics tests of the earth material and experience of design engineers. Because of the nature of velocity distribution in canals, higher mean velocities are allowable for deeper depths than for shallow depths to give the same velocities near the canal boundaries.

The principle of using limiting tractive forces has come into use in design of canals in recent years. (See Laboratory Facts No. 56, Tractive Force Studies in the Laboratory.) Use of this principle permits determination of the shear transmitted to the boundaries of canals by the flowing water regardless of the depth. To be stable, a channel must not scour on the sides and bottom, and objectionable deposits of sediment must not occur.

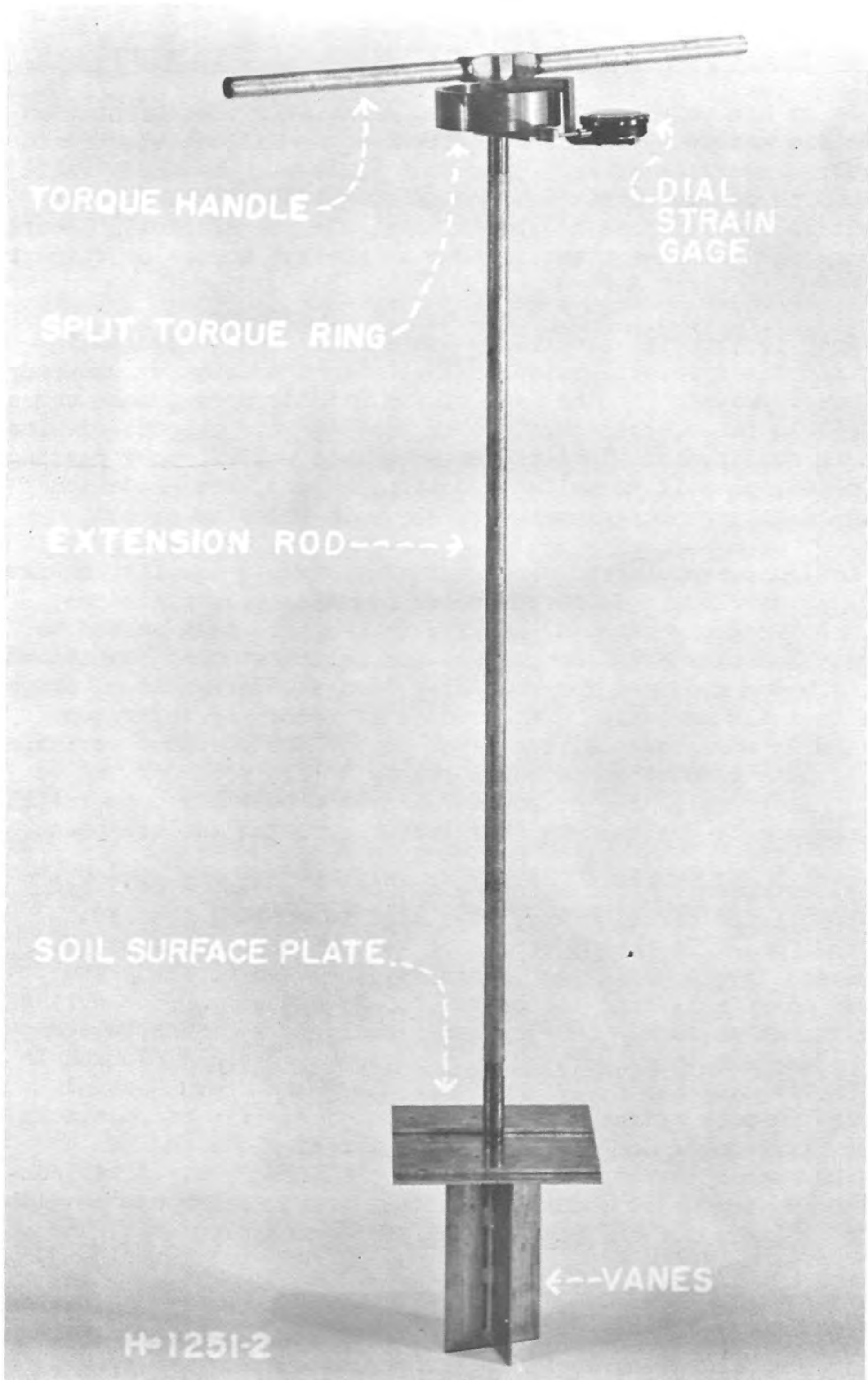
To help establish better design criteria for earth lined and unlined canals, field studies of erosion and tractive forces on fine cohesive soil materials are being conducted jointly by the Earth and Hydraulic Laboratories as part of the LCCL Program. The program includes several earth lined and unlined canals with a variety of soils types which have been subjected to different climatic and hydraulic conditions.

The field studies are accomplished in the following manner. Two trips are made to each test site. The first trip is made while the canal is in a dry condition. Reaches of channel suitable for testing are selected and earth samples obtained. The second trip is made when the canal is flowing near maximum discharge and hydraulic data and vane shear test information are obtained.

The earth materials are classified and the samples are tested to obtain data on densities, compressive strengths, mechanical analysis, Atterberg limits, percentage of compaction for earth linings, and petrographic and chemical properties. Also, undisturbed samples are subjected to a laboratory erosion test to determine the approximate tractive force resistance of the soil for correlation with the field test results. Hydraulic data are analyzed to determine velocity profiles, average velocities, discharge, hydraulic radius, average tractive forces, tractive force distributions, Manning's "n" values, suspended sediment concentration, and water temperatures.

The tractive force distribution is determined from the Prandtl-von Karman velocity distribution equation, by a method developed in the Hydraulic Laboratory and explained in Laboratory Facts No. 56.

A variation in canal sizes from large to small subjected to three conditions of erosion are being tested: (1) stable, (2) slightly scoured or on the point of scouring, and (3) moderately scoured. A number of channels of each type have been analyzed to date in an effort to establish which of the many physical properties of the soil makes the principal contribution toward erosion resistance.



Vane shear tester designed to measure shear resistance of soils near the soils surfaces in canals where water is flowing. Shear resistance is correlated with resistance of soils to erosion by flowing water to improve design criteria for outlined canals.

L A B O R A T O R Y   F A C T S

No. 6
March 15, 1956

ELECTRONIC INSTRUMENTATION IN HYDRAULIC INVESTIGATIONS

As it has in many other fields, electronic instrumentation has become vital to modern hydraulic investigations. Without electronic instruments observations of many important hydraulic phenomena would be impossible. The design, construction and operation of electronic devices require the services of specialists. In the Hydraulic Laboratory these specialists comprise a small group in the Hydraulic Investigation Section.

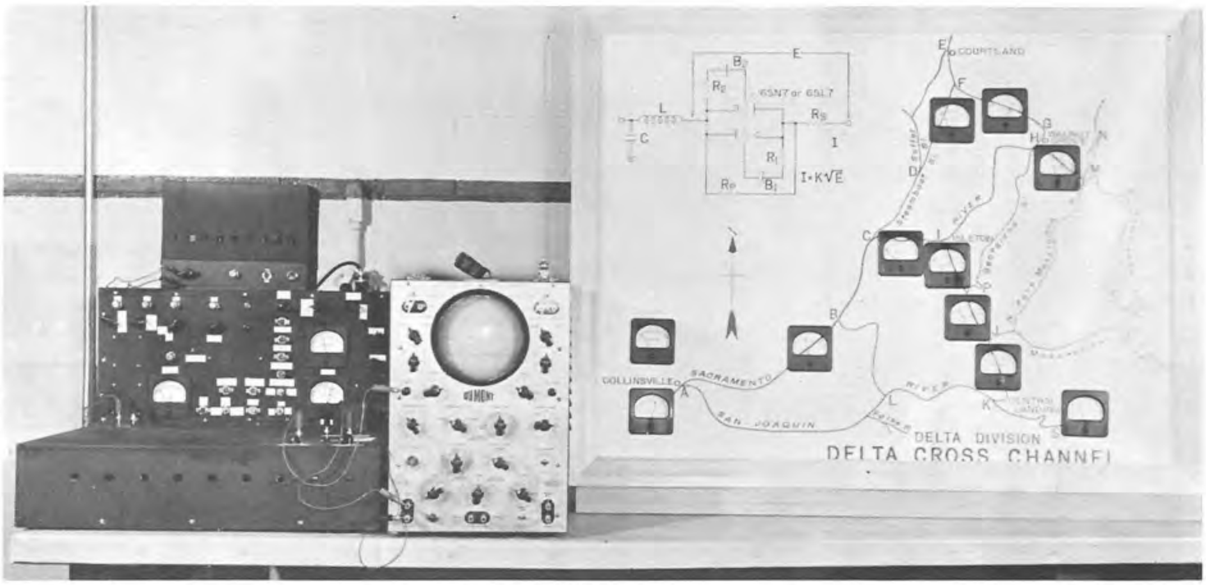
Need for special electronic instrumentation in hydraulic laboratory and field investigations arises when transient or unsteady phenomena are involved. In the case of a hydraulic model, measurements may include velocities, pressures, water depths, wave characteristics, and vibration amplitudes. In field measurements all of the foregoing may be involved, as well as salinity determinations, sedimentation studies, and discharge measurements by the salt velocity method.

Design procedure for electronic instruments usually consists of choosing or developing basic components such as pickup devices, recorders, coupling circuits, or amplifiers that are best suited to the purpose. The pickup is the part of the equipment that conditions the quantity being measured for recording, and its design is of utmost importance in instrumentation. The choice of recording instrument is determined in most cases by the frequency of the measured variable. Coupling circuits used to connect the pickup to the recorder may be mechanical, electrical, or electronic. Wherever possible commercially available components are used to facilitate servicing the equipment.

As examples of such instrumentation, a pressure cell and necessary associated circuits were developed to measure transient pressures that occur in the operation of valves, gates, and pumps. Salinity meters developed in the laboratory are used to study the intrusion of ocean salt into the Sacramento-San Joaquin Delta during spring and summer seasons. An electronic analogue was constructed to represent the electrical equivalents of the rivers and sloughs in a portion of the same delta, as an aid in the Delta Cross Channel studies. The purpose of the analogue was to accelerate computations for the distribution of combined tidal and stream flows and to determine the capacities of proposed artificial channels. After construction of an artificial channel, a tidal current meter was developed to check the validity of the computation of channel capacity.

Another instrument, the magnetostriction oscillator, was constructed to study the resistance to cavitation of various materials. Also, radio-reporting precipitation gages were developed to enable a periodic check on the rates of rainfall at several remotely located stations in a watershed, as a means to facilitate flood control operation of a reservoir.

The above examples indicate only partially the extent to which the Engineering Laboratories utilize the resources of electrical instrumentation. More will come later.



Electronic analog of conditions of flow and tide action in channels of the delta at the confluence of the Sacramento and San Joaquin Rivers. (H-929-10)