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TWENTY YEARS OF BUREAU OF RECLAMATION HYDRAULIC LABORATORY PRACTICE

By

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The purpose of this discussion is to indicate the extent to which the Hydraulic Laboratory is utilized in reclamation engineering. The space allotted here does not permit a comprehensive account of all the studies of the past 20 years, but allows only a description of the evolution of the Bureau laboratory with a few examples as a cross section of that period. The projects touched upon in this paper present only a fraction of the output of the laboratory during this period.

At the time of the publication of the ASME and VDI volume "Hydraulic Laboratory Practice" in 1928 there were over 50 hydraulic laboratories in the United States and Canada. Most of these laboratories were developed for purely academic purposes, and only those at Cornell University, University of Iowa, and Worchester Polytechnic Institute were of appreciable size. In the past quarter century the art of the Hydraulic Laboratory has been greatly expanded not only by several leading universities but also by such agencies as the Tennessee Valley Authority, United States Waterways Experiment Station, and the Bureau of Reclamation.

The unprecedented magnitude of Hoover, Grand Coulee, and Shasta Dams, together with the corresponding increase in the size of their hydraulic features, made experimental studies imperative for their general design. In the interest of economical and safe design, with structures of this magnitude, unfamiliar factors could not be left entirely to chance or individual judgment. It was later discovered that savings in cost and improvement in designs of smaller hydraulic structures, made possible by model studies, were alone sufficient to justify the operation of a hydraulic laboratory on a full-time basis. Whereas 20 years ago the laboratory was charged only with testing or checking hydraulic designs of structures about to be contracted for construction, the present day laboratory has many responsibilities interwoven through the various phases of water resource development, from project planning through design and construction problems to those in the operation and maintenance or irrigation and power projects and river control.

This discussion will be devoted to the significant contributions to the reclamation, irrigation, and power engineering profession by the hydraulic laboratory engineer. Before discussing the product of the advancement in the art, mention should be made of the transformation of hydraulic laboratory engineering to its present state.

Probably the greatest contribution to more effective laboratory investigation is the rapid development of instrumentation. Electrical, more specifically electronic, instruments such as specially designed oscillographs, scopes, pressure cells, high speed photography, have all made it possible to observe hydraulic phenomena not possible 25, 20 or even 15 years ago.

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The application of electrical analog computers to the solution of hydraulic problems of a complex nature has been the outstanding development in recent years.

Of course engineering laboratories appended to a design and construction organization would most likely be engaged principally in applied research; however, occasionally the necessity arises to pursue some basic research in the laboratories or in conjunction with qualified university laboratories. Accordingly, the Bureau takes full advantage of the research of others, including Governmental agencies, foreign laboratories, industrial corporations, engineering experiment stations, and the work of individuals in colleges and universities. A concerted effort is constantly made to keep in touch with and to utilize the research work of all agencies in order to avoid duplication of work.

The Bureau began hydraulic laboratory studies at the Colorado Experiment Station, Colorado A&M College at Fort Collins, Colorado, in 1930. Since that time Bureau hydraulic laboratories have been established and operated in various places as the particular need arose. During the summer seasons of 1931 to 1936, a laboratory was operated on the Uncompahgre Project near Montrose, Colorado, where a head of 50 feet and a discharge of 200 second feet of water were available, (Figure 1). It was in that laboratory that the final design of the side-channel spillways for Hoover Dam was studied to a scale of 1:20. A complete model of the Imperial Dam and its appurtenant works, to a scale of 1:40, was studied there for two seasons to develop the final arrangements of the structure; and the final design of the Grand Coulee Spillway bucket was studied on a scale of 1:15. A hydraulic laboratory was maintained continuously from 1934 to 1937 in the basement of the Old Customhouse, in Denver, Colorado, in which many of the smaller structures designed during that period were studied. In 1937, when an addition to the New Customhouse in Denver was completed, the equipment in the Old Customhouse was moved into the New Customhouse laboratory. The Fort Collins laboratory building was expanded to about four times its original size in 1935 to meet the increasing load of assignments. However, with the new laboratory established in the New Customhouse, the personnel from Fort Collins was gradually absorbed until the Fall of 1938 when the Bureau discontinued its operation of the Fort Collins laboratory. In 1939, testing facilities were installed in the Arizona Canyon wall outlet works at Hoover Dam to utilize the head of 350 feet and a discharge of 200 second feet for the study of the final design of the tube valves developed to control the outlets at Shasta Dam. That laboratory was operated for several months in 1940, in 1941, and again in 1945, its program being geared to the studies made in the Denver laboratory on smaller models. In 1946 the Bureau Denver laboratory was moved to its present quarters at Denver Federal Center. Upon the construction of Olympus Dam, Estes Park, Colorado, provisions were made for a medium head (100 feet, nominal) open-air laboratory for general problems requiring up to 75 second feet (Figure 2).

Provisions for high head testing in closed conduit problems were provided at the Estes Park Power Plant. A head of 550 feet through an 18-inch bypass together with adequate metering facilities have been utilized for high head model tests on turbine and energy absorbers.

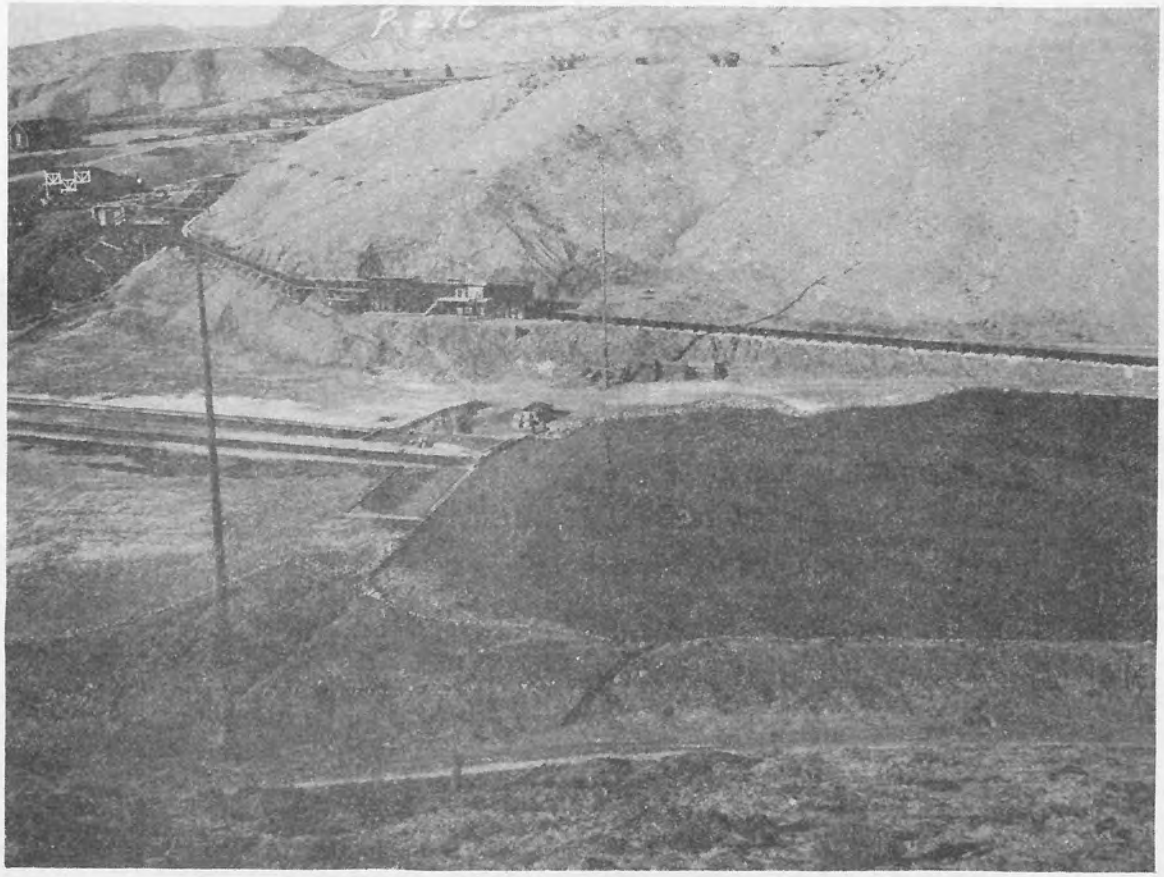

Figure 1. Montrose laboratory operated from 1931 to 1936.

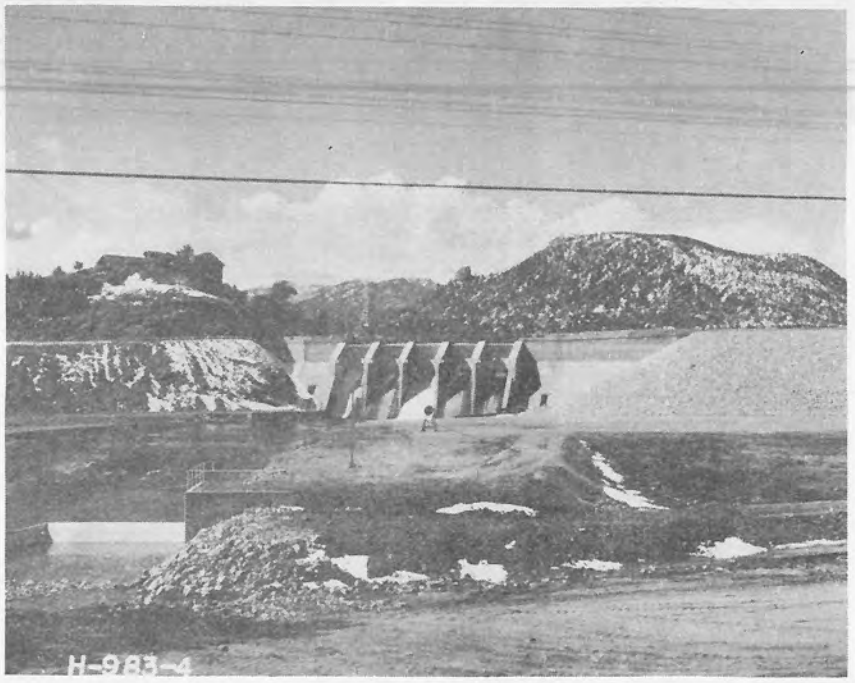

Figure 2. Outdoor laboratory site on left bank of Big Thompson River at Olympus Dam, Colorado.

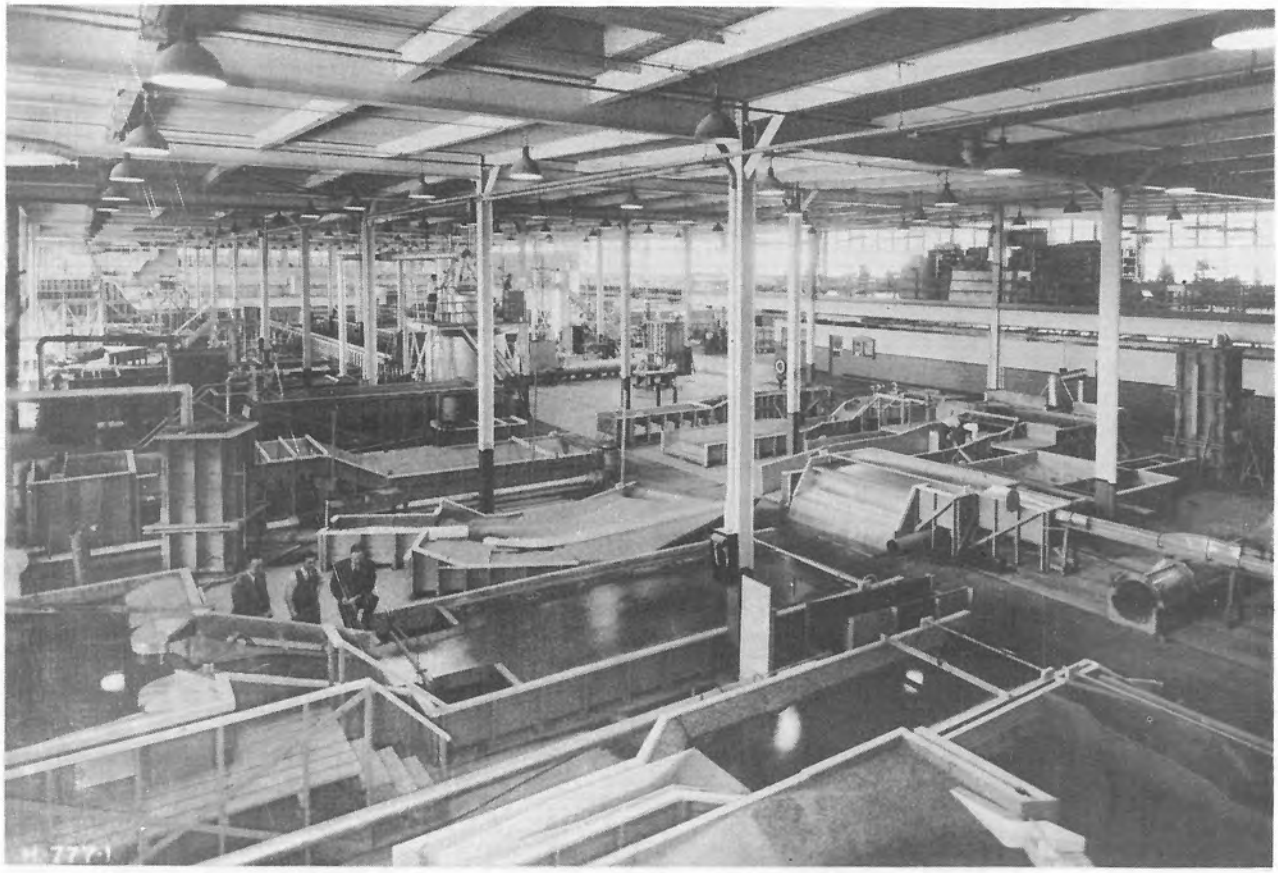

Figure 3. Denver Hydraulic Laboratory.

The main portion of the Denver Hydraulic Laboratory is 300 feet long by 120 feet wide, with 28 feet of head room. The water supply facilities include vertical, as well as horizontal, pumping units, with a total capacity of about 80 second feet. Measurement of the water is accomplished principally by venturi and orifice meters. A volumetric calibration tank in the center of the laboratory is used for calibration of meters. The timing is done by an electronic counter controlled by 100-cycle tuning fork.

The laboratory (Figure 3) is equipped for many types of hydraulic testing, and includes blowers for air testing.

The Hydraulic Laboratory is a section of the Engineering Laboratories Branch in the Design and Construction Division.

A large volume of the work of the laboratory emanates from the operation and maintenance of hydraulic works. The Hydraulic Laboratory is a clearing house for a host of problems in hydraulics and allied fields. For example, the very complex field of water measurement in irrigation design and operation very logically centers around research. Unusual problems in river system control such as those encountered on the Central Valley project are often referred to the laboratory engineer for suggestions in connection with general project feature layouts. Development of equipment for the solution of special problems or the procurement of special data are often referred to the laboratory.

Spillways--Crests

When funds for the extensive study of the Boulder Canyon Project became available, all practical forms of spillways were studied and analyzed as to cost. These forms included glory holes, side channels, (with and without gates) and various combinations. Extensive tests of models (1:20 and 1:60 scales) were necessary to secure safe and economical design. While some model studies on this spillway were being conducted at the Fort Collins laboratory, other model studies were being conducted in the specially constructed laboratory at Montrose, Colorado. Many questions arose regarding overflow crest section, concerning which reliable data were insufficient to permit dependable solutions. Therefore, a series of tests was initiated to provide more information on the designs of the various overflow crest shapes proposed for the Hoover Dam spillway. As this field of study was extremely broad, only a few of the experiments were completed previous to the actual construction of the spillway. The subject, however, was of such universal interest to dam designers that the work was continued. With the trend toward higher dams and greater depths of flow over flood spillway crests, the importance of providing a correct profile was materially increased. The rather exhaustive studies were subject to considerable interruption and complete analysis of the test results was delayed for some years. Much of this work was published as Bulletin 3, Part VI, of the Boulder Canyon Project Final Reports, Hydraulic Investigations, under the title "Studies of Crests for Overfall Dams," in 1948.

Of course since the days of the Hoover Dam design dozens of dams have been built and laboratory and field data are available on many of them.

An analysis of these data has been made and published as Bureau of Reclamation Monograph No. 9 under the title "Determination of Spillway Coefficients" to provide the designer with experimental information by which he may determine, with a fair degree of accuracy, the coefficient of discharge at any head for irregular overfall spillway shapes.

Pressures on spillway crests have been studied on many models with the tendency toward the recommendation of moderate negative pressures at the critical section for economy purposes, especially in the case of uncontrolled overflow sections. A laboratory study on a crest designed for a head of 0.587 feet and a coefficient of discharge of 3.99 indicated the feasibility of increasing the head moderately. This crest is described on Figure 4. The curves (Figures 5a and 5b) indicate, for example, that at piezometer 1, the point of least pressure, for a head of twice the maximum design head, the pressure is -1.21 x the head on the crest, and the coefficient of discharge is observed on Figure 5a to be 4.38.

Roller Type Bucket

In the preliminary tests for the development of a design for a suitable and economical stilling basin for Angostura Dam, South Dakota, a roller bucket offered the best possibilities, although erosion with some of these concrete buckets has been somewhat serious.

For the Angostura stilling basin, a slotted-type energy dissipator bucket (Figure 6) a savings of about $500,000 was realized over a sloping apron design which would have been necessary. The three principal factors of the development were: (1) the radius of the bucket for a given flow condition; (2) shape and spacing of the teeth; (3) the degree of slope of the apron downstream from the teeth. All of these factors are important in the design of a bucket that will produce the desired dissipation of energy, a smooth water surface, and a minimum amount of erosion of the river channel.

Rectangular Stilling Basins

A compilation was made of some 40 horizontal stilling basins utilizing spreader teeth at the upstream end, and dentated sills near the downstream end. All 40 were developed or checked by model studies over a period of 20 years by many individuals. From the compilation, the following general criteria for design are apparent:

(1) Length of pool--three times theoretical D_2

(2) Height of spreader teeth--equal to D_1

(3) Height of dentated sill--$0.2D_2$

(4) Width of spreader teeth = height or D_1

(5) Width of teeth on end sill = 0.8 height

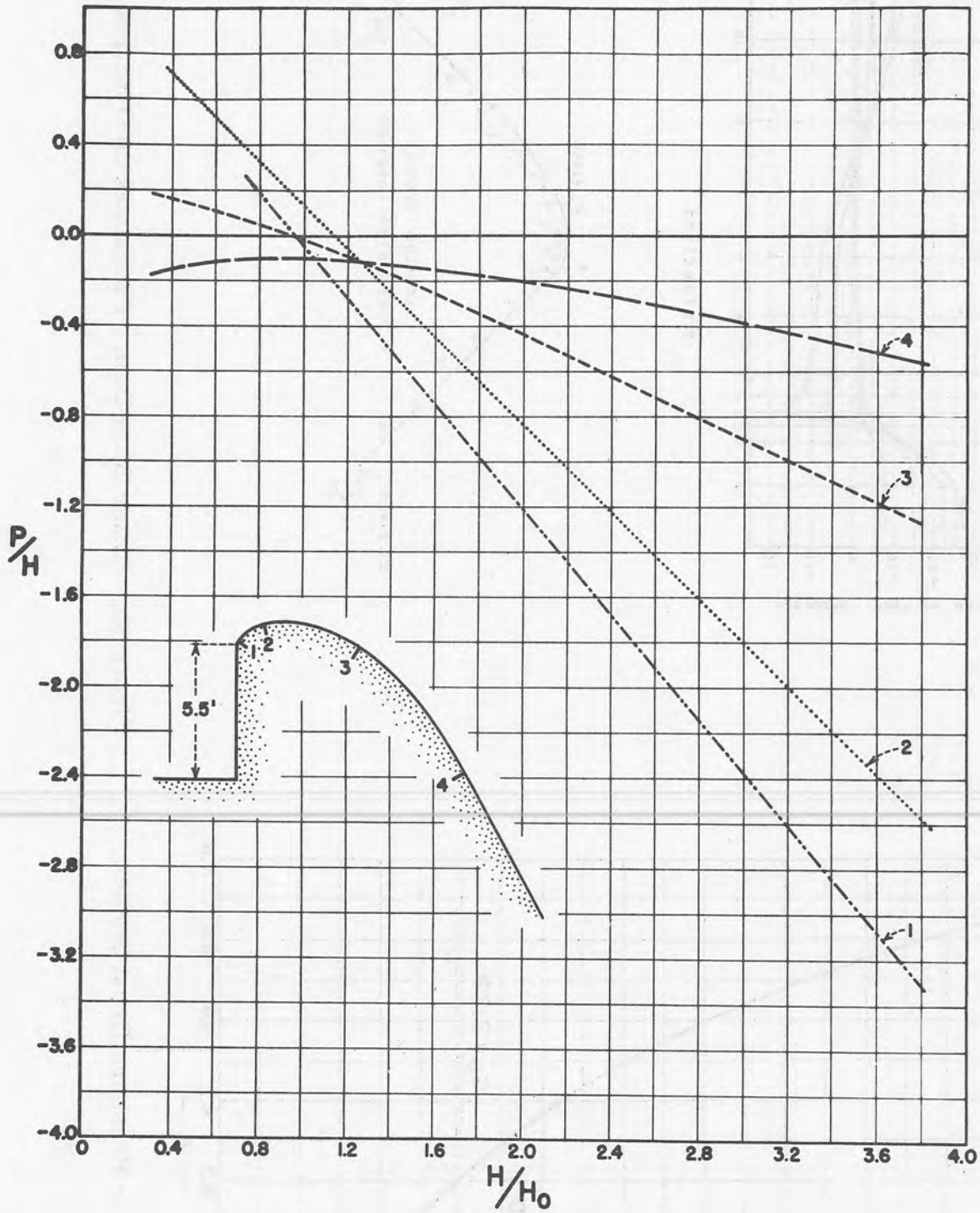

Figure 4. Negative Pressure Crest Studies.

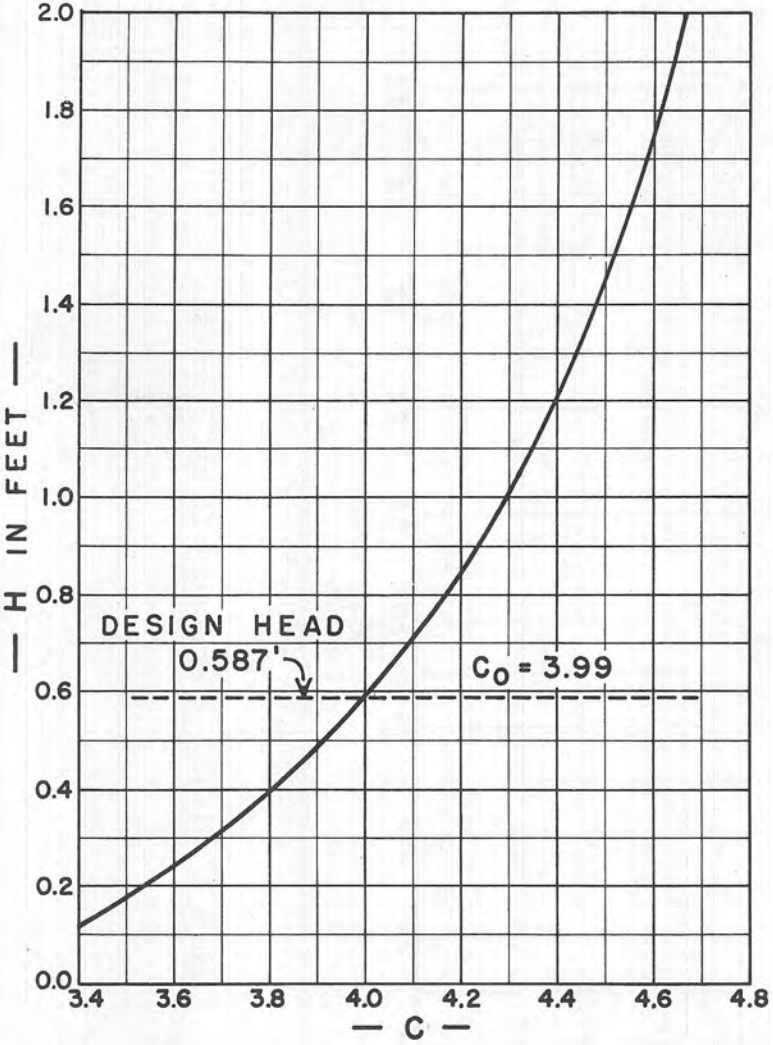

Figure 5a. Negative Pressure Crest Studies.

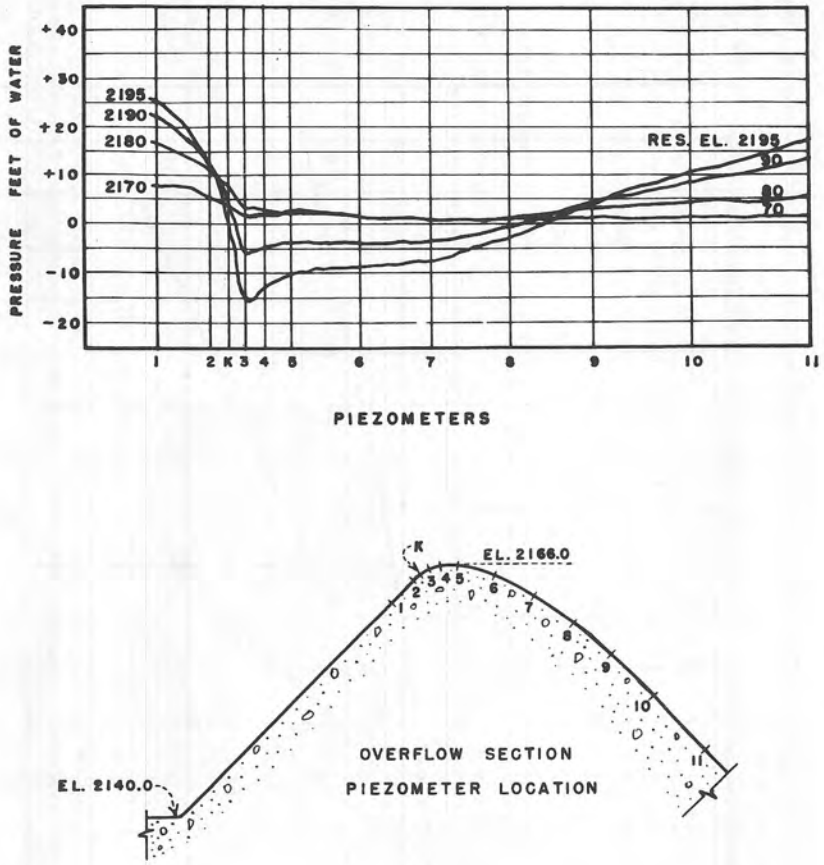

Figure 5b. Cedar Bluff Dam--Pressures on Overflow Section.

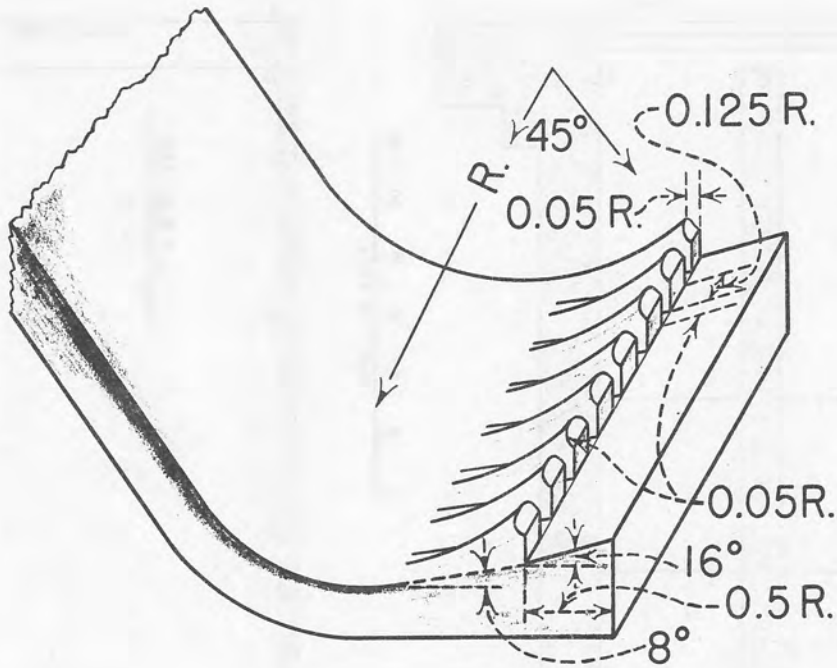

Figure 6. Bucket for Angostura Dam spillway.

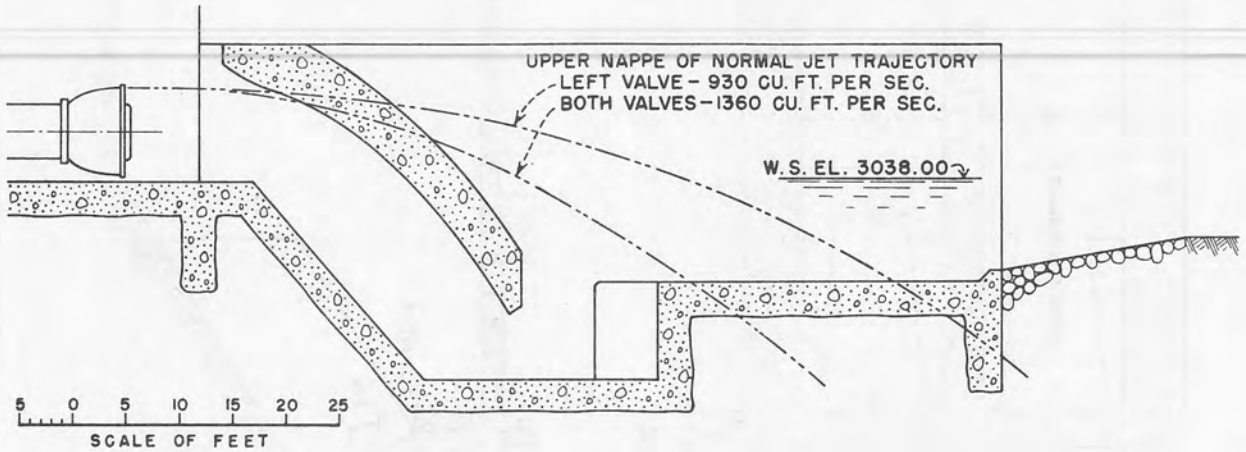

Figure 7. Section through Enders Dam outlet stilling basin. (Nebraska).

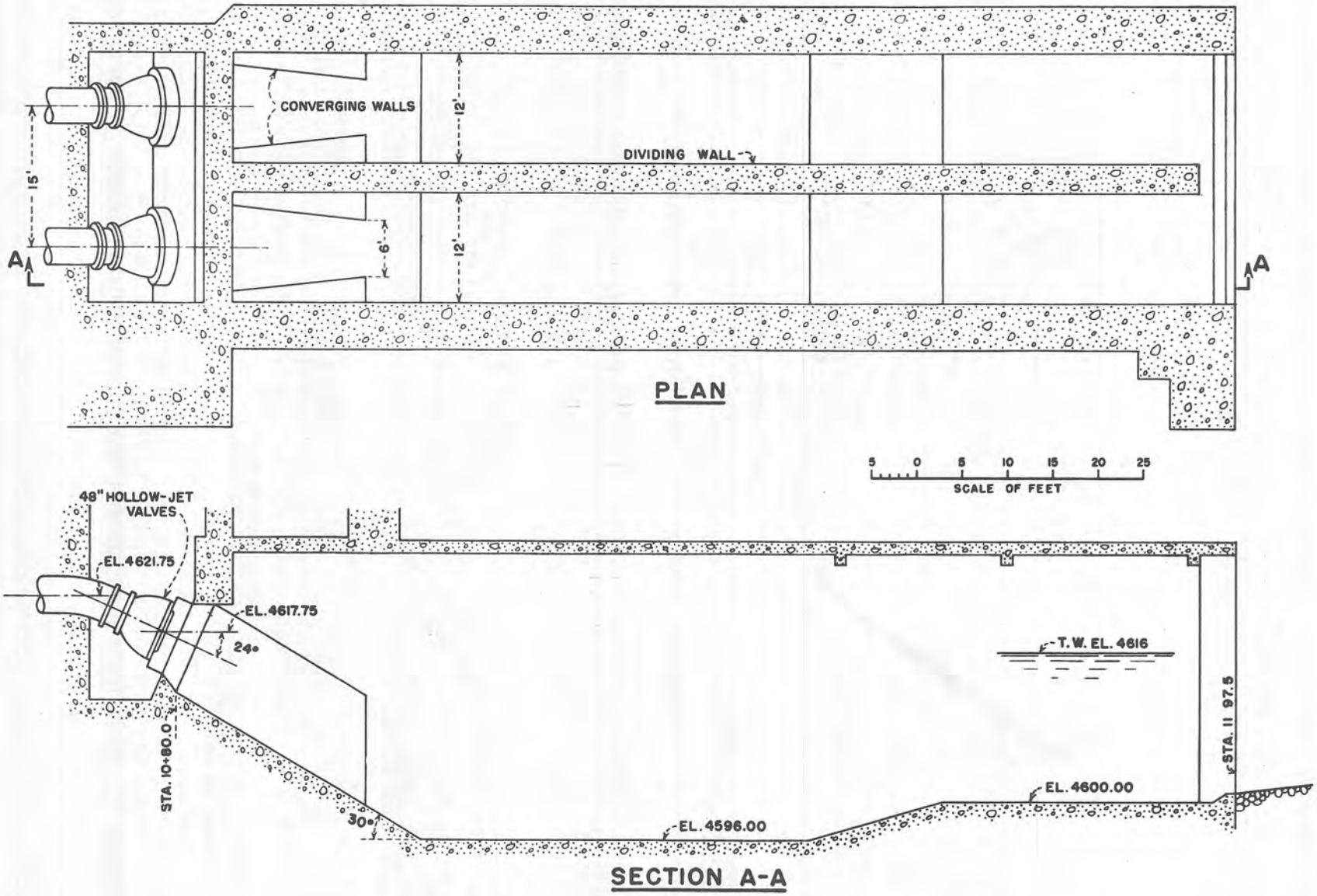

Figure 8. Boysen Dam outlet stilling basin. (Wyoming).

(6) In both cases width of teeth = width of spaces

(7) Locate stilling pool floor so as to utilize full depth D_2 - skimp on length rather than depth

(8) The slope of the chutes leading to the pools varied from 15° to 34° with the horizontal, with no appreciable difference in the shape of the hydraulic jump or length.

The above rules will result in an economical and safe design provided the jet entering the pool is uniform. Model studies will not be needed unless entrance conditions or spreading of the chute introduce uncertainties. Several of the stillingbasins investigated showed the length of pool to be less than $2D_2$. A length less than $3D_2$ should be used only when model studies indicate this to be advisable.

In the case of concrete overfall dam spillways, horizontal stilling pool aprons are seldom used. Sloping aprons or buckets are more practical and usually more economical.

Outlet Works

With the development of the designs for the outlet works at Enders and Boysen Dams, an improvement over the conventional hydraulic jump stilling basin was sought in the interest of economy of materials and quality of performance. Outlet works with one of two valves operating require an expensive dividing wall to achieve symmetry of action. When the basin discharges directly into a canal or into a powerhouse tailrace, the pulsations in the basin are carried downstream, causing objectionable waves and surface disturbances. Using hydraulic models, each of the designs was first tested, using a conventional basin. Then, taking advantage of local conditions, each design was modified and developed to produce better performing structures which could be constructed at less cost.

For the Enders Dam basin, a deflection hood was placed to turn the two valve jets downward into a relatively deep pool (Figure 7). The center dividing wall was removed from the basin entirely, and the structure was reduced from 175 to 75 feet in length. Improved performance, particularly a quiet water surface, was obtained with a shorter, less costly structure.

For the Boysen Dam basin, the valves were pointed downward, making a deflection hood unnecessary (Figure 8). Satisfactory performance resulted from the use of wedge-shaped inserts in the basin to protect the valve jets until the entering flow was well submerged.

In the Soldier Canyon basin, a single valve was used. The jet was directed to the bottom of the deep pool by a transition hood. With energy dissipation occurring well below the surface, the water surface in the basin was exceptionally smooth, making it possible to discharge directly into a canal without fear of wave effects on the canal banks (Figure 9). Hydraulic tests on the prototype have confirmed the prediction of performance based on the model studies.

Canal Structures

The design of the stilling pool for the Gila Canal chute, California, was a subject of an extensive model study, which employed the hydraulic jump with stepped aprons, baffle piers, and sills. Several design criteria were established. Since the model chute was the same width throughout and the depth of flow was uniform across it, the results could be applied to similar chutes at various widths by designing on the basis of discharge per foot of width. Accordingly, by applying this principle and numerous model scale ratios, a general diagram was prepared which is applicable to rectangular stilling pools under a wide range of conditions, Figure 10. These relations should be used only for low heads and are applicable when certain rules and relationships are followed.

In the experiments leading to development of the overchutes for the Coachella Canal, California, it became evident that serious effects would result in the stability of the structures if degradation were to take place. The type of structure resulting from hydraulic laboratory study consisted of a sloping chute which could be extended as the stream bottom degraded, with closely placed baffles on the chute floor to dissipate a large part of the energy of the falling water as it passed down the chute (Figures 11 and 12). Although model studies on this type of structure have not been adequate to generalize the data, this overchute design has proved satisfactory.

The original design capacity of the Sunnyside Canal, Yakima Project, in the State of Washington, constructed in the period from 1907 to 1916, was seriously exceeded by the late 1930's. With the gradual increase of flow came an increase in channel velocity which scoured the canal to such an extent that a series of 23 check drops was constructed. The scour downstream from at least 18 of these drops had been serious. In 1938, the problem of the redesign of the check drops was assigned to the Hydraulic Laboratory. The first step in the redesign was to build and operate a model of Check Drop No. 4 to determine the similarity of behavior between the prototype and the model (Figure 13).

The second step was to study the cause of scour patterns and introduce features into the original structure which would remove the cause without excessive cost. The studies, extending intermittently over 6 months, finally produced a design in which the scour is completely eliminated. Drop No. 4 was remodeled during the Winter of 1939-40. The field reports that after several seasons of operation the behavior is still satisfactory and that several other drops have been remodeled along the same line (Figures 14 and 15).

As a result of these model studies a new structure design was developed which has proven particularly satisfactory at least insofar as elimination of erosion is concerned.

Several studies have been made to develop satisfactory drop structures of trapezoidal cross section which would dissipate the energy at the base of the drop, provide uniform flow distribution across the entire trapezoidal section at the downstream end of the drop structure, and provide a

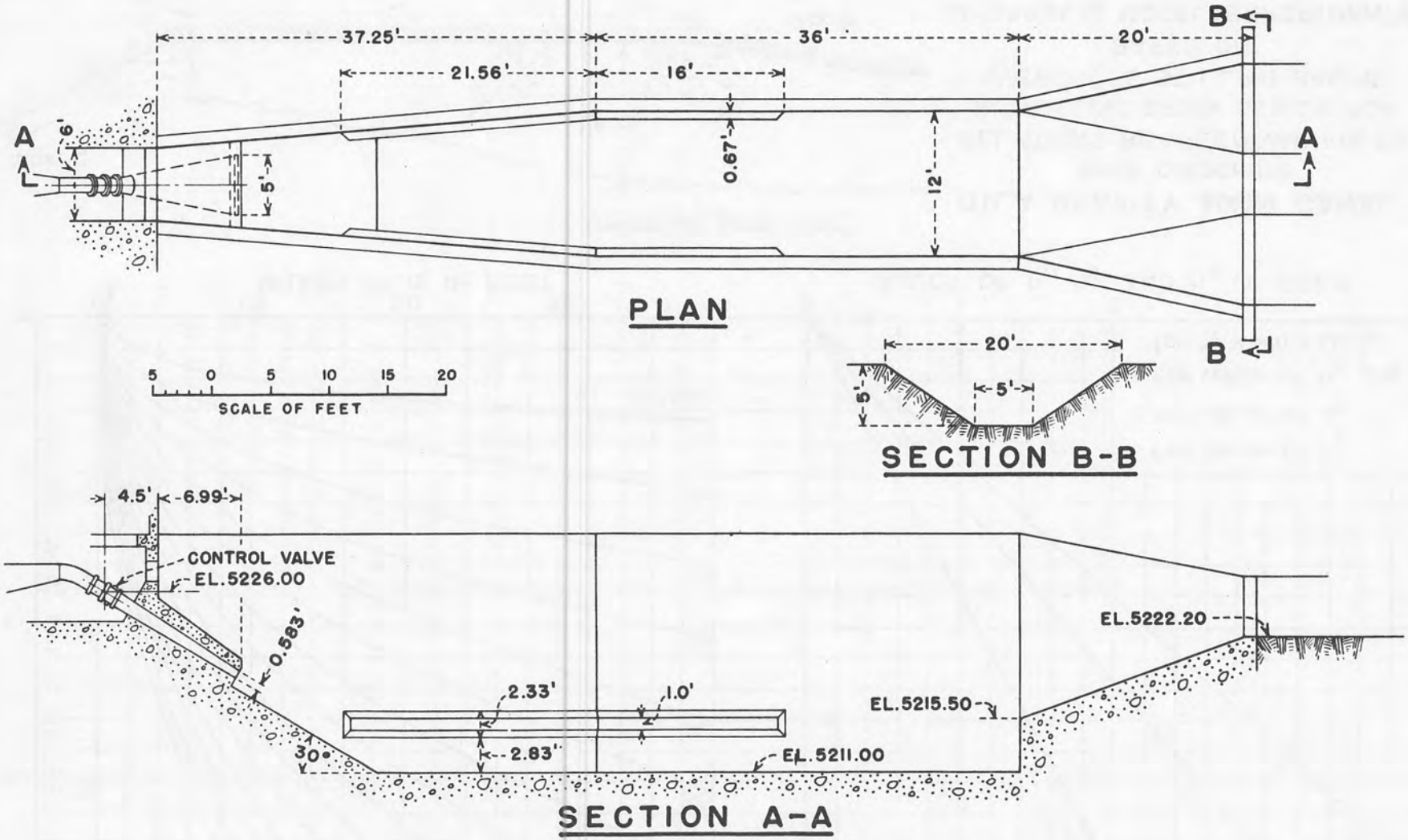

Figure 9. Soldier Canyon outlet basin with butterfly valve. (Colorado).

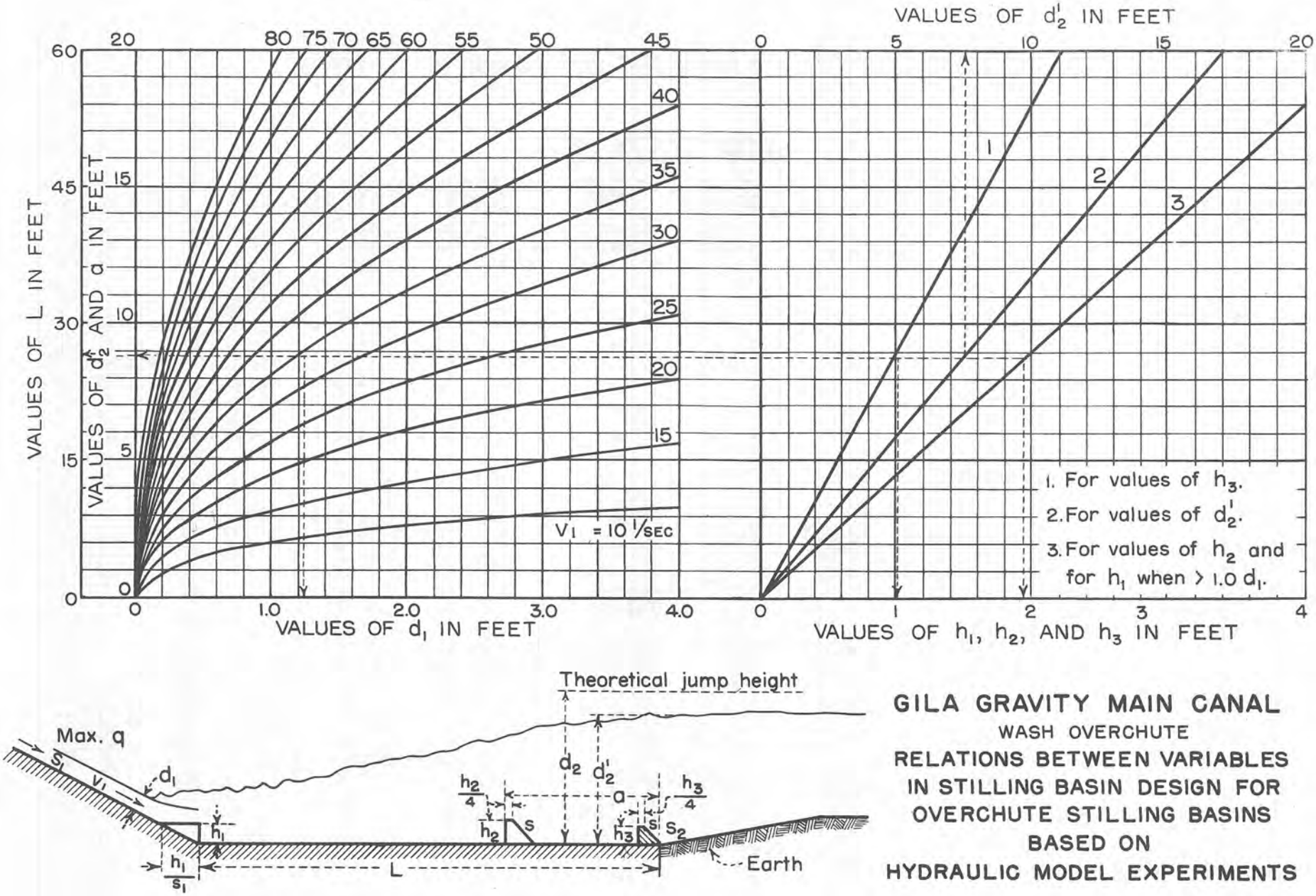

Figure 10. Stilling Basin Design Chart.

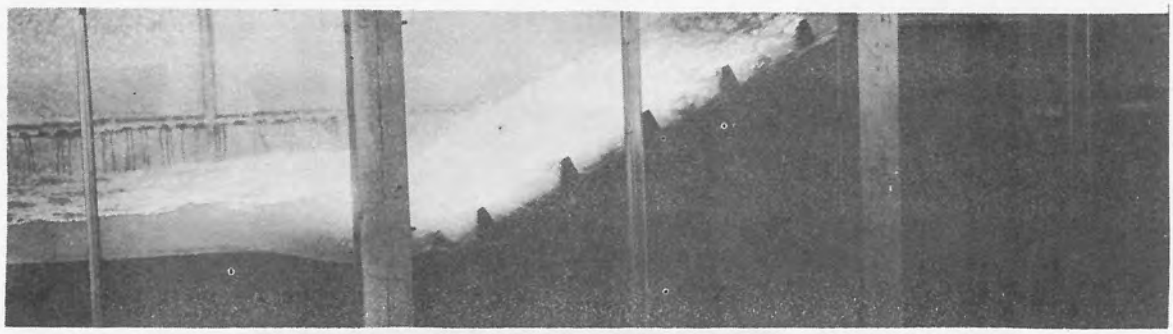

Figure 11. Sectional view of model of overchute design for Coachella design.

Figure 12. Typical overchute in which baffle piers are staggered.

Figure 13. Model of Drop No. 4, Sunnyside Canal. Fully developed scour pattern after extended operation.

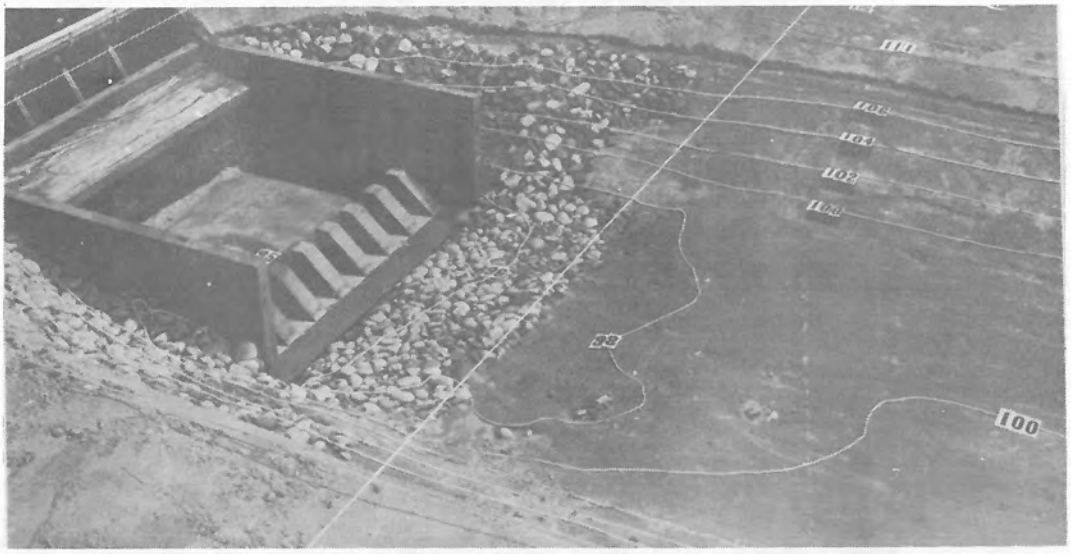

Figure 14. Drop No. 6 was constructed similar to Drop No. 4.

smooth surface at the entrance to and in the lower canal. An additional requirement of developing a control notch for use above the drop structure which would provide a predetermined stage-discharge relationship complicated the development studies. Figure 16 illustrates one such development for the Sand Hollow Wasteway, Boise Project. A model of a trapezoidal drop is shown in Figure 17.

Gates and Valves

The first large valves of the needle type were used in the outlet facilities at Hoover and Alcova Dams. The damage to valves at these projects motivated a program of model tests which revealed the source of the cavitation erosion and provided information for revising the shape of the boundary surfaces to eliminate it. The 6-inch model (Figure 18) served also to demonstrate the effects of the area-shaping procedure of design passages that helped to introduce the flow net as a tool for studying the details of flow in the passage.

A reduction in the weight of the needle valve, as well as a reduction in the operating power, was realized by substituting a tube for the needle plunger. There were two reasons for using the tube from which the valve receives its name "tube valve," (Figure 19). First, it eliminated part of the area of the needle that was subject to cavitation erosion; and secondly, it reduced the hydraulic thrust against which the valve had to be operated.

A special tube valve with a long slim shape and operated by an internal hydraulic cylinder was developed by extensive tests, using a 1:17 scale model and a 1:5.1 scale model. The model tests demonstrated that there was a range of openings varying from 0 at low head to the range from 65 to 90 percent opening at maximum of 323 feet, wherein operation should be restricted because of the cavitation erosion which would result. Field tests of the valve, including pressure measurements and determinations of air flow, checked closely with the respective valves predicted from the model tests.

In 1940 the demand for a futher decrease in the cost-discharge ratio prompted the Bureau to initiate a program of valve development. One of the most notable accomplishments during the ensuing years was the development of the hollow-jet valve, a regulating control for use exclusively at the end of an outlet conduit, which not only weighs less than the tube valve, but discharges about 35 percent more water (Figure 20).

Complete balance is not attainable without special facilities external to the valve, but partial balance is secured by providing fixed openings in the face of the needle of the shut-off plunger. Pressure from the flowing water is transmitted to the inner compartment by way of the fixed openings to counteract the hydraulic force on the needle tip. Locations of the openings to provide minimum unbalanced force was established through tests on a 6- and 24-inch valve.

Actual proportions of the jet flow valve were established through extensive tests on a 6-inch model under heads up to 350 feet (Figure 21). This valve was designed to insure against cavitation erosion and was developed to replace the special tube valves previously developed for Shasta Dam outlets, since the cost of the tube valve proved to be exorbitant.

Model experiments with the jet-flow valve have indicated that the jet whose cross section is roughly rectangular can be adapted to free discharge conditions. This type of valve has been developed for the Palisades Dam outlet in Idaho.

Gate Seals

Hydraulic laboratory tests were made to determine the manner of the failures of the bottom music note rubber seal on high head coaster and fixed wheel gates and to develop a satisfactory seal. These gates are normally operated with balanced water pressure across them but during emergency closure have reservoir water pressure on the upstream side and a much lower pressure on the downstream side. Music note seals have given unsatisfactory service under heads of from 200 to 300 feet when the gates are closed under unbalanced pressures. From a study of the mechanical behavior of this seal and its geometric shape (not the improvement of the materials of the sealing surfaces) the double-stem types of seals were found to be the most reliable. One of the types is reinforced with heavy-gage brass; the other type is unreinforced (Figure 22).

Pipe Line Irrigation Distribution Problems

When the Coachella Irrigation Distribution System was put into operation it was found that the longer laterals in the flat valley floor could not be operated satisfactorily because of severe surging which occurred regularly with a period of around 60 seconds. The laterals were located along section and mid-section lines and quarter-mile sublaterals were provided to serve adjoining lands. The general criteria required a turnout for a farm delivery to each 40 acres of land, or one or possibly two turnouts at each quarter mile of lateral. To maintain a low internal head on the concrete pipe lines open-topped box or pipe stands were constructed at each turnout point, with the top of the stand 2 feet higher than the maximum operating water surface (Figure 22a).

The surging was of such magnitude that farm delivery difficulties were experienced.

Hydraulic Laboratory and analytical studies were made to determine the causes of the surging and methods of controlling the surges. It was found that the surging was caused by two separate but complementary factors: first, the introduction into the system of induced and other flow oscillations of small magnitude; and second, the ability of the system to amplify small oscillations into surges of unacceptable proportions (Figure 22b and c respectively).

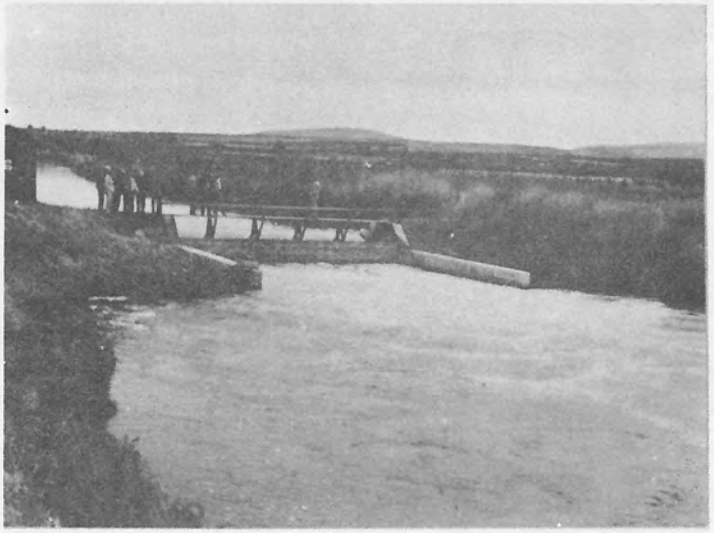

Figure 15. The effectiveness of this type of drop structure by the quietness of water surface--Drop No. 6.

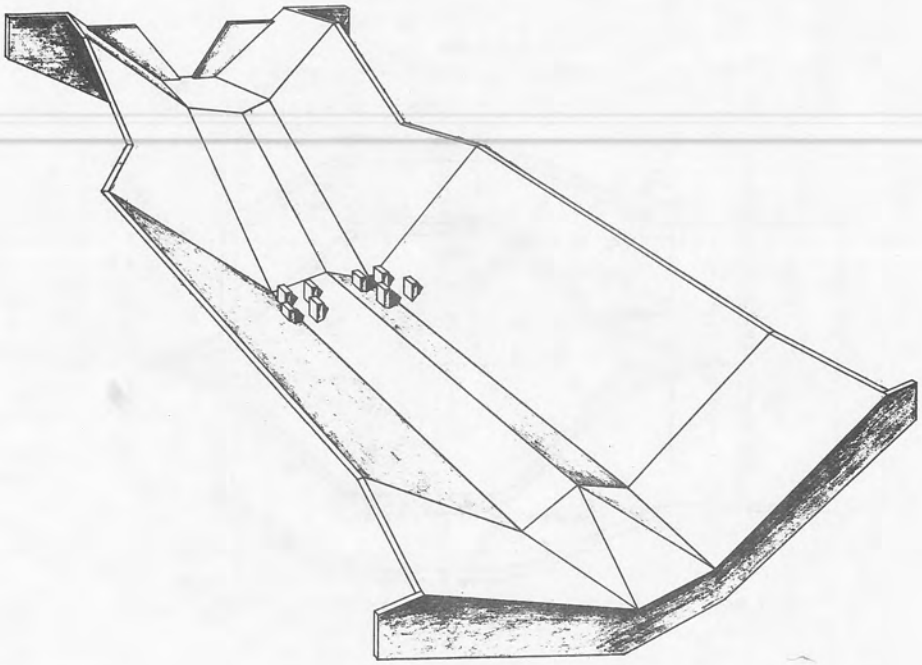

Figure 16. Perspective view of trapezoidal concrete drops--Sand Hollow Wasteway--Boise Project.

Figure 17. A 1:6 model of a trapezoidal concrete drop with two water stage-discharge control notches, Wyoming Canal.

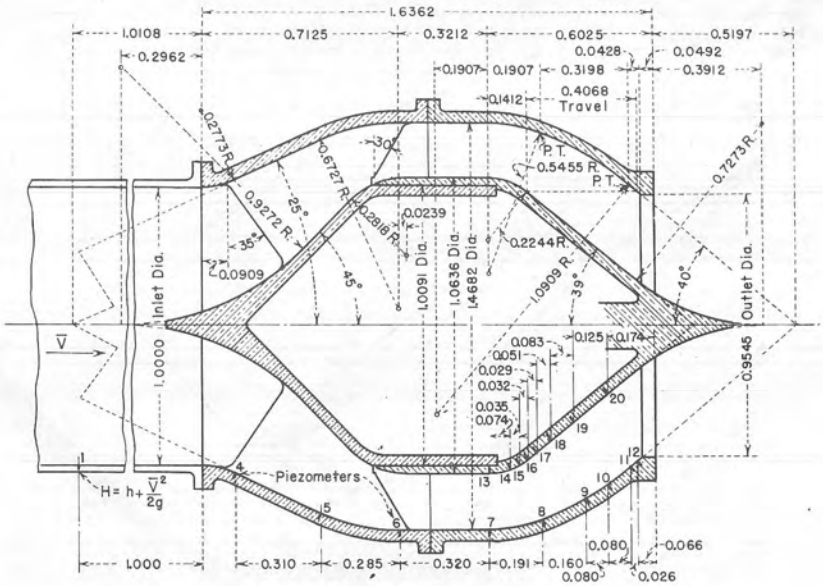

Figure 18. Section through model of needle valve.

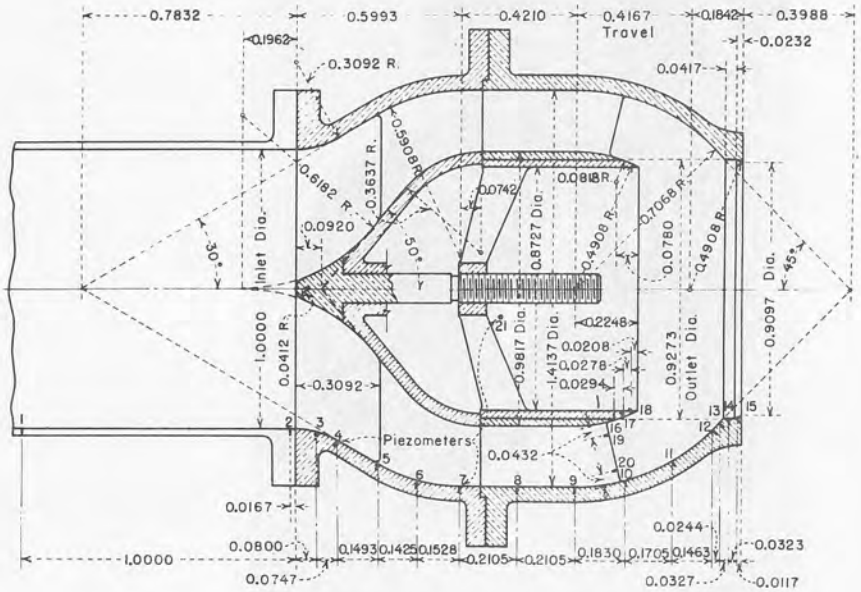

Figure 19. Section through model of tube valve.

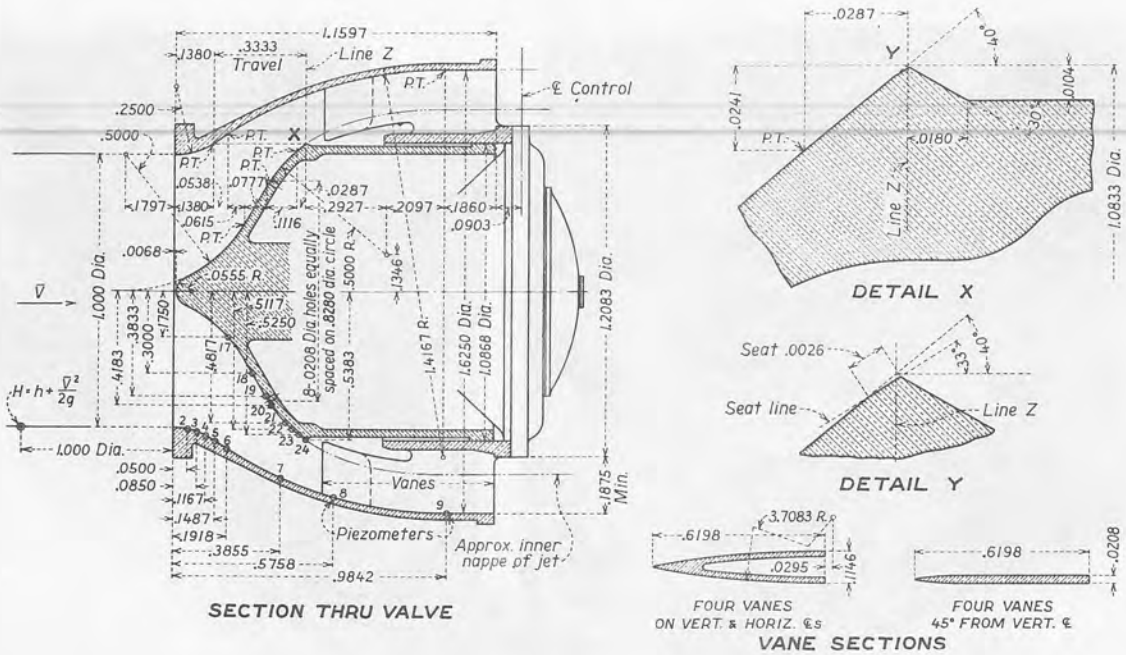

Figure 20. Hollow-jet valve.

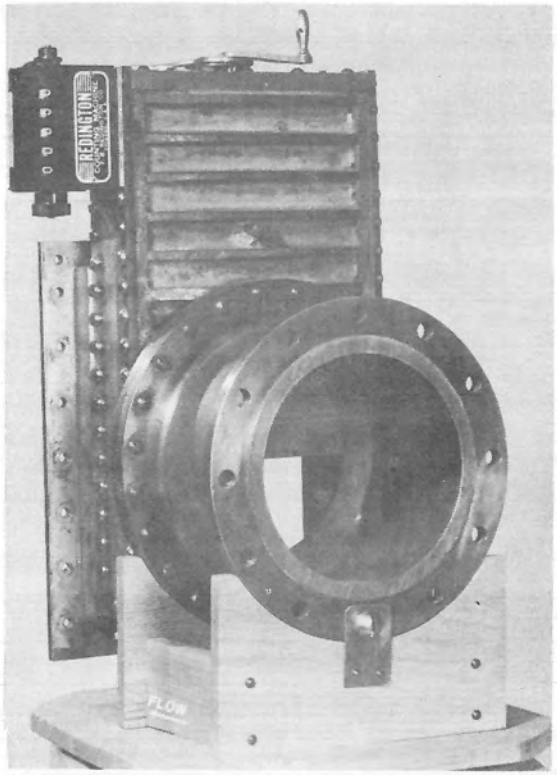

Figure 21. 6-inch model of a circular jet-flow valve.

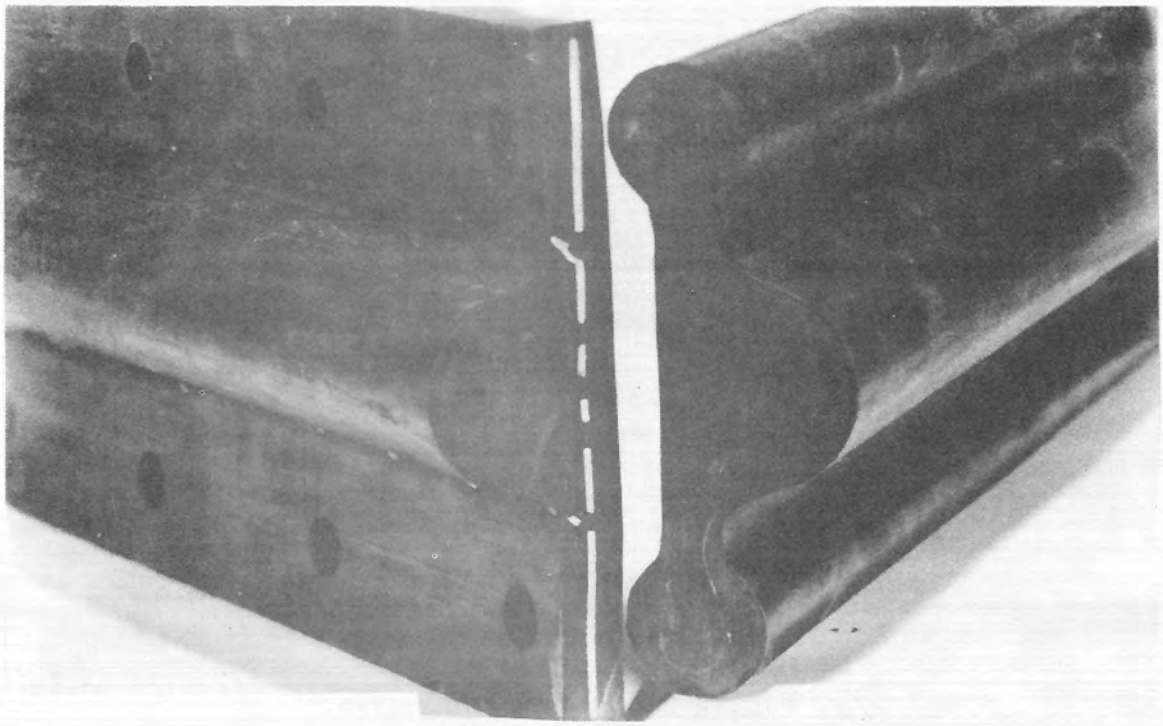

Figure 22. Cross-sectional views of two of the better types of seals tested. The white line in the left specimen denotes a plane of reinforcement.

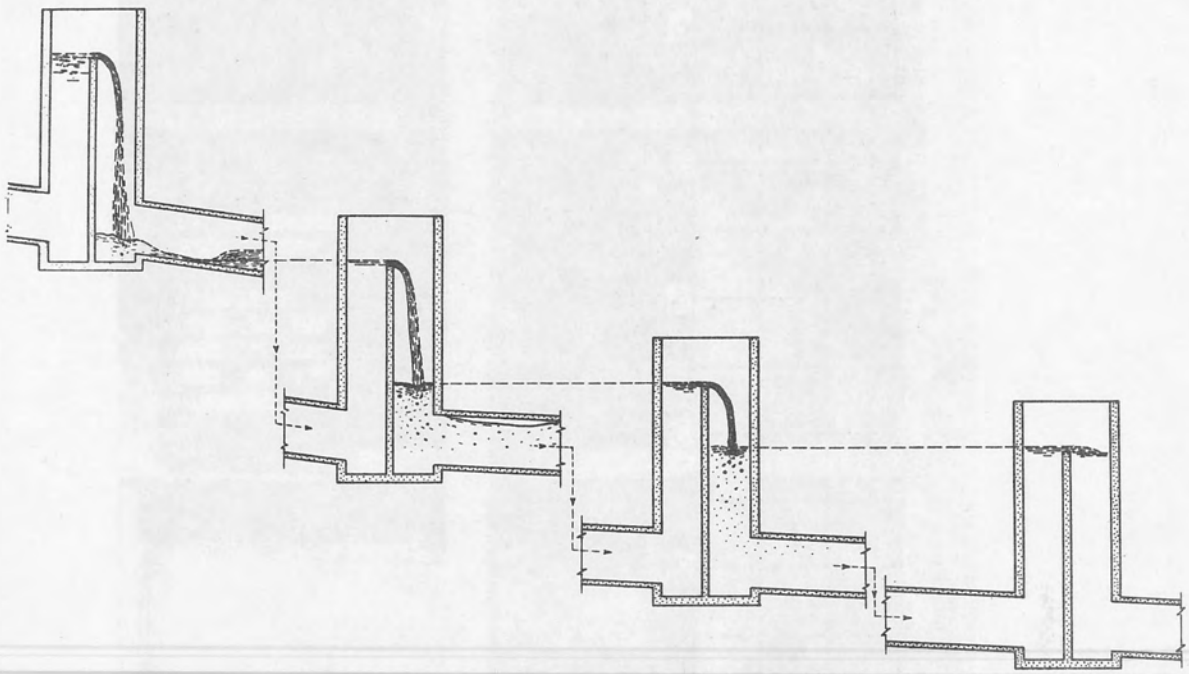

Figure 22a. Schematic profile of distribution pipe line with weir stands.

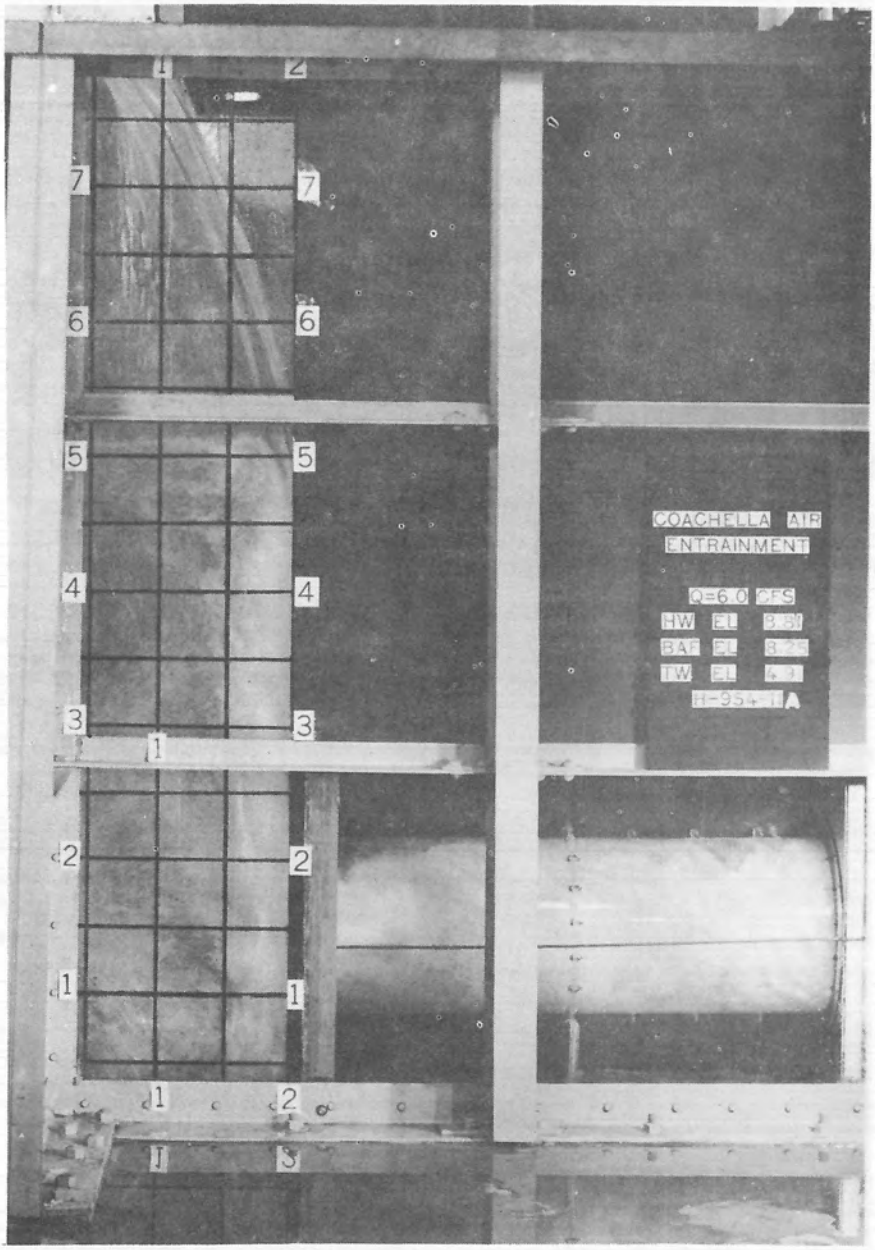

Figure 22b. Air is entrained in the pipe line and induces surges.

Figure 22c. Surges in pipe line distribution system cause overflow at weir stand.

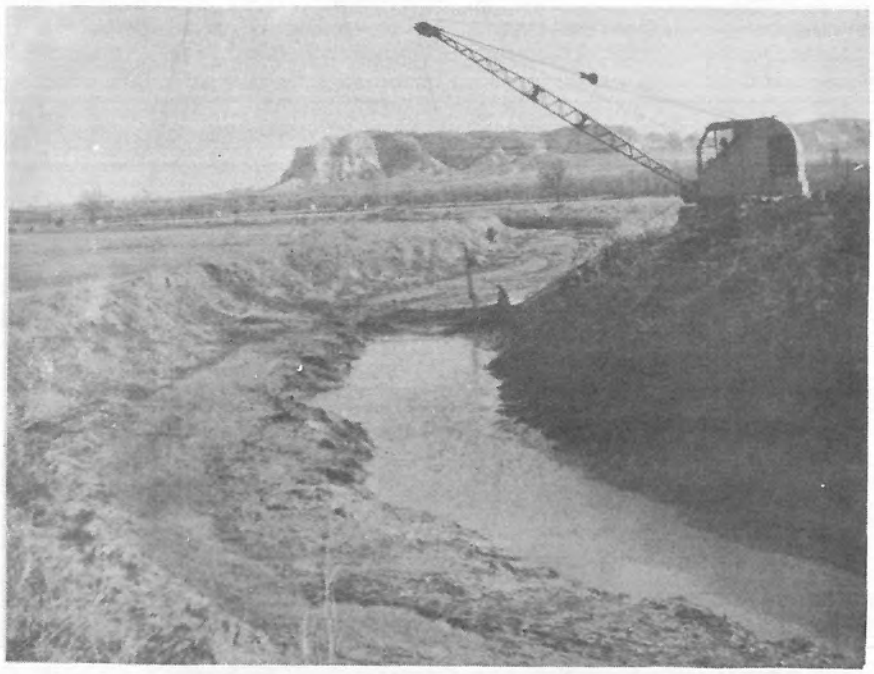

Figure 23. A sediment cleaning operation on the Winter Creek Canal diverted from the North Platte River.

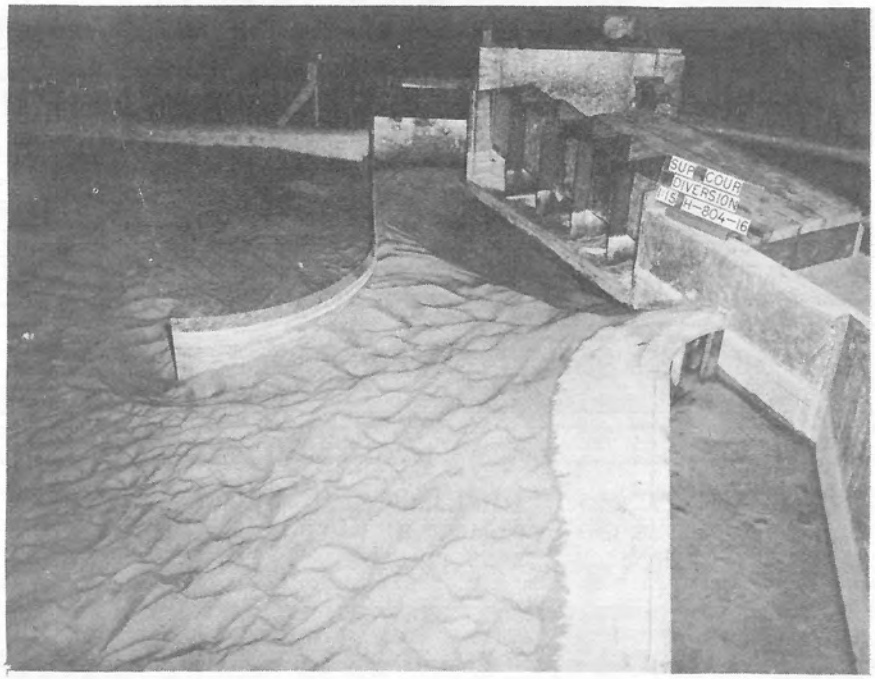

Figure 24. 1:15 model of Superior-Courtland Diversion Dam--Superior Canal headworks. (Nebraska).

Air-tight covers were found to provide surge control by (a) modifying the periods of the pipe reaches to avoid resonance, (b) reducing the number of successive reaches in which amplification can occur.

A section of lateral using covers was found to have a number of natural periods equal to the numbers of pipe reaches in that section. Only the primary (longest) period is of importance since the resonance becomes weak at the shorter periods.

Sedimentation Studies

The first important study in the sediment field was made on the Imperial Dam model at the Montrose laboratory to study any problems which might arise at the Imperial Dam, California, due to the heavy sediment content of the Colorado River. An undistorted model of the dam and surroundings was constructed to a scale of 1:40, and extensive experimentation was conducted. These studies were initiated to determine the manner in which the sediment would be deposited in the reservoir, the best form of desilting device, the effect of river approach direction on intake conditions, and the effect of trashrack and training dike features on the general operation of the canal intake and spillway.

To arrive at a decision as to the form of desilting device, it was necessary to determine the amount of power required to drive the machinery which would accomplish mechanical sediment selection. Accordingly, tests on a 1:3 scale model for a portion of the basin and scraper, with the trenches and pipes, indicated that this method of sediment removal was feasible and enabled improvements in the type of orifice through which the sediment would be discharged. Tests on a full-scale model revealed that the main force required to remove the sediment is a regular function of the sediment depth; also, that for all depths, the force increases very rapidly with a speed up to 16 feet per minute, and less rapidly above this point. In practically all cases, the force increased if the sediment was allowed to consolidate longer than the usual time.

In recent years the principal effort in sediment research and investigations has been in connection with the design of diversion structures and canal headworks. An important part of the design studies is the reduction of sediment entering canals (Figure 23).

A 1:15 scale hydraulic model (Figure 24) of Superior-Courtland Diversion Dam headworks and sluiceway was used to improve a conventional design. The guide wall extending upstream from the left side of the sluiceway forces the water to flow in a curve, thereby causing the bed sediment to move to the inside of the curve and into the sluiceway. Installation of the guide wall in the model reduced the amount of sediment going into the canal to approximately one-tenth of the amount that entered when conventional design was used.

Pump Testing

Performance tests on larger pumps in recent years have utilized the salt velocity method rather than the weir method for measurement of discharge. Until 1950 the discharge usually was measured by a weir in accordance with the Hydraulic Institute standards (Figure 25).

Improvements in the method have been developed in the hydraulic laboratory to a point where the argument originally used by opponents relative to the increased specific gravity of the salt cloud is no longer significant. The sensitive recording oscillograph and related instruments (Figure 26) now employed to record the passage of the salt cloud are sufficiently sensitive to permit the use of a very small quantity of salt--in the order of 0.0005 pound for each ounce of water brine. The method of injecting the salt brine through pop valves by hydraulic cylinders, (Figure 27) employing the advantage of balanced pressure in the injection cylinder, is an additional improvement over the previous methods. This method permits use of a small unbalancing force for the injection by correspondingly simple and inexpensive apparatus. Figure 28 illustrates a typical electrode pick-up station.

Development and Standardization of Water Measurement Devices

The experience of the Bureau of Reclamation with the measurement of water shows there is a growing necessity for adequate recording of irrigation water delivered to the distribution systems and to the ultimate consumer. With the complete utilization of our water resources in the West now approaching reality, the need for accurate recording of available supplies has focused attention on the devices used for measurement of water. Accordingly, in 1947 the Bureau of Reclamation was authorized to institute the current program of development and evaluation of water measurement devices to cover all types of irrigation water distribution systems. Although some investigations have been made on weirs, orifices, and Parshall venturi flumes, the greatest emphasis in the program has been in the field of devices for closed conduit systems and for farm lateral turnout devices as well as integrating meters for canal laterals. A comprehensive set of tests to determine the critical design criteria and limitations of meter gates was run in 1950 and 1951. A great deal of effort has been exerted in the evaluation of various types of closed conduit measuring devices in connection with the development of the Coachella Distribution Systems and several districts in the Central Valley development. Various commercial types of integrating meters proposed for use by the irrigation districts themselves have been tested in the laboratory to determine their efficiency, limitation, and the necessary design possibilities. Among the indicating type of measuring device tested in various scale models was the concrete pipe weir stand. Hydraulic characteristics and economic studies of the stand have been made.

All the data will be incorporated in laboratory reports and water measurement tables are incorporated in the Bureau Water Measurement Manual which is being published this year, the first tentative edition having been issued in 1947.

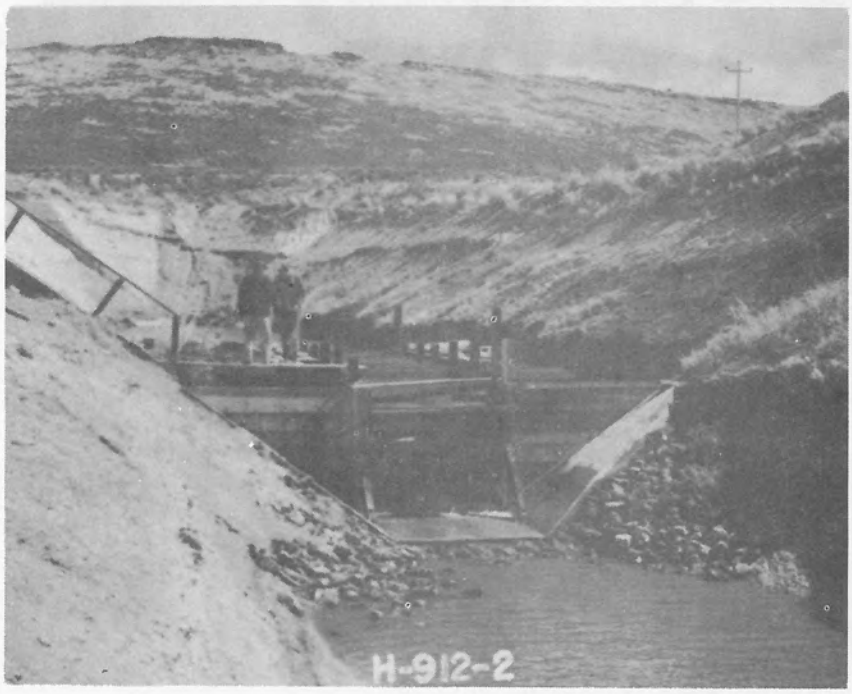

Figure 25. A typical weir installation for the measurement of discharge for pump efficiency test.

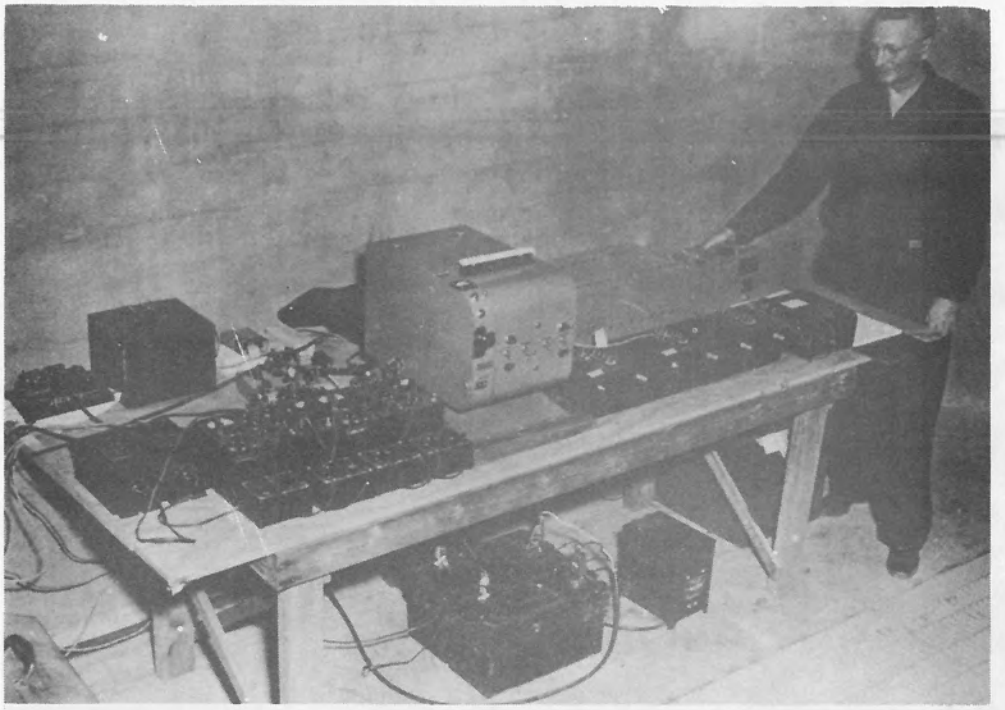

Figure 26. Recording instruments required for low voltage salt velocity technique.

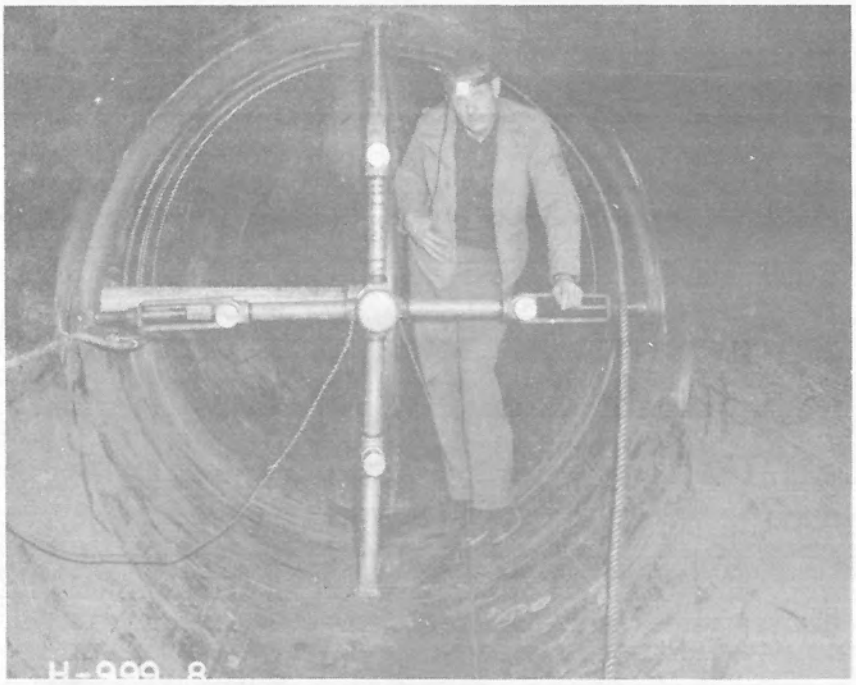

Figure 27. Injection station using pop valves in a 6-foot pump discharge line.

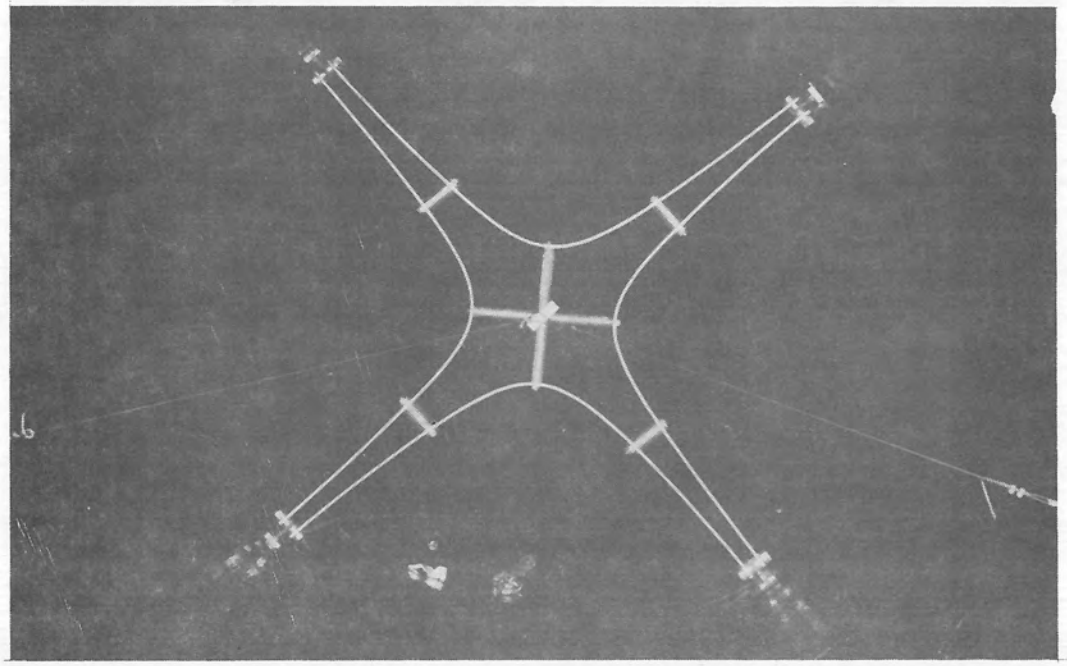

Figure 28. An electrode station in a salt velocity determination. Two such stations are required for a test.

Canal Seepage Tests

In connection with the Bureau's program of research for the development of lower-cost canal linings, the hydraulic laboratory has conducted a large number of laboratory and field tests. The seepage loss measurements were made for three specific purposes:

a. To evaluate the merits of various methods for determining seepage losses

b. To determine the effectiveness of different types of lining materials.

c. To ascertain the need for lining.

The quantity of water lost by seepage was measured by three methods; namely, (1) ponding, (2) inflow-outflow, and (3) seepage meter.

The ponding method is considered to be the most accurate known technique of measuring seepage losses from irrigation canals and laterals. Seepage losses from short reaches of canal may be measured by this method with great accuracy. Seepage losses are determined by isolating a reach of canal with watertight barriers and filling the test reach of canal with water (Figure 29). Two disadvantages of the ponding method are: (1) the canal must be taken out of operation during tests, and (2) the construction and removal of the watertight barriers required in the formation of the ponds is rather costly.

The inflow-outflow method of measuring seepage losses consists simply of measuring the quantity into and out of a certain reach of canal. The difference between the inflow and outflow represents the seepage loss, together with the evaporation loss. Gaging stations, weirs, Parshall flumes, current meters, and other measuring devices can be used for measuring the flow. Small inaccuracies in the measuring devices can become a major concern in the accuracy of the actual seepage loss. Comparatively long reaches of canal are required for the inflow-outflow method in order that the seepage loss will be of measurable magnitude.

The seepage meter is an instrument for the measurement of seepage losses from canals and laterals. This meter may be used in flowing water during the irrigation season. In no way does the meter interfere with canal operation. The accuracy of this seepage loss is questionable, although the instrument appears to have merit in indicating seepage loss trends.

Special Studies and Investigations

One phase of the Central Valley development in California, was the planning and design of the so-called "Delta Cross Channel." This cross channel would perform the function of transferring Sacramento River water across the delta to the Tracy Pumping Plant, which serves lands in the

San Joaquin Valley. Two different plans were under consideration to carry out the transfer function: one involving a new channel capable of carrying some 12,000 second feet of water, skirting the delta, and estimated to cost 35 million dollars; the other a simple diversion out of the Sacramento River into the existing delta channel and estimated to cost 5 million dollars. Because utilization of natural channels might act to increase the intrusion of ocean salinity and thus contaminate the transferred water, the saving of some 30 million dollars represented by the difference in cost between the two plans could not be realized without definite proof that contamination would not occur. A comprehensive hydraulic model study was directly responsible for the decision to use the natural channels. However, the next problem was how to bring the Sacramento River water across the delta to the San Joaquin side without upsetting the balance of forces which holds the salinity in check.

An electronic analog computer, (Figure 30) which was built to expedite these computations, not only was successful for this purpose, but also gave a more rapid means of studying flow distribution in the delta and evaluating the effect of tidal currents on the effective flow resistance of the delta channels.

The various studies of tidal diffusion of ocean salinity into the channels of the delta were handicapped by the lack of precise data relating to the distribution of salinity in the various channels. To obtain a more truly representative mean salinity, a meter was developed which proved to be capable of recording the degree of salinity continuously with time. The principal components of the shore station salinity meter developed in the laboratory are: a float with conductivity cells attached, a modified stage recorder with self-balancing bridge attached, and an amplifier. A sufficient number of salinity meters to define completely the pattern of salinity intrusion has been installed throughout the delta area. Data from the shore stations are augmented by those data taken with the portable meter attached to a power boat. Since the salinity encroachment is held in check by stream flow, which tends to flush the salinity out of the channels, trends in salinity gradients in the various channels, when known, can be used to predicate the necessity for releases from Shasta Reservoir during periods of low flow in the delta. The laboratory staff and the project staff have developed a method of analysis of salinity and flow data which will be used in determining the requirements for additional diversion if it becomes necessary with the development of the Delta-Mendota Canal area.

Downpull Tests on Cylinder Gates

Some time ago, investigations were initiated to ascertain the adequacy of the stems of the Hoover Dam intake cylinder gates to withstand excessive hydraulic downpull forces which might occur on the gates during an emergency closure. Model tests were, therefore, made which did disclose the possible presence of excessive downpull forces due to cavitation pressures on the bottom of the gates at small openings with low water surface elevation within the towers. Accordingly, it was considered desirable to measure the actual downpull forces on the field structure. Strain gages

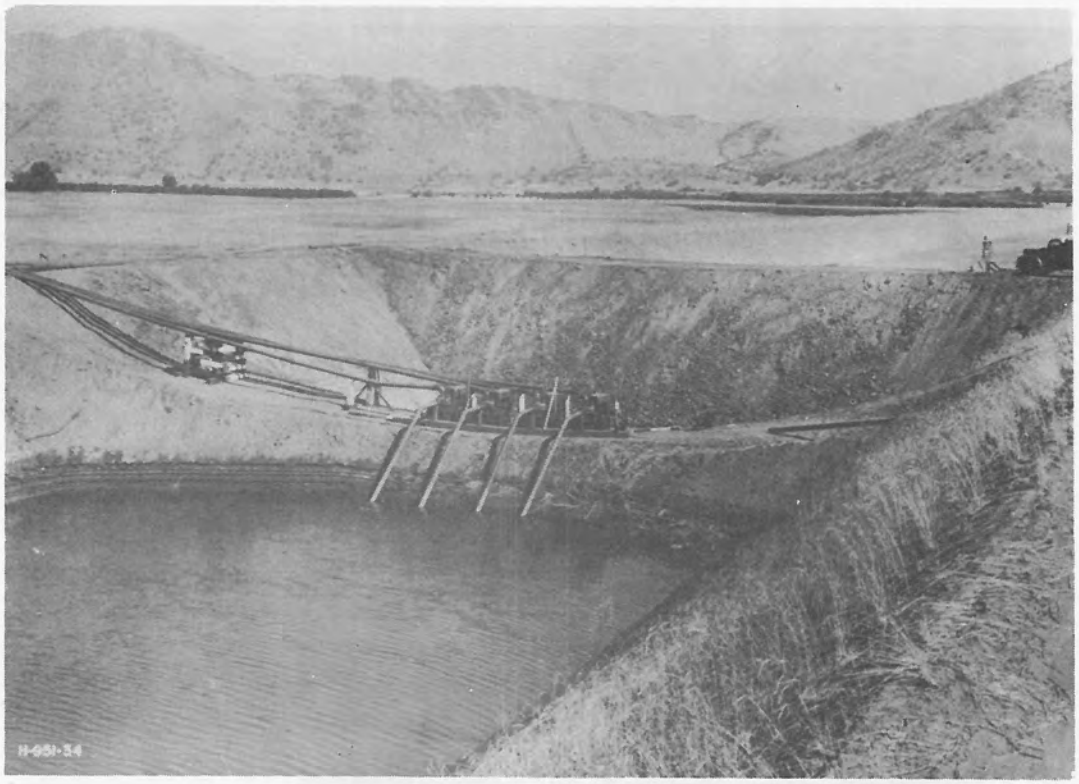

Figure 29. Determination of canal seepage losses by the ponding method.

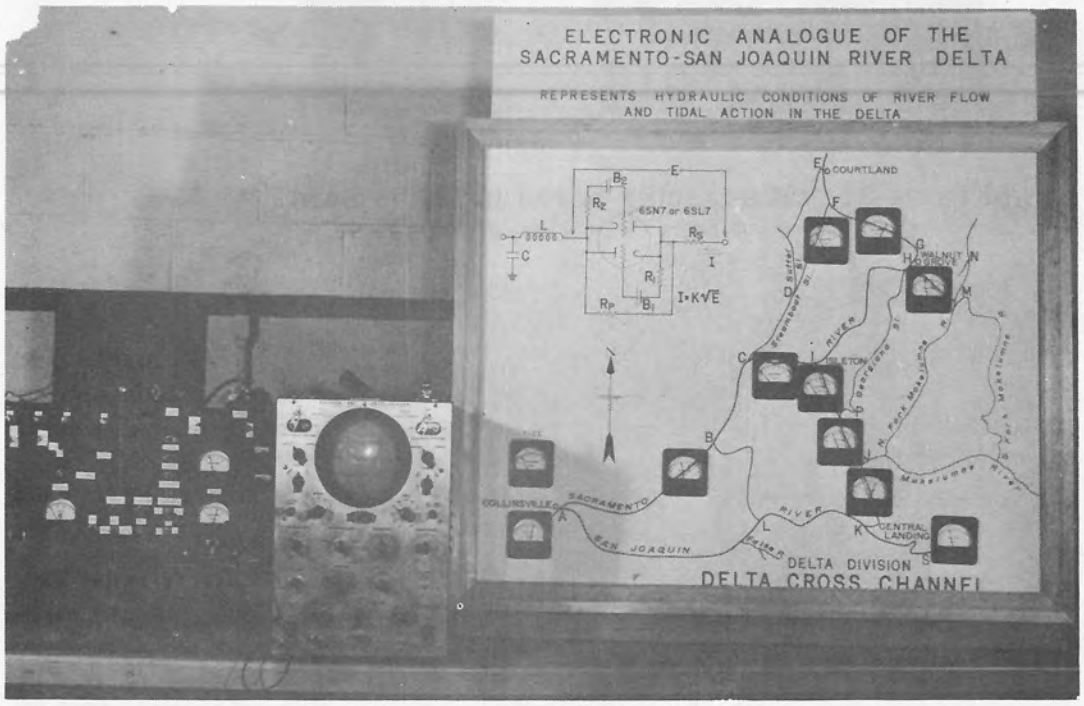

Figure 30. Electronic analog of the delta.

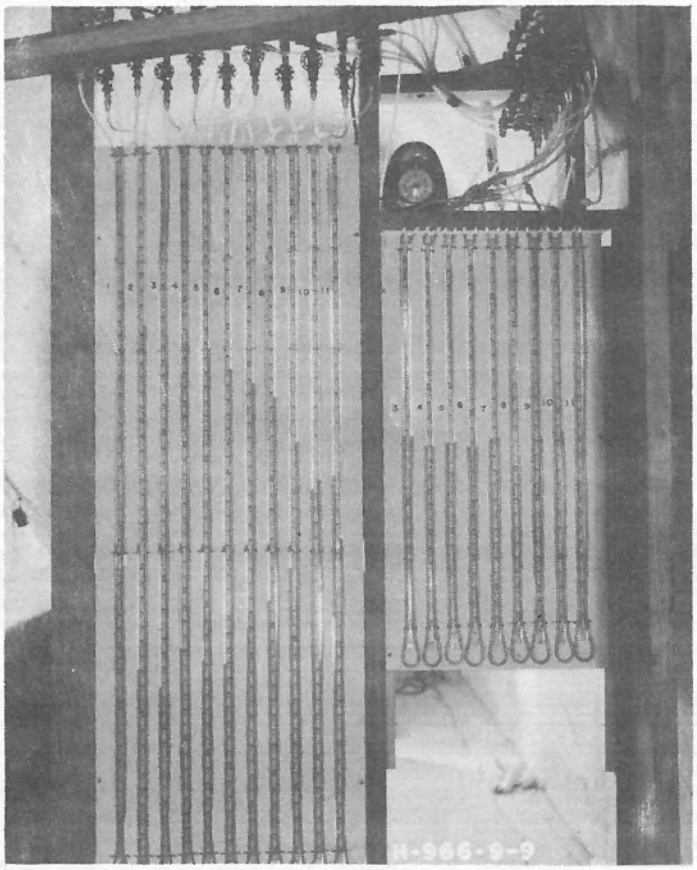

Figure 31. Manometer board in Davis Dam gallery--spillway pressure tests.

of the SR-4 type were mounted on the nuts of the three operating stems of the lower gate in the upstream intake tower on the Arizona side of the canyon to measure the strain induced by the hydraulic downpull forces under emergency closure conditions. The tests were confined to a lower cylinder gate because hydraulic conditions for an emergency closure were more severe than for the upper gate. The relationship between the strain observed and the total force applied to each stem nut was obtained by calibration.

Comparison of the data observed on the prototype with that taken on the model revealed a remarkable agreement which will be helpful in studies of this type in the future.

High Head Francis Turbine Model Studies

The invitation for bids for the Francis turbine to be installed in the Pole Hill Power Plant of the Colorado-Big Thompson Project, Colorado, stipulated that the manufacturer receiving the contract for these units would be required to furnish a suitable hydraulic model to be tested under heads approximating 500 feet to determine various hydraulic characteristics at heads greater than scale model heads normally used in determining the efficiency of such units.

A 1:4 scale model was set up on the deck of the Estes Park Power Plant and a complete set of tests for various alternate types of runners was made.

In addition, a series of models of turbine bypass energy dissipators were made during the course of the turbine model tests.

Prototype Tests

One of the more important phases of the Bureau's Hydraulic Laboratory program is its extensive long-range program for tests on prototype structures. The studies fall into nine categories: (1) spillways--the data to be obtained consist of pressures for various gate openings at heads up to the maximum and spillway discharge measurements, see Figure 31; (2) air entrainment--velocity measurements for the entire spillway, the depth of water on the spillway face, and spillway discharges; (3) air demand studies for various types of shaft spillways, tunnels, gates, valves, and other closed conduit; (4) closed conduits--observation of pipe friction losses, bend losses, losses in elbows, siphon losses, pressure measurements; (5) gates and valves--draw-down data, pressure measurements, head loss measurements; (6) water measurement--data desired are the calibration of Parshall flumes, large weirs, orifices in large pipe lines, venturi meters, and slide gates; (7) sedimentation--data obtained consist of Manning's roughness values, tractive force values and bed slopes; (8) vibration studies--data consist of vibration observations on deep spillway chutes and pumping plant conduits; and (9) miscellaneous--projects not otherwise classified.

Research

By and large, the hydraulic laboratory confines its research activities to specific studies of the applied type. Although every model study contributes something to the fund of knowledge concerning the action of flowing water, the significance of the contribution is seriously limited and may be missed entirely unless there is a definite effort to generalize it so that it is not limited by the conditions of the test.

The current program, divided into six major divisions, consists of 41 different projects.

Hydraulic structures investigation and development includes stilling basins for high head outlet works, siphon spillways with air control, canal drops, spillway crests, hydraulic jump and bucket studies, turnout structures for canals, pipe line distribution analysis, and pumping plant intake. Valve and gate investigations and development includes submerged valves for outlet works, radial gates for high head controls, butterfly valves for regulation, ventilation of gates and valves in conduits, gate slots, gate and valve seals, pipe line irrigation valves, pressure conditions in high-velocity penstock branches, and downpull on coaster gates. In the sedimentation field, the program consists of stable channel studies, sediment control devices for canals, density currents and changes in rivers. The remainder of the research projects fall in the lower-cost canal lining hydraulic studies, water measurement device studies, and the development of engineering techniques for general application such as erosion testing of foundation material, chemical dilution method of discharge measurement, and so forth.

Acknowledgment

The material for this paper was gathered from numerous laboratory reports, memoranda, and papers prepared by various staff members of the Hydraulic Laboratory over a period of more than 20 years.

Interior - Reclamation - Denver, Colo.