UNITED STATES

DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION

- - -

MEMORANDUM TO CHIEF DESIGNING ENGINEER

- - -

SUBJECT: PROGRESS OF STUDIES OF THE FLOW OF WATER IN OPEN CHANNELS WITH HIGH GRADIENTS WITH PARTICULAR REFERENCE TO OBSERVATIONS AT BLACK CANYON DAM.

BY

C. W. THOMAS, ASSISTANT ENGINEER

- - -

Denver, Colorado

May 31, 1939

JEW:AZ

Denver, Colorado, May 31, 1939

MEMORANDUM TO CHIEF DESIGNING ENGINEER
(C. W. Thomas)

Subject: Progress of studies of the flow of water in open channels with high gradients with particular reference to observations at Black Canyon Dam.

1. The salt-velocity method of measuring velocities in open channels with high gradients was first applied in the field in the tests on the Kittitas wasteway described in a memorandum to the chief designing engineer, dated July 27, 1938, under the subject "Progress Report on Studies of the Flow of Water in Open Channels with High Gradients". In this structure the electrodes were of 1-inch by 1/4-inch extruded aluminum belt moulding fastened securely to the sides of the channel. They extended above the water surface thus facilitating attachment of the electrical leads to the oscillograph. In the case of measuring velocities on the face of an overfall dam where the training walls are separated by a considerable distance and the probability of the flow extending from one training wall to the other is remote, the installation of electrodes and electrical conductors from them becomes a matter difficult of solution. Furthermore, it is not convenient to attach electrodes to the face of an overfall dam although the test installation may be of a temporary nature. Therefore, portable electrodes suspended in the flow by a cable were proposed. Development of a suitable type of electrode and lead was necessary. Considerable thought was given to these details in connection with the contemplated tests at Norris Dam. A brief description of the proposed equipment is given in a letter from the chief engineer to Mr. T. B. Parker, Chief Engineer, Tennessee Valley Authority, dated January 23, 1939 (copy included on the appendix of this report). In accordance with this letter, model studies were made in the hydraulic laboratory to design the electrodes.

2. The laboratory studies consisted essentially of observing the action of different types of electrodes in the flow over the 1:40 and 1:68 scale models of Shasta Dam Spillway. The original type tested was a streamlined weight proportioned such that the width at the maximum section was one-fourth of the length and the height at the maximum section was one-sixth of the length. The bottom was a plane surface. It was apparent that the ratio of height to length was too great for the velocities existing in the models. A number of curved plates were tried with varying degrees of success. These

plates were elliptical in plan and were curved in longitudinal and transverse cross-sections such that the ratio of height to length was small (the height being from one-tenth to one-twenty-fifth of the length). The ratio of length to width was roughly three to one. The plates were suspended in the flow with the long axis of the ellipse parallel to the streamlines. The degree of curvature perpendicular to the long axis had little apparent effect on the behavior of the electrode in the flow. However, the degree of curvature on the long axis of the plate governed its action. The downward force on some of the plates was sufficient to cause them to adhere to the face of the dam. This prevented lowering them to the desired position on the spillway. After a series of tests it was concluded that a curved plate electrode could be designed to give satisfactory results for a definite velocity in the model, but would not be satisfactory for a range of velocities. The most satisfactory type of electrode for the range of velocities in the models was found to be a lightweight tube open at both ends and held in the flow with the long axis parallel to the streamlines. The flow of water through the tube produced a stabilizing effect. Such an electrode offered little resistance to the flow consequently the pull on the cable was slight.

3. Before the observations in the laboratory were completed a series of vibration tests at Black Canyon Dam - Boise Project - Idaho necessitated the use of the oscillograph and other equipment used for salt-velocity tests in the field. Since Black Canyon Dam is of the overfall type and sufficient water was available for test purposes, it was considered advisable to make a few observations on the face of the dam with the salt-velocity apparatus for the purpose of studying the action of the electrodes and cables under field conditions.

4. As there is no bridge over the spillway at Black Canyon Dam, a cable was suspended across Gate No. 2 from Pier No. 2 to Pier No. 3 (figures 1 and 2). This cable supported two traveling carriages equipped with sheaves through which the cables to the electrodes were passed. The carriages were fastened together by a length of rope. The position of the carriages on the cable and hence the lateral position of the electrodes was controlled from Pier No. 2 by two hand lines secured to the carriages. One line passed through a snatch block on Pier No. 3 and back to Pier No. 2. The other extended from the carriages to Pier No. 2. This system of rigging permitted control of the lateral movement from Pier No. 2. The electrical cables to the electrodes extended from Pier No. 2 to the sheaves in the carriage and thence down the face of the dam to the electrodes. Movement of the electrodes up or down the face of the dam was controlled by hand from Pier No. 2. Simplex-Tirex 18-2, S.J. Cord, round, rubber-covered

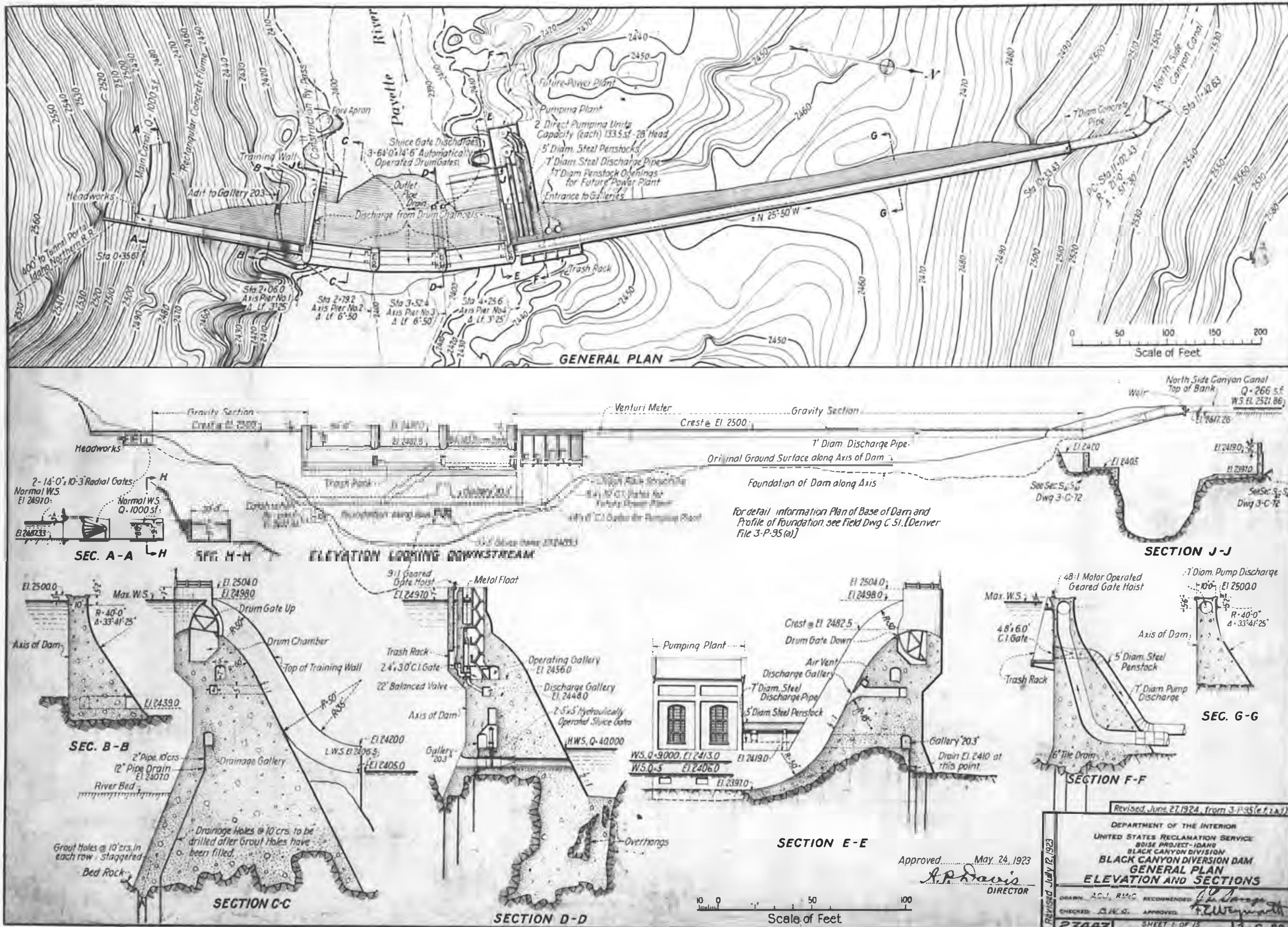

GENERAL PLAN
Payette River
Headworks
Main Canal Q-1000 s.f.
Rectangular Concrete Flume
Training Wall
Construction By-Pass
Fore Apron
Sluice Gate Discharges 3-64'0"x14'6" Automatically Operated Drum Gates
Adit to Gallery 203
Outlet Pipe
Drain
Discharge from Drum Chambers
Future Power Plant
Pumping Plant
2 Direct Pumping Units Capacity (each) 133.5 s.f. - 28' Head
5' Diam. Steel Penstocks
7' Diam. Steel Discharge Pipe
7' Diam. Penstock Openings for Future Power Plant
Entrance to Galleries
Trash Rack
N 25°50' W
7' Diam. Concrete Pipe
North Side Canyon Canal
Sta 11+42.63
PC Sta 11+02.43
Sta 10+33.43
Sta 0+35.61
Sta 2+06.0 Axis Pier No.1 Δ Lf 3'25
Sta 2+79.2 Axis Pier No.2 Δ Lf 6'50
Sta 3+52.4 Axis Pier No.3 Δ Lf 6'50
Sta 4+25.6 Axis Pier No.4 Δ Lf 3'25
400' to Tunnel Portal Idaho Northern R.R.
Scale of Feet
ELEVATION LOOKING DOWNSTREAM
Gravity Section
Crest @ El 2500
Venturi Meter
7' Diam. Discharge Pipe
Original Ground Surface along Axis of Dam
Foundation of Dam along Axis
Trash Rack
For detail information Plan of Base of Dam and Profile of Foundation see Field Dwg C 51. [Denver File 3-P-95 (a)]
North Side Canyon Canal Top of Bank
Weir
Q-266 s.f.
W.S. El. 2521.86
El 2517.26
See Sec. S4-S4 Dwg 3-C-72
SECTION J-J
2-14'0"x10'3" Radial Gates
Normal W.S. El 2497.0
Normal W.S. Q-1000 s.f.
SEC. A-A
SEC. H-H
SEC. B-B
El 2500.0
Max. W.S.
R-40'0" Δ-33°41'25"
Axis of Dam
El 2439.0
SECTION C-C
El 2504.0
El 2498.0
Drum Gate Up
Drum Chamber
Top of Training Wall
Drainage Gallery
2" Pipe, 10' crs.
12" Pipe Drain El 2407.0
River Bed
L.W.S. El 2406.5
El 2420.0
El 2405.0
Drainage Holes @ 10' crs. to be drilled after Grout Holes have been filled.
Grout Holes @ 10' crs. in each row - staggered
Bed Rock
SECTION D-D
9:1 Geared Gate Hoist
El 2497.0
Metal Float
Trash Rack
2.4'x3.0' C.I. Gate
22" Balanced Valve
Axis of Dam
Operating Gallery El 2456.0
Discharge Gallery El 2448.0
2-5'x5' Hydraulically Operated Sluice Gate
H.W.S. Q-40,000
Gallery 20.3
Overhangs
SECTION E-E
Pumping Plant
Crest @ El 2482.5
Drum Gate Down
Air Vent
Discharge Gallery
7' Diam. Steel Discharge Pipe
5' Diam. Steel Penstock
W.S. Q-9000 El 2413.0
W.S. Q-5 El 2406.0
El 2419.0
El 2397.0
Gallery 20.3
Drain El. 2410 at this point.
SECTION F-F
48:1 Motor Operated Geared Gate Hoist
Max. W.S.
4.8'x6.0' C.I. Gate
Trash Rack
5' Diam. Steel Penstock
7' Diam. Pump Discharge
6" Tile Drain
SEC. G-G
7' Diam. Pump Discharge
El 2500.0
Axis of Dam
Approved May 24, 1923
A.P. Davis
DIRECTOR
Scale of Feet
Revised June 27, 1924, from 3-P-95 (e, f & g)
Revised July 12, 1923
DEPARTMENT OF THE INTERIOR
UNITED STATES RECLAMATION SERVICE
BOISE PROJECT - IDAHO
BLACK CANYON DIVISION
BLACK CANYON DIVERSION DAM
GENERAL PLAN
ELEVATION AND SECTIONS
23443
3-C-80

FIGURE 1

A. Velocity Measuring Equipment

B. Gate Completely Lowered - Head on Gate 7.7 Feet
Showing Spread of Jet on Face of Dam

BLACK CANYON DAM - BOISE PROJECT - IDAHO cable was used for electrical conductors from the electrodes to the oscillograph located in Pier No. 2. Two-conductor cord was used because of the additional strength of this type as compared to a single conductor cord. The two conductors were bonded together at the ends to serve as a single conductor. The electrodes were 1-3/4-inch O. D. by 1/8-inch wall seamless brass tubing and were 18 inches in length. The cable was attached to one end by a bail of 1/8-inch brass rod welded to the tubing. The "Tirex" cord was tied to the bail of the electrode. A soldering lug was attached to both conductors in the cord and fastened to the electrode with a machine screw. For the initial testing four electrodes, arranged as two pairs, were used. Two "Tirex" cords were fastened side by side with metal clips to serve as a single cable. This cable extended from the oscillograph through the sheave on the carriage to one electrode. One cord was secured to this electrode while the other cord passed through the electrode and extended fifteen feet downstream to the second electrode. This constituted the negative terminals of the two pairs of electrodes. The positive terminals were arranged in the same manner. The positive and negative electrode of a pair were at the same elevation and separated horizontally by a ten-foot interval during initial testing. The equipment was suspended on the face of the dam on the centerline of Gate No. 2.

5. Initial tests indicated that ten-foot horizontal spacing between the two electrodes of a pair necessitated the use of an excessive amount of salt. The distance was reduced to five feet. By using approximately one gallon of flour salt per ball a suitable deflection was recorded by the oscillograph element. It was also necessary to move both pairs of electrodes closer to Pier No. 2 in order to control the location of the salt ball as it was thrown into the flow. Observations were made (1) using the electrodes as two pairs; (2) using the two upper and the two lower electrodes as two positive electrodes and completing the circuit by a ground connection to the dam; and (3) using the four electrodes as positive electrodes separated by known elevations and completing the circuit by a ground connection to the dam. Most of the observations were made with the drum gate completely lowered, but a few were made with the gate slightly raised to ascertain if the electrodes would remain in the jet or break through the under side of the nappe. No indication of the electrodes breaking through was observed. Observations were made for all three of the conditions enumerated above with the electrodes at various elevations on the face of the dam. The head on the crest varied from 6½ to 7 feet. The discharge was approximately 4,000 second-feet.

6. Observations indicated that the tubular electrodes were not entirely stable in the flow. The 1/8-inch brass rod bails were badly damaged in a short time due to a tendency of the electrode to

repeatedly strike the face of the dam. They were replaced by a ½-inch plate welded to the electrode and extending two inches upstream. The front end was rounded and ground smooth. This type of bail, although not entirely satisfactory, was much better than the original, particularly for the downstream electrodes. The cords to the lower electrodes passed through the upper electrodes, thus preventing them from striking the face of the dam at an angle. For this reason the bails on the upper electrodes were not badly damaged. The electrical conductors were fastened through holes drilled in the upstream ends of the plates. The plates, and the knots in the conductors, caused disturbances in the flow at the upstream ends of the electrodes and prevented the flow from passing through the tube as intended. In fact, the distrubance was so severe in high velocities that air pockets were formed around the major portion of the electrodes when they were held slightly below the watersurface. The result of this condition was that only a small part of the surface of the electrode was in contact with the water and the greater part was not effective as an electrode. No observations were possible at depth, but similar conditions evidently existed because the amount of salt necessary to produce a readable deflection was large.

7. An electrode made of 3½-inch O. D. galvanized pipe 30-inches long, with a plate bail was attached to the cable and the action observed. This electrode was more stable in the flow than the smaller electrodes and although the pull on the cord was not actually measured, it appeared no more than with the smaller electrodes. The additional weight of the larger electrode caused it to be more stable for positions at or near the surface of the flow. Observations at depth were not possible but by placing an ear to the cord less vibration was observed with the larger electrode. Failure of the cable resulted in the loss of the electrode before observations were made regarding its electrical properties.

8. The most trouble was experienced with the electrical connection to the electrode. The original connection was by means of a soldering lug on the end of the cable screwed to the brass tubing. The copper conductor was broken from the lug after a few minutes in the water. The lug was then screwed to the plate that served as a bail and the lead securely fastened with friction tape. This connection withstood the action of the water for a longer period of time, but was still susceptible to breakage because of damage to the tape. By drilling small holes through the plate and fastening the conductor securely with wire, breakage was reduced but was never eliminated.

9. The stress in the rubber covered cable was quite high when the electrodes were at low positions on the face of the dam. Measurements of the amount of pull on the cable were made with different lengths of cable in the flow. These results are given in Table I.

TABLE I

Length of Cord in Flow in Feet.	Pull on Upper End In Pounds	Approximate Average Velocity Along Cord In Feet Per Second
15	20	36
32.5	75	43
47.5	90	49
62.5	100	53
77.5	160	57

The pull on the cord was measured with a pair of spring scales. All measurements were made by suspending known lengths of one double cord with two electrodes attached in the flow. The cords had a tendency to twist around one another which undoubtedly increased the friction between the water and the cords. Also the metal clips holding the two cords together offered additional resistance. No trouble was experienced with breakage of the cables except at the point where the electrodes were attached. Friction at this point caused chafing of the rubber cable and although a protective cover of tape was applied, breakage occurred. Four electrodes were lost in the stream due to failure of the cable at the point of attachment. Difficulty was also experienced with one cable because of a splice. The cord when purchased was specified to be in continuous lengths of at least 250 feet. When it was removed from the reels one reel was found to contain two lengths, one 150-foot and one 100-foot. This necessitated splicing. It was very difficult to make any kind of a splice that would be watertight and transmit the stress. Since the electrodes were used near the pier rather than on the centerline of the gate the 150-foot length of cable downstream from the splice was sufficient, and it was never necessary for the splice to carry any stress. A wrapped splice such as was employed would probably have failed if subjected to the stress found to exist.

10. With the electrodes connected such that the two at the same elevation on the face of the dam served as a pair; that is, one negative and one positive, a satisfactory deflection of the oscillograph element was obtained if approximately one gallon of salt, moistened and formed into a ball, was used. When the two upper and two lower electrodes were used as positive electrodes and the circuit completed by a ground connection to the dam the amount of salt necessary to produce a readable deflection was diminished slightly but not as much as would be expected in view of the fact that the positive electrode area was doubled and, since the face of the dam served as a negative electrode, it was relatively quite large. Evidently the face of the dam was considerably less efficient as an electrode than a metal electrode of similar area. With the four electrodes suspended

in the flow one above the other at 15-foot intervals along the cord and used as positive electrodes, the face of the dam used as a negative electrode, the amount of salt necessary to produce readable deflections was approximately the same as when the electrodes were used in pairs. Since all observations were visual, it was not possible to tell if the different methods of connecting the electrodes gave different velocities.

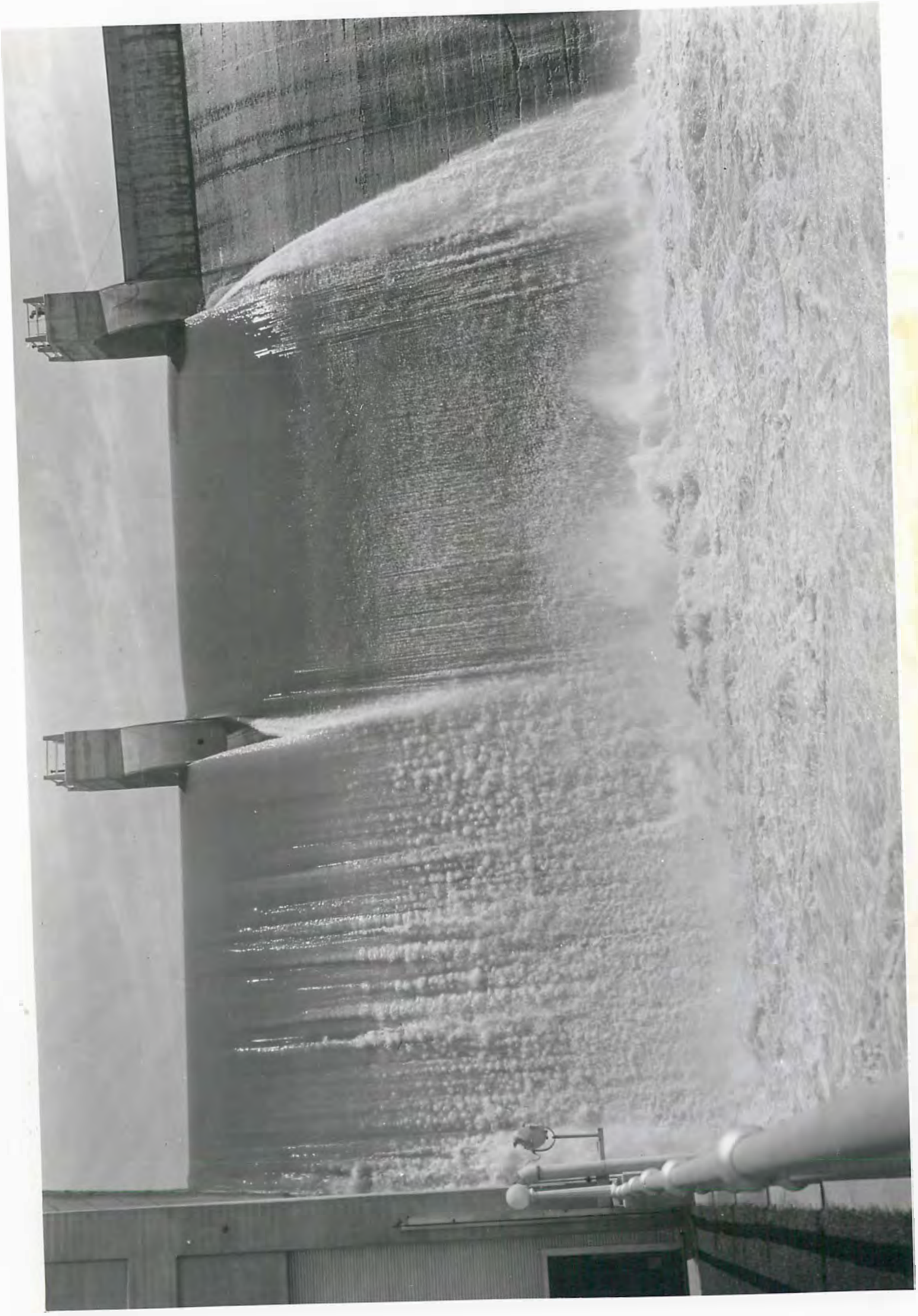
11. Connections to the oscillograph were made through a control box whereby the resistance of one circuit could be balanced against the resistance of another circuit by means of a bridge circuit. The control worked very well, but it was difficult to get a circuit such that the deflection of one element would not influence the other elements. The only test films that were made gave no results because of this difficulty in making connections. During the vibration tests records were kept of the temperatures at which the oscillograph operated. It was found that the best results were obtained when the temperature was maintained at 15 degrees Centigrade (59 degrees Fahrenheit). If the temperature fell below 13 degrees Centigrade (55 degrees Fahrenheit) the trace of the light beam on the film widened perceptibly. An increase in temperature to 17 degrees Centigrade (63 degrees Fahrenheit) caused some change in the width of the trace of the light beam. The refractive quality of the damping oil in the elements apparently changes with temperature. The temperature of the oscillograph was controlled by means of a light bulb placed inside the oscillograph case as needed. Some kind of heating device should be installed in the oscillograph case near the elements in order that a more constant temperature may be maintained in the instrument during future field tests. Very little trouble was experienced with the camera in the oscillograph. The main drive belt and the small belt to the take-up spool failed during the vibration tests and were replaced. The instrument is very awkward to move from one place to another and should be equipped with handles on the ends of the case.

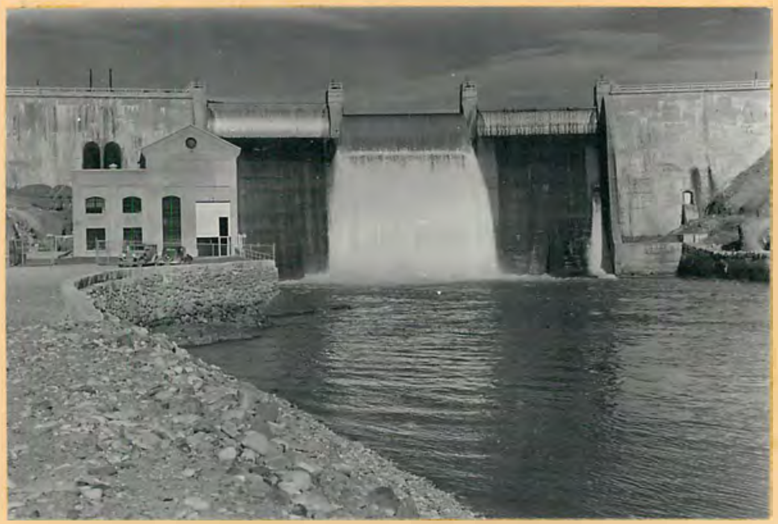
12. Flow conditions on the face of the dam were observed for different gate elevations, different combinations of gate openings, and different reservoir elevations during the time the vibration tests were in progress. Air entrainment in the flow, aeration of the jet when the gates were partially raised and conditions relative to point gaging the flow were noted in particular and a few pictures were taken to record some of the conditions. When the gates were completely lowered the edges and upper surface of the jet contained considerable air. Just how far the air penetrated the jet was not determined. When the gates were slightly raised the conditions were greatly changed. Air entering from the under side was carried through

the jet and emerged from the upper surface causing a boiling appearance. A similar condition was noted near the edge of the jet when the gates were completely lowered. The air in this case was evidently carried in from the sides by turbulence caused from the piers. Motion pictures were made of the flow conditions to show a comparison of the surface conditions and the action of the boils. These pictures are on file in the hydraulic laboratory. The comparison may also be seen in figure 3. Another condition noted at Black Canyon and elsewhere is the irregular line formed where the water surface first becomes roughened and begins to entrain air. The top of the jet presents a glassy appearance for a short distance below the crest and then small waves or ripples begin to appear. The magnitude of the ripples increases as the jet continues downward. The line may be seen in figure 4-B and in the motion pictures. This surface condition is undoubtedly caused by friction along the air-water contact. The line was observed to move up the jet when a wind was blowing upstream thus indicating that the condition is a function of the relative water and air velocities. The degree of aeration of the jet was greatly influenced by the thickness and by the position of the gate. Flow conditions for one gate at different elevations are shown in figure 4.

13. No water surface measurements were made during the tests. Visual observations of flow conditions on the face of the dam and experience with the cable equipment used to suspend the electrodes yielded some information of value in further planning for water surface measurements. It was noted that the hand lines used to control the location of the carriage on the cable had a tendency to sway considerably. For this reason the use of hand lines to control the swing of the plumb bob, as suggested in the letter from the Chief Engineer to T. B. Parker), dated January 23, 1939 (copy included in the appendix of this report, may not be advisable and an alternate means of controlling the swing may be necessary. The carriage used on the cable at Black Canyon Dam had only one sheave on the main cable and one sheave for the electrical conductor to pass through. With the pull of the electrodes acting downward and the pull on the conductor between the sheave and the pier acting in a horizontal direction the resultant force was at 45 degrees. The hand line acting in a horizontal direction and the cable supplied the reaction. An overturning force was exerted on the carriage causing it to clamp on the cable. With a heavy pull on the electrode lines it was impossible to move the carriage by means of the hand line without first slacking the electrode lines. In the design of equipment for measuring the water surfaces on the face of a dam careful consideration should be given to the design of the plumb bob carriage. The carriage should have two sets of rollers or sheaves separated by rigid side plates possibly two feet in length. The sets of rollers should consist of one roller above and one below the cable to provide for the overturning force and insure smooth operation of the

FIGURE 3





A. Gate Raised 6.1 ft. - Head on Gate 2.8 ft.

B. Gate Raised 4.7 ft. - Head on Gate 4.25 ft.

C. Gate Raised 3.2 ft. - Head on Gate 5.8 ft.

D. Gate Completely Lowered - Head on Gate 9.1 ft.

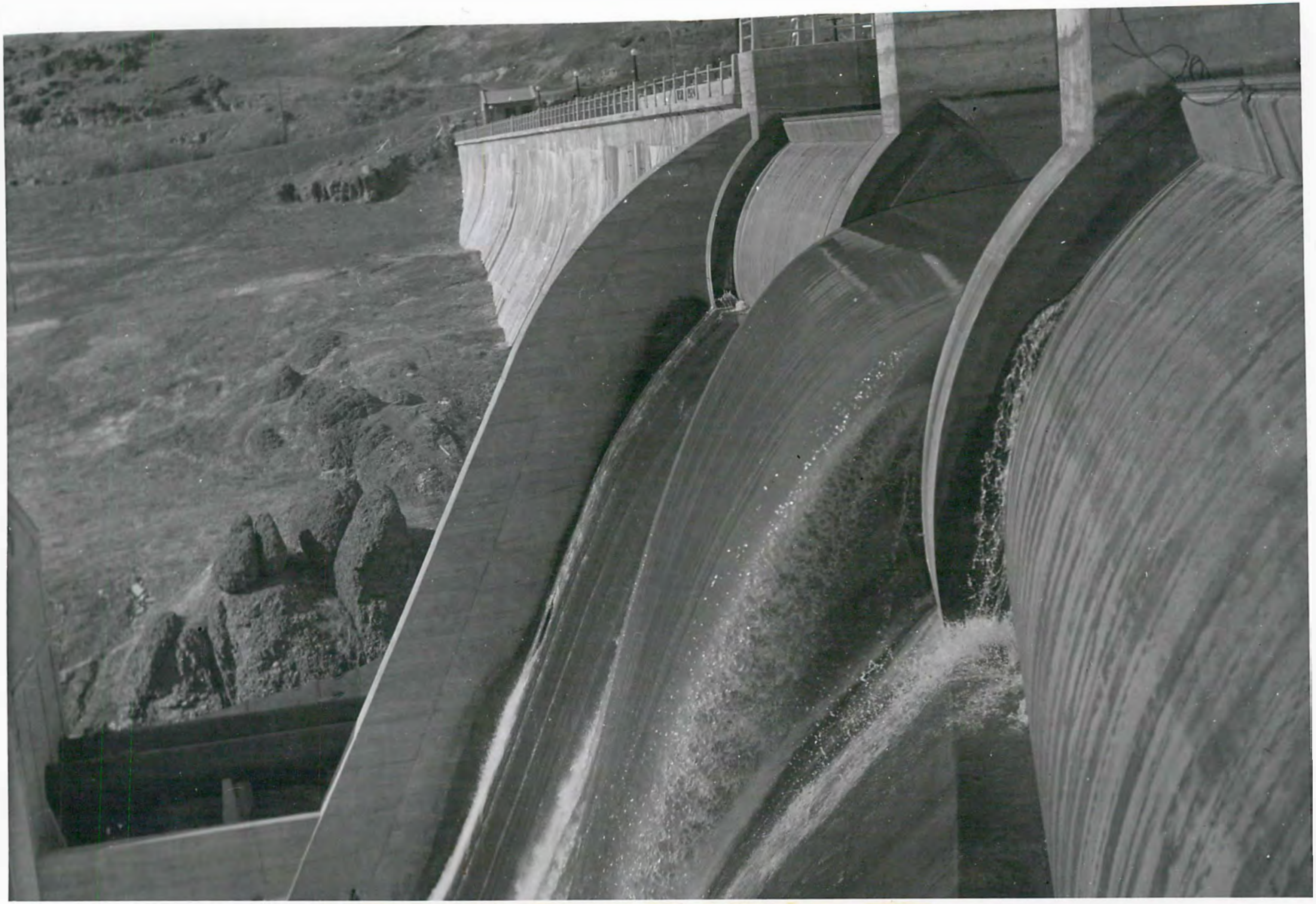
BLACK CANYON DAM- BOISE PROJECT - IDAHO

FIGURE 4

carriage. Considerable lateral spread of the jet was noted (figure 2). This spread was more pronounced for the higher heads. The spread was also greater when the gates were raised. This spread caused a thinning near the edges but apparently did not affect the greater part of the jet. The fact that the spread was evident on the slope of 1/2 to 1 may indicate that it would be appreciable on dams having a flatter slope on the downstream face. The point gage readings should be made near the centerline of the gate in order that they may not be influenced by the thinning of the jet due to the lateral spread. In the case of short gates at the crest and a flat slope downstream, it is possible that even the center of the jet may be affected by the spread. The spray conditions were at no time severe and fluctuations of the water surface were not large. It appeared that little difficulty should be encountered in obtaining a very good surface profile.

14. The jets from the drum gates were aerated for all conditions of flow observed. The velocity of the air entering under the jets was quite high at times as indicated by observing bits of paper thrown from the tops of the piers. Evidently a large quantity of air is absorbed by the underside of the nappe. Turbulence on this surface is greatly increased by the rivet heads on the lip of the drum gate and air entrainment starts immediately. This air is carried through the jet by turbulence and produces the boiling effect at the upper surface. A typical example of the flow from the drum gates is shown in figure 5.

15. The results of the series of observations lead to the conclusion that the tubular electrodes may be developed to produce satisfactory results. However, points that have been considered minor details are relatively as important in evolving a satisfactory electrode as the proportions and shape. The upstream end of the electrode and the mechanical connection to the cable must be given further consideration. Streamlining should be employed to reduce the turbulence and lessen the friction between the electrode and the water. If streamline flow along the surface of the electrode can be obtained, the amount of salt necessary for deflection of the oscillograph elements should be greatly reduced and the pull on the cable would be lessened. The electrical connection between the cable and the electrode must be well protected and should be completely enclosed to avoid breakage in the high velocities. It is also possible that a special cable with enlarged portions wrapped with bare copper or brass wire could be made up for a nominal cost. This type of equipment could be streamlined more easily and would permit the use of internal connections to the electrodes. It would offer little resistance to the flow and, therefore, should produce less pull on the cable. The practicability of developing such a cable should be considered further. If velocities are higher or if the length of cord in the flow is greater than at Black Canyon, the electrical cable should be stronger. All splices



Gate Raised 4.5 feet - Head on Gate 4 feet

BLACK CANYON DAM - BOISE PROJECT - IDAHO

FIGURE 5

should be avoided particularly where high stresses or high velocities may be encountered. If two or more conductors are fastened together, the clips should be made such that they offer a minimum resistance to the flow.

16. The use of flour salt was satisfactory. However, in cases where the distance between piers is great and there is no bridge across the spillway, it will be necessary to provide some means of dropping the salt balls from a cable or employing the electrodes near a pier so the location of the salt in the water may be controlled. The use of positive electrodes in the flow and completing the circuit by utilizing the face of the dam as a negative electrode was satisfactory. Since the observations at Black Canyon were for the most part visual, it would not be well to adopt this practice for general use until a number of records are made and analyzed to determine if velocities recorded by this method are identical with those obtained by the use of dual electrodes and if the deflection curves bear the same characteristics.

17. The use of a 128-frame motion picture camera and a telephoto lens on a 64-frame motion picture camera produced a series of pictures that add much to the study of high velocity flow. This film has been titled and is filed in the hydraulic laboratory.

- - -

APPENDIX

COPY-JSC

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CUSTOMHOUSE
DENVER, COLO.

January 23, 1939.

Mr. T. B. Parker,
Chief Engineer,
Tennessee Valley Authority,
Knoxville, Tennessee.

Dear Mr. Parker:

Reference is made to our office letter of November 30, 1938, and to telegrams of December 20 and 21, 1938, in regard to proposed measurements of velocity and flow over Norris Dam.

In accordance with the suggestion in the last paragraph of your November 15 letter, Mr. Warnock of this office discussed the problem with members of your staff both in Knoxville and at the hydraulic laboratory in Norris on December 28 and 29. A verbal agreement of cooperation was reached which is believed will result in a further step in the study of the characteristics of supercritical velocities in channels with steep gradients. The details of the plan evolved by your hydraulic staff and Mr. Warnock are offered for your approval.

The problem of high-veolcity flow as previously studied by the hydraulic laboratory staff in this office is divided in two parts: (1) the measurements of actual velocities on the slope of steep chutes or spillways; and (2) the measurement of the actual depths of flow under the same conditions. Observation of the behavior of the high-velocity sheet down the face of the spillway of such dams as Norris, Cle Elum, and Alcova dams shows that a flow condition is reached at which apparently a large quantity of air is absorbed by the water and the stream is changed from one of solid water to one of an air-water mixture. It is believed that the coefficient of friction of this air-water mixture is greater than that of solid water in which case the velocity of approach to a hydraulic jump stilling pool would be less than that computed using the standard equations of flow. In spillways or chutes with low heads this condition is of no consequence, but in a structure of the magnitude of Shasta Dam, the proposed Fontana Dam, and certain irrigation canal chutes, the absorption of air may reduce the velocity and increase the depth sufficient to require higher training walls than have previously been used, and the hydraulic jump in the stilling pool may be affected by the reduction of entrance velocity.

The method of measuring the depth of flow agreed upon in the discussion will be to point-gage the water surface using a mercury-loaded plumb bob suspended from a carriage on a cableway over the spillway. This cableway will be suspended above the centerline of the middle drum gate with the upper end attached to a ring bolt on the underside of the highway bridge across the dam. The lower end of the main cableway will be attached to a second cable suspended from anchors on top of the spillway training walls. The position of the carriage on the main cableway will be controlled by a rope or hand line extending from the carriage through a block attached to the junction of the main cable and cross cable, up to the control station on the highway bridge and back to the carriage. The position of the point gage below the carriage will be controlled by a single line attached to the carriage and passed through a block on the point gage, through a sheave on the carriage and up to the control station on the bridge. It is also considered advisable to attach two light hand lines to the point gage so that it can be pulled away from the water surface when it begins to swing in pendulum fashion due to impact with the high-velocity water. One man will be stationed on each training wall to handle these lines. The point gage will consist of a mercury-loaded plumb bob with a target so designed that its reference point can be sighted from any angle by two transits, one located over a reference hub on each spillway training wall. The control station on the bridge and the two transit stations on the training walls will be connected by telephone to coordinate the activities of the personnel during the point-gaging. The personnel to handle this apparatus will consist of a supervisor, two transitmen, one target lineman on the bridge, and two target linemen on the training walls.

The procedure of determining the water surface profile down the face of the spillway for a particular discharge will be to lower the point gage at successive points along the cableway until it touches the water surface and determine the elevation and position of the reference target at each point, and hence the elevation of the water surface by triangulation from the transit points at the ends of a base line extending from one training wall to the other and parallel to the axis of the dam.

The profile of the spillway will be point-gaged with no flow over the crest and the subsequent plotting of these data with those from the measurement of the water surfaces will produce the depth of flow. The use of triangulation will produce a considerable amount of original data which should be analysed immediately to determine the consistency of the measurements, but advantage can be taken of the intervals between runs to make this necessary analysis.

The velocity of the water will be measured by the salt-velocity method utilizing two pairs of electrodes suspended in the flow by cables suspended from the upstream side of the highway bridge with an interval of approximately ten feet between the two sets. The two electrodes in each pair will be connected to the ends of individual conductors and so arranged that the interval between the two electrodes can be varied to produce the most satisfactory results as indicated by preliminary tests. The upstream terminals of the electrode conductors will be connected to an oscillograph which records photographically the passage of the salt cloud between the electrode sections. The salt cloud will be produced by dropping a ball of flour salt into the water at a suitable interval above the first electrode section. The amount of salt in each injection and the proper point of introduction will be determined by experiment just prior to the actual record test. The oscillograph has a reflecting mirror and ground glass in which the impulses can be studied without recording on the sensitized film in the camera.

During the conference on December 28 and 29, the necessary equipment and personnel was discussed and a fairly definite plan of cooperation was developed. The following plan which is offered for your approval is based on that discussion. The cable rigging and point-gage carriage with necessary personnel for the water surface measurements will be designed and furnished by your organization. The telephone system for the water surface measurements will be furnished by this Bureau. The mercury-loaded point-gage will be constructed in the hydraulic laboratory of this Bureau and shipped to Norris, Tennessee. The oscillograph, electrodes, conductors, and salt for the velocity measurements will be furnished by this Bureau. Model studies will be made in this hydraulic laboratory to design the electrodes to procure good performance in the field measurements. Two engineers from this office will be available to assist in this test program, particularly to make the oscillograph records of velocity. One of these engineers, Mr. Thomas, was in charge of similar tests on the Kittitas Wasteway near Cle Elum, Washington, during May 1938, and is thoroughly familiar with the test procedure. No definite agreement was reached as to the two transits to be used. The availability and necessity of precision equipment will be checked by both interested parties and a later decision reached as to where they will be procured. The design and installation of the point-gaging equipment with the exception of the point-gage itself will be handled by your organization.

It is understood that the opportunity to make these tests depends on the occurrence of floods of sufficient magnitude as to require the filling of the reservoir to a sufficient depth over the spillway to provide water for the experiments. It is further understood that if conditions warrant, there is a possibility of filling the reservoir a few feet above the spillway crest at the end of the spring flood season after there appears to be no further flood run-off. The latter would be expressly for the purpose of providing sufficient water to obtain a few observations.

In our letter of November 30, 1938, a copy of each of two reports prepared by members of the Bureau hydraulic laboratory staff were enclosed. These reports deal with the present status of this problem. Detailed criticism of the analysis and results as outlined by interested engineers of your organization will be appreciated.

Very truly yours,

Chief Engineer.