J. N. Bradley

REPAIR OF GRAND COULEE BUCKET

Denver, Colorado, July 9, 1943.

MEMORANDUM TO CHIEF DESIGNING ENGINEER:
(J. E. Warnock)

Subject: Hydraulic Model Studies on Repairs and Maintenance of Grand Coulee Dam Spillway Bucket.

1. A number of experiments have been completed during the past month to investigate the feasibility of various methods proposed for bypassing a portion of the low-water flow at Grand Coulee Dam by the installation of temporary additional outlet facilities in the right-powerhouse turbine bays. This supplemental outlet capacity will make it possible to avoid operation of the spillway during low-water season, thus permitting maintenance of the spillway gates, face, and bucket, and avoid unequal gate discharges which have caused eddy currents and excessive bucket erosion in the past. This report is a description of the various methods studied and the results obtained from the hydraulic-laboratory experiments.

2. Five methods of releasing the additional flow were considered, as follows:

(a) The first proposal was to secure advance shipment of standard Grand Coulee turbines, complete with spiral cases, wicket gates, servomotors, oil pumps, and storage tanks, but without runners. These empty turbine cases would be installed and the steel bulkheads at the upper end of the penstocks removed, using one of the regular penstock gates for unwatering the upper end of the penstock. The capacity of each turbine as determined by model studies would be approximately 11,000 second-feet as compared to 5,200 second-feet with the turbine runner installed. A high degree of energy dissipation would be effected by the vortex flow out of the scroll case into the draft tube and by reduction of velocity in the draft tube due to sudden expansion. This plan would utilize equipment already on order, but the delivery of which has been deferred by a War Production Board stop-work order. By installing these units in the bays nearest the spillway, no difficulty would be experienced from the resulting draft-tube velocities of about 20 feet per second. These installations could be controlled either as ordinary outlet works or as synchronous bypasses.

(b) A second proposal, similar to the first, would be to install oversize turbine units, without runners, with individual capacities of 15,000 second-feet.

(c) A third proposal would be to borrow 84-inch needle valves from the canyon-wall outlet works at Boulder Dam for installation in the right powerhouse, connecting them to the power penstocks already in place. One of the regular penstock gates would be used for unwatering the upper end of the penstock and removing the steel bulkhead. In the first variation of this proposal, the needle valves would be placed as a horizontal continuation of the turbine penstock, discharging into energy absorbers similar to those on the turbine synchronous bypasses at Boulder

Dam. The water at a greatly reduced velocity and head would flow through connecting elbows into the draft tubes, where an additional reduction of velocity would be obtained by the draft-tube action.

(d) A fourth scheme would utilize the 84-inch Boulder needle valves attached to the exposed ends of the turbine penstocks in the right powerhouse as in (c), but conduits attached to the downstream ends of the valves would be placed to discharge above the tail-water surface. A transition from a circular to a rectangular cross section and a bend would disperse the jets of water over a large area with very little disturbance in the tail water.

(e) In a fifth scheme--considered most practicable because of the minimum amount of critical material required, the minimum of time required for installation, and the simplicity of design--the 84-inch Boulder needle valves would be connected to the turbine penstocks in a horizontal position but with the center lines of the valves intersecting the vertical center lines of the draft tubes. An elbow attached to the outlet end of each needle valve and embedded in a concrete block over the draft-tube opening would divert the jet from the valve downward into the draft tube. The energy largely would be dissipated in the turbulence in the draft tube and the flow conditions in the tailrace would be similar to those from a regular turbine installation.

3. To study the hydraulic behavior of the first and second proposals, the turbine model used in the study of the design of the Grand Coulee draft tubes was reinstalled without the turbine runner and dynamometer. Preliminary tests indicated the feasibility of the scheme and also indicated the need for comprehensive model studies to provide information on the torque on the wicket gates and pressure distribution within the draft tube. The model was revised by shifting the speed ring until the wicket gates and stay vanes were in line when the wicket gates were 60 degrees from the closed position. The conical section at the top of the draft tube was replaced by a cylindrical section so as to provide a sudden expansion below the scroll case, and a filler block was installed in the horizontal portion of the draft tube to provide a second sudden expansion. A sudden expansion is one of the best methods of dissipating energy in a closed conduit without damaging the conduit due to cavitation and pitting. One wicket gate was remounted in ball-bearing supports and attached to spring balances to provide means of determining the magnitude of torque at different gate openings. The shape of the wicket gates was altered slightly to conform to the design in the Grand Coulee turbines. The fairwater cone with a vent pipe to the atmosphere and a ring representing the runner shroud were installed. With these changes, the capacity of the scroll case under a head of 345 feet was 11,000 second-feet when the wicket gates were 60 degrees from the closed position. The maximum designed opening as determined by the stroke of the servomotor was 60 degrees. The discharge when the wicket gates were

at 70 degrees, or 10 degrees beyond the limit of the servomotor, was 13,000 second-feet and, when radial, or 80 degrees open, the discharge was 12,600 second-feet. In terms of the prototype, a vent pipe with a diameter of approximately 33 inches was required through the fairwater cone to prevent cavitating pressures in the draft tube. Four 9-inch pipes were also needed to relieve excessive subatmospheric pressures at the sudden expansion below the scroll case, but no aeration was needed at the filler block in the horizontal portion of the draft tube. If aeration was not provided, the vibration of the scroll case and draft tube was excessive and the pressures in the prototype would have reached vapor pressure and caused cavitation and pitting. With aeration as described, there was slight vibration at all openings of the wicket gates, it being least severe when the gates were radial, or 80 degrees, from the closed position. At 60 degrees the torque on the wicket gates when operating without the turbine runner was six times the torque at the position of maximum operating capacity when the turbine runner was installed; at 80 degrees the torque was 50 percent greater. To have completely explored the feasibility of this scheme, it would have been advisable to conduct tests on a model operating with prototype heads, which would require 8 to 10 months. The uncertainty of knowledge of the behavior without high-head tests, the excessive time involved in installation of the scroll cases, and the excessive amount of critical material required led to favorable consideration of another scheme. The principal disadvantage was that the installation could not installed available for use prior to the low-water season of 1945-46.

4. The hydraulic behavior of the third proposal, in which the Boulder 84-inch needle valves would have been installed at the lower end of the turbine penstocks so as to discharge into energy absorbers, was obvious from the satisfactory performance evolved from model studies made several years ago and since verified in the prototype installation on the turbine synchronous bypasses at Boulder Dam. The scheme, however, would have required an excessive amount of critical material and the installation might not have been available for use during the low-water season of 1944-45.

5. In the fourth scheme, where the Boulder 84-inch needle valves would have discharged above the tailrace through conduits attached to the downstream end of the valves, the model indicated no adverse behavior insofar as the valves and conduits were concerned. The spray from the jets of water would have been objectionable and considerable excavation of concrete would have been required in the downstream wall of the powerhouse in placing the conduits and later in removing them when the turbines were installed. Most of this excavation would require caissons on the downstream face of the powerhouse to permit excavation of the concrete and installation of the conduits during high-water season.

6. The objectionable features of the fourth proposal were the excessive excavation of concrete in the downstream wall of the powerhouse in placing the conduits and later in removing them and the caissons required to permit work during the high-water season. To utilize the draft tubes, which were already equipped with steel bulkheads at the downstream end, consideration was given to the discharging of the needle valves directly into the draft tubes. To study the feasibility of this idea, a model needle valve with a discharge diameter of 2.8 inches, which had been used previously as a 1:30 model of the 84-inch Alcova valves, was mounted in a vertical position above a 1:24 model of a Grand Coulee draft tube. With the jet from the valve tangent to the back face of the elbow of the draft tube, the performance was excellent. The flow was well distributed through the three passages of the draft tube and the disturbance at the tailrace water surface did not greatly exceed that with flow from normal turbine operation. In the prototype, however, the vertical mounting was not structurally feasible, so, in the subsequent test, the model was mounted in a horizontal position with a 90-degree elbow between it and the draft-tube opening. A number of positions were tried as to the angle between the center line of the turbine penstock and the needle valve and as to the point of introduction of the jet into the draft tube. In the final design, the angle between the center line of the penstock and the valve was 41 degrees and the center line of the needle valve intersected the vertical center line of the draft tube. The elbow between the needle valve and draft tube had a transition from a circular section 84 inches in diameter downstream from the valve to a section 15 percent larger in area composed of a circle on the back coinciding with the diameter of the draft tube at the point of connection and a straight line opposite. The circle and the straight line were connected by circles of lesser diameter. The 15-percent increase in area was introduced to create low pressures in the elbow which would cause a flow of air through a wind box between the needle valve and the elbow. The air demand was created to start turbulence and energy dissipation in the jet as it issued from the valve and to prevent local cavitation due to irregularities on the surface of the metal lining. With the valve and elbow in place, trials were made as to the quantity and point of introduction of air. Through cooperation with the mechanical section, a combined air box and expansion joint was developed on the top of which will be connected an air-vent pipe at least 18 inches in diameter. An additional air-vent pipe at least 6 inches in diameter will be installed extending vertically upward through the concrete block over the draft-tube opening. This second pipe can be either extended upward to the necessary height or can be connected across to the 18-inch vent pipe. With these vent pipes in place, the lowest pressure measured was -8.0 feet of water at a point on the under side of the elbow near the point of tangency to the draft tube. Without these vent pipes, the pressures in the elbow will be of the magnitude which will cause vibration, cavitation, pitting, and ultimate destruction of the under side of the elbow and the adjacent concrete in the supporting block. The model of the final design of this

installation and the conditions on the surface of the tailrace are shown in the accompanying photographs. The 1:24 model of the Grand Coulee draft tube used in the preliminary tests of this installation is shown in the background of the first photograph.

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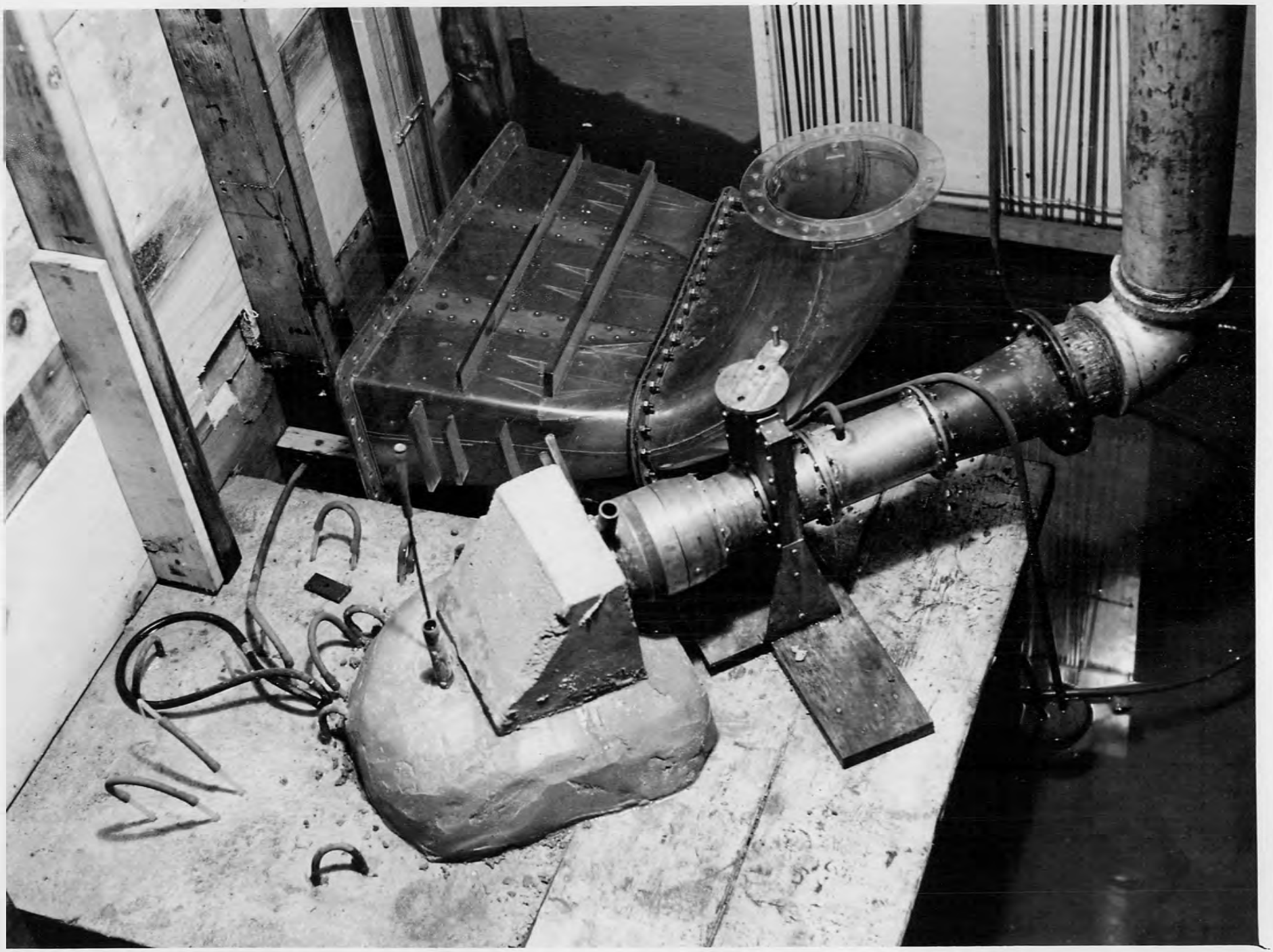

UNITED STATES
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BUREAU OF RECLAMATION

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HYDRAULIC LABORATORY REPORT NO. 132

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HYDRAULIC MODEL STUDIES ON REPAIRS AND MAINTENANCE OF GRAND COULEE DAM SPILLWAY BUCKET

By

J. E. WARNOCK

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Denver, Colorado
July 9, 1943

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By

J. E. WARNOCK, SENIOR ENGINEER

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Under Direction of

R. F. BLANKS, SENIOR ENGINEER

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Denver, Colorado,

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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Branch of Design and Construction
Engineering and Geological Control
and Research Division
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Laboratory Report No. 132
Hydraulic Laboratory

Compiled by: J. E. Warnock

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a. 1:30 model of a single by-pass outlet for right powerhouse - Draft tube of 1:24 model

b. Flow conditions in tailrace with by-pass outlet operating.

MODELS USED IN TESTING OF BY-PASS OUTLET FOR RIGHT POWERHOUSE OF GRAND COULEE DAM